OBSERVATIONS OF SPATIAL AND TEMPORAL VARIATIONS OF THE JOVIAN H_2 QUADRUPOLE LINES

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Abstract. We have made high resolution scans of the Jovian H_2 4–0 S(1) line at 6367.75 Å and the 3–0 S(1) line at 8150.67 Å, in an attempt to establish improved equivalent widths and to measure any spatial-temporal variations across the disc. Preliminary analysis indicates that temporal changes in the 3–0 S(1) line can be as large as about 40% over a period of about a week; furthermore, this line is systematically weaker at the limb (about 10%) and stronger at the poles (about 20%) than it is at the center of the disc. The 4–0 S(1) line shows very little temporal change, but does have a similar center to limb variation. Current theoretical models of line formation and cloud structure on Jupiter are not able to explain the observed variations although it is clear that some sort of two-layer model is necessary.

We used a PEPSIOS spectrometer, consisting of three Fabry-Perot etalons in series with an interference filter, at the coudé focus of the Smithsonian Observatory's 60-in. telescope. Following Trauger and Roesler (1972) we operated the PEPSIOS in an off-axis mode, so that the large rotational smearing of Jovian spectral lines is exactly compensated.

Examples of spectra taken at various points on the disc and averaged over one night's observing are shown in Figure 1. Each profile has been fitted with a Gaussian line shape, shown by plus signs. Although a fairly good fit has been obtained, there are systematic departures which can be seen in the 3–0 S (1) profiles; in particular, the wings of the line are slightly stronger than allowed by a pure Gaussian profile, and also an asymmetry in the line core can be detected. The observed 3–0 S (1) line profiles have widths (FWHM) of about 85 mÅ, which can be accounted for if we combine the intrinsic line width (about 47 mÅ) and instrumental width (about 27 mÅ) with the effects of image motion due to seeing on the order of FWHM = 3.7″ or less (63 mÅ). However, we are basically concerned here with the equivalent widths, which are plotted in Figures 2 and 3.

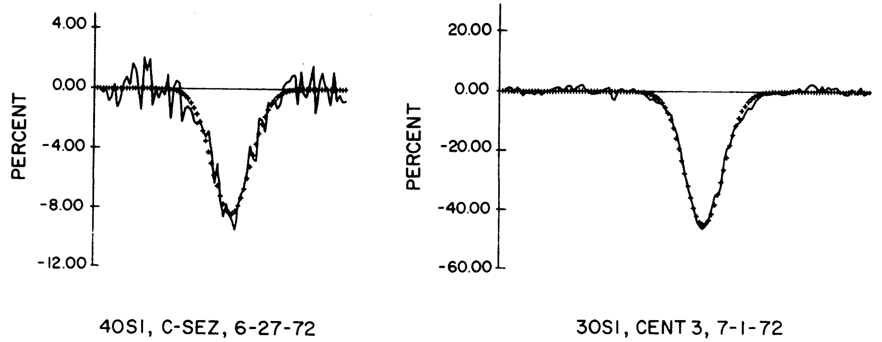

Fig. 1. Examples of the scans of the Jovian H_2 4–0 S(1) and 3–0 S(1) lines obtained at various points of the disc.

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In Figure 2, the longitudinal extent of our various sized circular apertures is shown by crosshatching, and the observed equivalent widths are plotted above in corresponding positions. The observations at various points on the disc for June 27, 1972 were made sequentially and cycle repeated several times, so time dependence is suppressed. First note that the equivalent width (EW) at the center of the disc in the south equatorial zone (SEZ) is slightly less than that at the same meridian but in the north equatorial belt (NEB) and great red spot (GRS). There is a further significant change in intensity (about -10%) toward the limbs, but still within the SEZ. We shall see later that it is difficult to account for this near-constancy in strength on the basis of current theoretical models, which predict either much greater or much

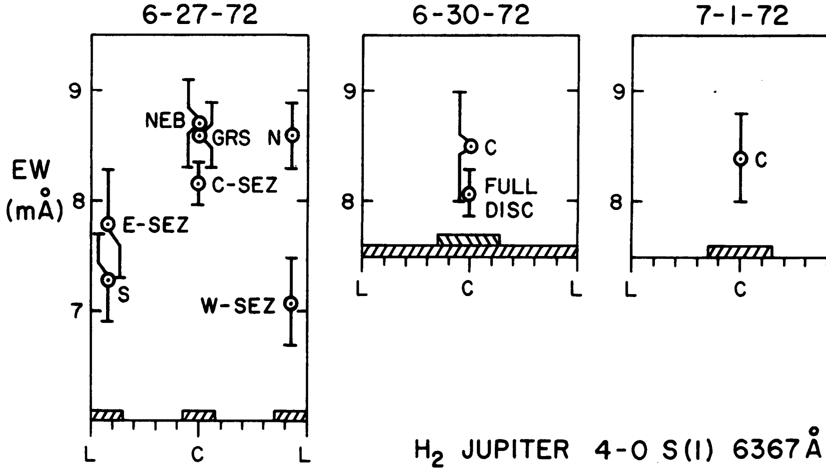

Fig. 2. Observed equivalent widths of Jovian H_2 4–0 S(1) line at various points of the disc.

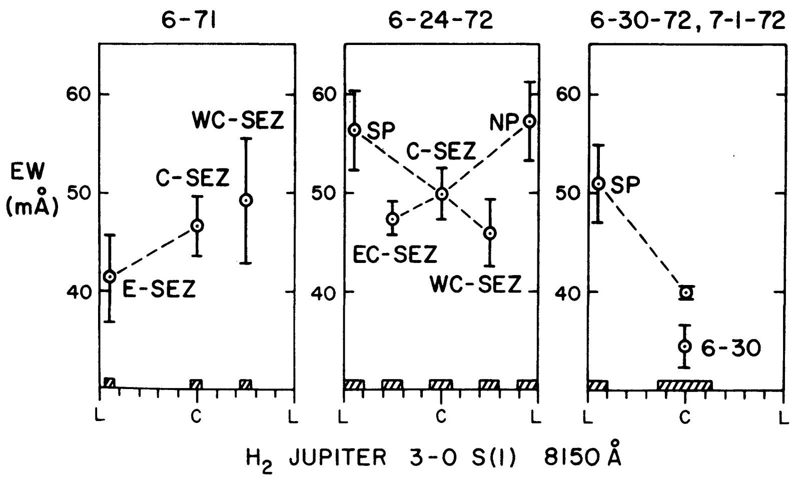

Fig. 3. Observed equivalent widths of Jovian H_2 3–0 S(1) line at various points of the disc.

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weaker lines toward the limbs. Note also that at the north and south poles (N, S) the line strength is not symmetric; we have no ready explanation for this behavior. Measurements at the center of the disc taken 3 and 4 days later are also shown; within our measurement errors the EW appears to have made no significant change in this period.

In Figure 3 we plot the EW's of a number of 4–0 S(1) observations. First, we show some averaged EW data from 1971 which were obtained over several days, and are useful mainly for showing that the EW at the limb is again only about 10% weaker than at the center. The error bar on the mid-radius observation is large, and should not necessarily be taken as evidence for an increase in EW.

The data for June 24, 1972 are of especially good quality, and show first that in the SEZ the greatest EW is on the central meridian. Altogether, the data so far described indicate a monotonic decrease in EW (in the SEZ) from center to limb. An entirely different trend is seen toward the poles, where the 3–0 S(1) EW increases dramatically. Six days later, the EW in the center of the SEZ has dropped by about 30%. The next day it has partially recovered, but to a value still clearly outside the indicated measurement error (one standard deviation). The difference between the first and last of these 3–0 S(1) observations is even more remarkable in that they both represent averages over nearly the same longitude limits, but separated in time by 17 revolutions of the planet. Finally, we note that again on the last set of observations, that the EW over the SP is significantly larger than at the center of the SEZ.

We now wish to compare these observations with the recent theoretical analysis by Hunt (1973) and by Margolis and Hunt (1973), where both the line profile and radiative transfer effects are accurately computed, for the chosen model atmosphere. Since the time variation in EW of the 3-0 S(1) line is clearly so large, it is most profitable to first discuss center to limb behavior. Hunt has calculated that the EW will increase strongly toward the limb in a clear gas atmosphere, but will decrease to nearly zero at the limb for the two-cloud model he has chosen; this is true for several values of anisotropy parameter in the adopted Henyey-Greenstein particle scattering function. This upper cloud effectively blocks sunlight at the limb from penetrating to the underlying atmosphere, and so causes a strong decrease in EW. Clearly, neither model describes the observations, which show nearly constant EW, with only a small (about 10%) drop toward the limb.

We suggest that there exists a cloud model which probably will explain the observations. Although we have not yet made any calculations for the case of H_2 on Jupiter, we have done a number of similar model studies for CO_2 on Venus, and we expect that this experience may carry over to some degree. For this purpose, we note that Hunt's upper cloud is actually a relatively extensive haze, and not a thin layer. It is well known that in a homogeneous infinite haze model, that EW will strongly decrease toward the limb. We believe that that is effectively what is occurring here, since as Hunt shows, the effective level of line formation goes up rapidly as the limb is approached. If, on the other hand, we use instead a physically thin, as well as optically thin, layer for the upper cloud, we achieve the desired 'shielding' effect near the limb, but

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still allow some light to penetrate to the gas and subsequently escape. Although it is extremely difficult to produce a constant EW from center to limb with this sort of cloud (which appears to be nearly the case with Venus), it is not hard to imagine only a 10% drop. We expect to be able to continue our calculations and produce such a model in the near future.

The polar EW behavior is quite different, appearing to increase for 3–0 S(1) at least. This suggests that the upper cloud is thinner or even absent at the poles. Support for this comes from Gehrels' (1969) polarization studies which indicate that the atmosphere is clearer over the poles than elsewhere.

TABLE I

H_2 Jupiter equivalent widths (mÅ)

	4-0 S(1)	3-0 S(1)
SPINRAD AND TRAFTON (1963)	8.0 ± 2.0	28, 40
BECKMAN (1967)	6.0 ± 2.5	
OWEN AND MASON (1968)	8.5 ± 1.5	49 ± 6
EMERSON, EDDY, DULK (1969)	7.8 ± 1.2	
FINK AND BELTON (1969)	9.0 ± 2.0	71 ± 8
TRAFTON (1972)		53 ± 2
TRAUGER (1972)	8.1 ± 0.2	
CARLETON AND TRAUB (1974)	8.4 ± 0.4 (-10% at limb)	34 to 50 (variable) (-10% at limb) (+20% at pole)

Finally, the problem of the constancy of 4–0 S(1) and variability of 3–0 S(1) must be discussed. This behavior is possibly even more dramatic than we have indicated, according to several observers whose results are compiled in Table I. Since 4–0 S(1) is weak (intrinsic depth ≈ 20%), it is formed deep in the atmosphere at about optical depth unity. The presence or absence of a thin haze at high altitude has no strong effect on the line. However, the 3–0 S(1) line is nearly saturated (about 80% deep), and hence is effectively formed at higher altitudes; introducing a scattering cloud at this higher level could conceivably affect this line noticeably. Clearly more calculations are required to investigate this possibility.

References

Beckman, J. E.: 1967, *Planetary Space Sci.* **15**, 1211.
Emerson, J. P., Eddy, J. A., and Dulk, G. A.: 1969, *Icarus* **11**, 413.
Fink, U. and Belton, M. J. S.: 1969, *J. Atmospheric Sci.* **26**, 952.
Gehrels, T.: 1969, *Icarus* **10**, 410.

https://doi.org/10.1017/S0074180900025572 Published online by Cambridge University Press

Hunt, G. E.: 1973, *Icarus* **18**, 637.
Hunt, G. E. and Margolis, J. S.: 1973, *J. Quant. Spectrosc. Radiat. Transfer* **13**, 417.
Owen, T. and Mason, H. P.: 1968, *Astrophys. J.* **154**, 317.
Spinrad, H. and Trafton, L. M.: 1963, *Icarus* **2**, 19.
Trafton, L.: 1972, *Bull. Am. Astron. Soc.* **4**, 358.
Trauger, J. T.: 1972, Ph.D. Thesis, University of Wisconsin.
Trauger, J. T. and Roesler, F. L.: 1972, *Appl. Opt.* **11**, 1964.
Trauger, J. T., Roesler, F. L., Carleton, N. P., and Traub, W. A.: 1973, *Astrophys. J.* **184**, L137.

DISCUSSION

Fox: What is the laboratory strength of the H_2 4–0 S(1) line you discussed?

Traub: This line has not been measured in the laboratory, but certainly should be measured if possible. We use the theoretical line strength calculated by Dalgarno *et al.*, and Birnbaum and Poll in the September, 1969, *J. Atmospheric Sci.*

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