ANOMALOUS OH ABSORPTION IN THE DIRECTION OF CASSIOPEIA A[*]

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The analysis of complex OH emission spectra at the four ground-state frequencies in terms of Zeeman patterns requires an accurate knowledge of the rest frequencies of the four lines. The most accurate values available are those of Radford (1964) as shown in Table I. Although the quoted accuracy of the frequencies is $\pm$ 2 kc/s, and stated to be four times the standard deviations of the measurements (Radford, 1964), it is clear the values given are mutually inconsistent. The line rest frequencies must obey the sum rule

$$\nu_{1612} + \nu_{1720} = \nu_{1665} + \nu_{1667} \tag{1}$$

and the values of Table I fail by 5 kc/s. A discrepancy of this amount is equivalent to approximately 1 km/s in radial velocity, so that attempting to match velocity components in complex spectra between any two OH lines becomes subject to some uncertainty.

Partially to overcome these difficulties, a series of high (frequency) resolution absorption observations were taken in the direction of Cassiopeia A. Previous Cas A observations showed excellent agreement between laboratory and astronomical determinations of the OH rest frequencies assuming that the interstellar OH had the same radial velocity as hydrogen, but observations had only been made at 1665 and 1667 Mc/s (Radford, 1964). In addition, the OH absorption lines in the direction of Cas A at radial velocity - 0.8 km/s have been shown to be split into two lines of width 4-5 kc/s (Barrett, Meeks and Weinreb, 1964), thereby making the Cas A absorption lines at velocity -0.8 km/s well-suited for an accurate determination of the rest frequencies. The observations reported here were made with the 140-foot telescope of the National Radio Astronomy Observatory at the Green Bank, West Virginia, field station. The receiver was similar to that used in our

earlier polarization studies (Barrett and Rogers, 1966).

The -0.8 km/s absorption line in Cas A is well split into two components at both 1665 and 1667 Mc/s as shown in Fig. 1. The line ratios are in the ratio 5:9, within the noise limitations of the observations, and agree with the previous observations of these two lines (Barrett, Meeks, and Weinreb, 1964). However, as can be seen from Fig. 1, neither the 1612 nor the 1720 Mc/s lines show the splitting. Not only was this result quite unexpected, but it prevents a determination of the rest frequencies of the lines until it is understood.

Note that the 1720 Mc/s observations shown in Fig. 1 may give evidence of OH emission at a velocity of approximately 1 km/s although the noise level of the measurement is such that further observations are required to confirm this. It is also clear from Fig. 1 that the absorption at 1612 Mc/s is greater than that which would be predicted if the 1612: 1665: 1667: 1720 intensity ratios were 1:5:9:1. Since the optical depths are less than 0.02, departures from the theoretical line intensities cannot be attributed to effects of large optical depths. One might argue that large optical depths are permitted because of small angular size associated with the OH clouds, but the agreement between absorption at 1665 and 1667 Mc/s with the 5:9 theoretical ratio would seem to rule this out.

The presence of large absorption at 1612 Mc/s and reduced absorption, or emission, at 1720 Mc/s can be understood theoretically by considering energy level populations. If the intensity of each transition ν_{ij} corresponds to its own excitation temperature T_{ij}, defined in the usual manner,

$$\frac{N_i}{N_j} = \frac{g_i}{g_j} e^{-\frac{h\nu_{ij}}{kT_{ij}}} \tag{2}$$

then if $kT_{ij} > h\nu_{ij}$ it can be shown quite simply that the T_{ij}'s must obey the

equation,

$$\frac{1}{T_{1612}} + \frac{1}{T_{1720}} = \frac{1}{T_{1665}} + \frac{1}{T_{1667}} \qquad (3)$$

For small optical depths this equation can be written in terms of the observed absorption profiles $\Delta T(\nu)_{ij}$,

$$\Delta T(\nu)_{1612} + \Delta T(\nu)_{1720} = \frac{\Delta T(\nu)_{1665}}{5} + \frac{\Delta T(\nu)_{1667}}{9} \qquad (4)$$

where the denominators 1, 5, and 9 represent the ratios of the optical depths and are a direct result of the statistical weights and transition probabilities of the four lines. If the rest frequencies were accurately known, Eqn. (4) could be written as a function of radial velocity. Because the rest frequencies are not accurately known, the velocity scales of Fig. 1 are subject to some adjustment. The observations can be used to test the validity of Eqn. (4), however, by integrating over the line profiles. Within the noise limitations of the observations, Eqn. (4) is found to be satisfied.

Eqn. (4) demonstrates that large absorption at 1612 Mc/s must be offset by reduced absorption, or emission, at 1720 Mc/s if the 1665 and 1667 Mc/s absorptions are in the ratio 5:9. Note that Eqn. (3) is a general result that must be satisfied by whatever population mechanism is responsible for establishing the various energy-level populations. Since the excitation temperatures T_{ij} may assume either positive or negative values, population-inverting mechanisms (masering) must also conform with Eqn. (3). The assigning of individual excitation temperatures to the transitions, which leads automatically to Eqn. (3), is simply another way of stating that the population mechanism must give different populations for the different energy levels, i.e. the mechanism must be dependent on the total quantum number, F.

REFERENCES

Barrett, A. H., Meeks, M. L., and Weinreb, S., Nature, 202, 475 (1964).

Barrett, A. H., and Rogers, A. E. E., Nature, 210, 188 (1966).
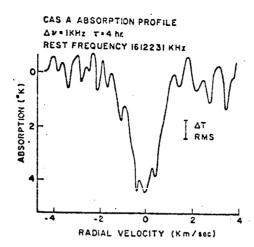
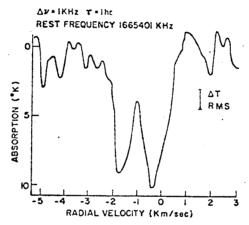Radford, H. E., Phys. Rev. Lett., 13, 534 (1964).

TABLE I

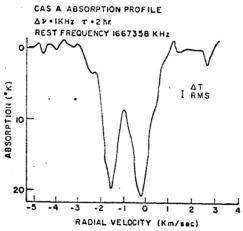Laboratory determinations of the OH rest frequencies (Radford, 1964)

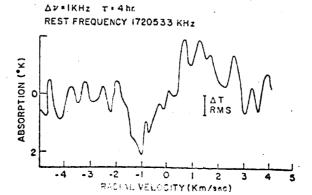| Transition	Frequency (kc/s)
$F = 1 \rightarrow 2$	$1{,}612{,}231 \pm 2$
$F = 1 \rightarrow 1$	$1{,}665{,}401 \pm 2$
$F = 2 \rightarrow 2$	$1{,}667{,}358 \pm 2$
$F = 2 \rightarrow 1$	$1{,}720{,}533 \pm 2$

FIGURE CAPTION

Fig. 1   OH absorption spectra in the direction of Cassiopeia A.   As
noted in the text, the velocity scales can be slightly adjusted
because of the uncertainty in the rest frequencies.

CAS A ABSORPTION PROFILE
Δν = IKHz τ = 4 hr.
REST FREQUENCY 1612231 KHz

ABSORPTION (°K)

ΔT
RMS

RADIAL VELOCITY (Km/sec)

Δν = IKHz τ = Ihr.
REST FREQUENCY 1665401 KHz

ABSORPTION (°K)

ΔT
RMS

RADIAL VELOCITY (Km/sec)

CAS A ABSORPTION PROFILE
Δν = IKHz τ = 2 hr.
REST FREQUENCY 1667358 KHz

ABSORPTION (°K)

ΔT
RMS

RADIAL VELOCITY (Km/sec)

CAS A ABSORPTION PROFILE
Δν = IKHz τ = 4 hr.
REST FREQUENCY 1720533 KHz

ABSORPTION (°K)

ΔT
RMS

RADIAL VELOCITY (Km/sec)