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ON THE STRUCTURE OF HYDROXYL MASER SOURCES

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SUMMARY

Recent interferometric observations of hydroxyl maser sources (Davies, Masheder & Booth; Harvey, Booth, Davies, Whittet & McLaughlin) are analysed and it is shown that radiation is observed only along isolated lines of sight characterized by a specific Doppler shift of frequency, a unique sense of circular polarization and a single transition. Some implications of this result for possible properties of pumping processes or for solutions of the equations of transfer are indicated and it is argued that the observations could be accounted for by a filter mechanism depending on a correlation between mass velocity and magnetic field in the source region. It may be that the rate of pumping is uniform throughout the source and that the filter allows stimulated emission only along a few lines of sight, at a few Doppler shifts with unique senses of polarization in single transitions.

1. INTRODUCTION

Although many different schemes have been suggested for inverting populations of Λ-doublet levels of hydroxyl in galactic maser sources, none has gained general acceptance and none accounts for all observations in any detail. One reason is that it is clear that there are at least two types of source—those associated with H II regions and those associated with infrared stars. A second reason is connected with the fact, emphasized by Weaver, Dieter & Williams (1968) and amply confirmed since, that the spectra of the four lines of the ground state Λ-doublet quartet of OH, as observed in emission sources, bear no relation one to the other. This observation, itself inconsistent with spontaneous emission, could well be a consequence of the possibility that in a saturated maser, stimulated emission can itself alter population densities, so that it may be expected that the populations if, for example, the four levels in the Λ-doublet complex of the ground state will depend not only on the inversion process but also upon the intensities of each of the four possible transitions. Detailed solutions of the equations of radiative transfer are needed to investigate this question and are in general not available although some relevant results have been obtained (Cook 1968; Bromley 1970, 1971). Cook (1968) and Bromley (1971) have each stressed the importance of disentangling the changes in population brought about by stimulated emission from those arising in the pumping process. Unless the distinction can be made, the physical requirements of the pumping process may be misappreciated. It was with the aim of attempting to specify more precisely the population of the quartet of ground state ($^2\Pi_{3/2}$, $J = \frac{3}{2}$) levels of hydroxyl that recent detailed interferometric surveys of some sources associated with H II regions were analysed, as described in this paper.

2. THE SOURCE W3(OH)

A detailed interferometric survey at 1665 MHz has been made by Harvey *et al.* (1974) extending and refining earlier work by Cooper, Davies & Booth (1971). They used an interferometer of 23 km baseline (127 km in the earlier work) associated with a correlation interferometer of 128 channels. Emission occurs from isolated spots, known from studies with very long baseline interferometers to be of the order of 10^{-2} arcsec in diameter (Moran *et al.* 1968a, b) and Baldwin, Harris & Ryle (1973) have shown that the spots lie around the margin of a compact H II region some 2 arcsec across (the likelihood of such a relation of OH sources to an H II region has been argued on physical grounds (Cook 1968)).

The observations of Harvey *et al.* (1974) are summarized in Table I. The emission from each of the 22 spots is characterized by a sense of circular polarization and by a frequency (which may be expressed as the velocity for a Doppler shift from the local standard of rest). The radiation at 1665 MHz comes from discrete directions in the sky, each subtending no more than 10^{-2} arcsec, and each with its characteristic Doppler shift and polarization. Now the Doppler shift must be supposed to arise from the mass motion of the hydroxyl atoms along the line of sight in the direction of the individual spot, and it is therefore possible to say that each direction in the source region is characterized by a line-of-sight mass motion.

Now consider the frequencies of components in the transitions at 1720, 1667 and 1612 MHz. No interferometric studies like those at 1665 MHz have been

TABLE I

Components of W3(OH) at 1665 MHz

Position RA (sec)	Position Dec. (sec)	Doppler shift (km s^{-1})	Polarization
1·25	−0·20	+3·4	R
0·95	0·28	−4·0	L
0·93	−1·32	+0·1	L
0·93	0·28	−3·4	R
0·93	−0·16	+5·7	R
0·90	−1·80	+3·2	R
0·90	−0·06	+1·4	R
0·89	−0·06	−2·3	L
0·82	−1·86	+0·8	L
0·77	−1·37	+2·9	R
0·72	−1·93	+4·3	R
0·68	−1·16	+2·4	R
0·56	−1·88	+0·6	L
0·47	−1·89	−0·5	L
0·46	−1·84	−1·1	L
0·40	−1·90	+3·7	R
0·39	−1·92	−0·3	L
0·30	−1·68	+2·1	R
0·08	−0·26	+4·0	R
0·06	−0·71	+0·8	R
0·0*	0·0*	0·0 (−45·1)*	R
−0·03	−0·21	−1·4	L

* Positions and Doppler shifts expressed as differences from those of the −45·1 km s^{-1}, R.H. component.

TABLE II

Doppler shifts of emission lines in W3(OH)

Doppler shift (km s^{-1})	1720	1667	1665	1612
−49·24			*	
−48·52			*	
−47·44			*	
−46·36			*	
−45·25	*			
−45·19			*	
−45·10			*	
−44·90		*		
−44·38			*	
−44·20	*			
−43·66			*	
−43·25		*		
−42·85			*	
−42·50		*		
−42·45				*
−41·60			*	
−41·44			*	

undertaken, but the original survey by Weaver, Dieter & Williams (1968) shows that no components in the four transitions have the same Doppler shift (see Table II). If, as is inferred from the survey at 1665 MHz, directions to the source are characterized by Doppler shifts, it follows that in no case do hydroxyl molecules in a particular direction radiate in more than one of the 1720, 1667, 1665 or 1612 MHz transitions.

A comparison of Table I and II shows that the 1665 MHz components identified by Harvey *et al.* (1974) and by Weaver *et al.* (1968) differ somewhat. Harvey *et al.* isolated 22 instead of 17 components and the actual values of the Doppler shifts also differ slightly. No doubt these differences reflect the greater precision of the interferometric survey but they do not affect the conclusion that the Doppler shift of no 1665 component coincides with that of any component of any of the other three lines, for all the Doppler shifts of those transitions are well differentiated from any in both lists of 1665 MHz components.

Harvey *et al.* (1974) have also studied the hydroxyl sources Sgr B2, W49 (positions 1 and 2) W75N and S and VY CMa at 1665 MHz, and VY CMa at 1667 MHz, whilst Cooper, Davies & Booth (1971) also studied W51. The results at 1665 MHz show that in each source radiation comes from discrete directions each characterized by a Doppler shift and a sense of polarization (see Tables III(a) and (b) for W49). Similarly the data of Weaver *et al.* (Tables IV(a), (b) and (c)) show that there are no coincidences between Doppler shift at 1665 MHz and those at any of the other three transitions for W49, W51 and W75. (Weaver *et al.* (1968) did not distinguish the sources W49 1 and 2 nor W75 N and S.) Table V gives the Doppler shifts found by Weaver *et al.* (1968) for NGC 6334 (not observed by Harvey *et al.* (1974)) and they include one of two coincidences between Doppler shifts in two transitions, namely that at −5·99 km s^{-1}; the other is in the Ori A source at 6·35 km s^{-1}.

The sources so far discussed fall into Class I of Turner (1970), those for which the strongest radiation is at 1665 or 1667 MHz. Harvey *et al.* (1964) also observed

Table III(a)

Components of W49 (position 1) at 1665 MHz

Position		Doppler shift	
RA (sec)	Dec. (sec)	(km s^{-1})	Polarization
1·13	2·81	−9·2	L
1·05	2·49	−7·3	L
1·02	2·43	−8·9	L
0·65	0·57	−9·9	L
0·48	0·5	−10·0	R
0·16	0·0	−4·1	L
0·16	−0·13	−4·4	L
0·15	0·19	−5·4	L
0·15	−0·01	−4·1	R
0·14	0·11	−5·4	R
0·14	−0·03	−3·0	R
0·09	0·7	−9·5	L
0·07	0·07	−2·0	L
0·06	0·33	−3·0	L
0·05	0·32	−2·4	L
0·00	0·81	−3·6	R
0·00*	0·00	0·0*	L
0·00	−0·14	−0·9	L
−0·03	0·76	−1·0	R
−0·03	0·64	−3·6	L
−0·13	0·88	−1·6	R
−1·07	0·1	−6·0	R

* Positions and Doppler shifts expressed as differences from those of the −20·9 km s^{-1}, L.H. component.

Table III(b)

Components of W49 (Position 2) at 1665 MHz

Position		Doppler shift	
RA (sec)	Dec. (sec)	(km s^{-1})	Polarization
0·50	−0·99	−1·8	L
0·43	−1·22	−4·9	L
0·39	−1·50	−2·7	L
0·34	−1·68	−1·7	R
0·33	−1·30	−3·1	R
0·33	−1·45	−2·3	R
0·33	−1·50	−2·5	R
0·33	−0·06	−0·9	L
0·32	−1·53	−3·2	L
0·30	−1·55	−2·8	R
0·21	−0·65	+2·9	L
0·21	−0·69	+3·2	L
0·18	−0·66	+5·9	L
0·15	−0·69	+6·2	R
0·12	−0·73	+2·5	L
0*	0	0*	R
−0·07	0·05	−1·0	R
−0·34	−0·57	+2·1	L
−0·44	−0·49	+0·1	L
−0·46	−0·62	+0·3	L
−0·49	−0·58	+1·7	L
−0·50	−0·42	+3·5	R
−0·50	−0·54	+4·7	R

* Positions and Doppler shifts expressed as differences from those of the +16·0 km s^{-1}, R.H. component.

TABLE IV(a)

Doppler shifts of emission lines in W49

Doppler shift (km s^{-1})	1720	1667	1665	1612
+0·78			*	
+0·97		*		
+1·86			*	
+1·87		*		
+2·59		*		
+2·76				
+4·39		*	*	
+4·93		*		
+5·28			*	
+5·83		*		
+7·71			*	
+7·80		*		
+7·90	*			
+9·15			*	
+9·78			*	
+11·13			*	
+12·12			*	
+13·29		*		
+13·65			*	
+14·10				*
+14·50	*			
+14·85				*
+15·18			*	
+15·54		*		
+16·07		*		
+16·08			*	
+16·45				*
+16·79		*		
+16·80			*	
+18·06			*	
+19·04		*		
+19·10	*			
+19·49		*		
+19·50			*	
+20·04			*	
+20·50	*			
+20·94			*	
+21·20		*		
+22·02			*	

TABLE IV(b)

Doppler shifts of emission lines in W51

Doppler shift (km s^{-1})	1720	1665
+57·34		*
+57·65	*	
+58·50	*	
+58·69		*
+59·23		*
+60·31		*
+61·48		*

TABLE IV(c)

Doppler shifts of emission lines in W75

Doppler shift (km s^{-1})	1720	1665
−0·37		*
+0·53		*
+0·98		*
+1·0	*	
+1·61		*
+2·96		*
+5·12		*
+5·2	*	
+5·30		*
+5·66		*
+9·44		*
+11·88		*
+12·68		*

TABLE V

Doppler shifts of emission lines in NGC 6334

Doppler shift (km s^{-1})	1720	1667	1665
−15·43		*	
−15·16		*	
−14·25		*	
−13·18		*	
−12·38			*
−12·37		*	
−11·66			*
−11·65		*	
−11·05	*		
−10·58			*
−10·57		*	
−10·35	*		
−9·86			*
−9·76		*	
−9·00			*
−8·86		*	
−8·87		*	
−8·24		*	
−8·06		*	
−7·97			*
−7·61		*	
−7·52		*	
−6·80			*
−5·99		*	
−5·63		*	
−4·91		*	
−3·92			*

VY CMa, the strongest radiation from which is at 1612 MHz. VY CMa has been observed by Davies, Masheder & Booth (1972) although details of the components at that frequency have not been published. There are two coincidences of Doppler shift between the 1665 and 1667 MHz transitions and two between L and R polarizations at 1667 MHz (Table VI) but Table VII shows that the corresponding elementary sources do not coincide in direction. The positional systems for 1665 MHz, 1667 mHz (LH) and 1667 MHz (RH) are unrelated, but the shifts in position needed to bring one pair of sources with the same Doppler shift into directional coincidence would not bring others into coincidence.

It can therefore be concluded that in no case is radiation in more than one transition observed from any direction in any source that has been observed in sufficient detail. This conclusion must however be qualified. No radiation has been observed in other than the single transition, but the sensitivity of equipment is such that radiation in another transition of an intensity less than one-thousandth of the observed radiation would not be detected. In the source W3(OH), 1665 MHz radiation comes from widely distributed parts of the source, and if the sites of emission in other transitions are identified by the correspondence between Doppler shift and position established in the 1665 MHz transition, it appears that the

TABLE VI

Components of VY CMa at 1665 and 1667 MHz

Doppler shift	1665 MHz	1667 MHz
7·3	L	
6·9		R
6·7	L	
6·6		R
6·3		R
6·2	L	
5·8	L	R
5·3	L	R
5·1		R
4·9	L	R
4·7		R
4·5		R
4·3	L	R
4·2		R
3·9		
3·7	L	
3·5		R
3·2		L
3·1	L	
2·7	L	
2·6		R
2·3	L	L
2·2		R
1·9		R
1·7		
1·6	L	
1·4		L, R
0·7		L
−0·3		L
−2·5		L, R

TABLE VII

Relative positions of the components with coincident Doppler shifts in VY CMa

Doppler shift (km s^{-1})	1665 MHz position (sec)		1667 MHz position (sec)			
			L.H.		R.H.	
	RA	Dec.	RA	Dec.	RA	Dec.
5·3	0·14	−0·32			−0·035	0·078
4·9	−0·11	−0·02			−0·048	0·054
1·4			0·14	−0·27	0·30	0·60
−2·5			0·11	−0·44	0·06	0·12

Positions relative to the following components:

1665 MHz (L.H.): 4·3 km s^{-1}
1667 MHz (L.H.): −0·3 km s^{-1}
(R.H.): 4·7 km s^{-1}

emission at 1720, 1667 and 1612 MHz is restricted to regions of the source where the Doppler shifts are about −42·5, −43·0 and −44·5 km s^{-1}; thus the 1665 MHz radiation from W3(OH) is both stronger generally and more widely distributed over the source region. Other sources studied by Cooper *et al.* (1971) seem to show the same behaviour—radiation from one transition, usually 1665 MHz, is the strongest, and radiation from other transitions is confined to a few regions of the source defined by the strongest radiation. Harvey *et al.* (1974) make this point explicitly for VY CMa, for which the strongest radiation is at 1612 MHz.

The foregoing analysis may be summarized by saying that along most lines of sight from the Earth to the source region there is no stimulated emission of any sort, for it is observed only from a few very restricted directions, and that in those few preferred directions, one transition alone gives the stimulated emission. A very similar state of affairs obtained for radiation characterized by changes of magnetic quantum numbers. It is observed that radiation from any particular source spot is circularly polarized in either the right- or the left-handed sense, that is to say that only the transitions in which m_F changes *either* by +1 *or* by −1 show stimulated emission.

From most directions in the source, no radiation is observed and if radiation is observed it is from a single transition, with a single sense of circular polarization and with a characteristic Doppler shift. It is possible that these characteristics may reflect variations in the pumping mechanism from place to place in the source, they may arise from properties of the solutions of the equations of transfer and population equations, or thirdly, they may be the consequence of a filter in the source. I consider the three possibilities in turn. Hitherto, it may be claimed that the discussion has been rather firmly tied to observation; now it becomes in some respects more speculative.

3. VARIATIONS OF PUMPING CONDITIONS

Consider first the pattern of the populations of the different levels which a pumping mechanism would have to generate if variations in it alone were responsible for the observed radiation.

Of the two levels into which the Λ-doublet interaction splits the $^2\Pi_{3/2}$, $J = \frac{3}{2}$, ground state, the upper has positive parity, while the lower has negative parity.

Interaction between the spin of the proton and the total angular momentum J further splits each Λ-doublet level into a hyperfine doublet. The upper of each hyperfine doublet has F, the vector sum of $J(\frac{3}{2})$ and $I(\frac{1}{2})$ equal to 2 while for the lower of each hyperfine doublet, F is 1. Numbering the levels 4, ... 1, giving that with greatest energy number 4, they are characterized by

Level 4	+,	$F = 2$
3	+,	$F = 1$
2	−,	$F = 2$
1	−,	$F = 1$.

The transitions (all electric dipole) are

	MHz
$4 \rightarrow 1$	1720
$4 \rightarrow 2$	1667
$3 \rightarrow 1$	1665
$3 \rightarrow 2$	1612.

Let n_i be the number density of molecules in level i. For stimulated emission in the transition (i, j) to occur from a given region of the source, it is necessary for n_i, the number in the upper level to be greater than n_j, the number in the lower level of the transition. Suppose that only 1665 radiation is received from a given direction. Then for stimulated emission to take place in the corresponding volume of the source region,

$$n_3 > n_1.$$

But since stimulated emission does not occur in other transitions,

$$n_4 \leqslant n_1, n_2 \quad \text{and} \quad n_3 \leqslant n_2.$$

It follows that

$$n_4 + n_3 \leqslant n_1 + n_2;$$

that is to say, the populations of the Λ-doublet, as a whole, are not inverted. In fact, a possible set of populations is

$$n_4 + n_3 = n_1 + n_2$$

together with

$$n_3 - n_4 = n_2 - n_1$$

so that the Λ-doublet levels, as a whole, would be in thermodynamic equilibrium whilst the hyperfine levels would not. The conclusion applies whenever stimulated emission is found at just one transition, and the relations between population densities of the upper hyperfine doublet for the four possible situations are

Emission at (MHz)	
1720	$n_4 > n_1$;
1667	$n_4 > n_2$;
1665	$n_3 > n_1$;
1612	$n_3 > n_2$.

In each case $n_4+n_3 \leqslant n_2+n_1$, and so the Λ-doublet as a whole is not inverted. On the other hand, the populations of hyperfine doublets are unequal, and satisfy the following relations:

Emission at (MHz)	
1720	$n_4 > n_3, \quad n_2 \geqslant n_1;$
1667	$n_4 > n_3, \quad n_2 \leqslant n_1;$
1665	$n_4 < n_3, \quad n_2 \geqslant n_1;$
1612	$n_4 < n_3, \quad n_2 \leqslant n_1.$

A similar analysis can be applied to the populations of sub-levels with different magnetic quantum numbers, m_F. The analysis is more intricate because there is more than one pair of levels for which the change of m_F is either $+1$ or -1, namely four pairs when F is 2 for both states (1667 MHz) two when F is 1 for both (1665 MHz) and three when F is different in the two states (1612 and 1720 MHz). As before, the absence of radiation from other pairs of levels implies that the Λ-doublet populations as a whole are not inverted. The question that recurs is, whether the particular disturbance of thermodynamic equilibrium arises from the pumping process (the first possibility listed above) or is it a consequence of redistribution of populations by stimulated emission in a saturated maser (the second possibility)?

Three possibilities may be suggested.

First, suppose that the inequalities of populations arise from some radiational pumping process by near ultraviolet (Litvak *et al.* 1966) or by far-infrared radiation (Litvak 1969). Then the inequalities might vary from place to place as a consequence of varying optical depth at the pumping frequencies. Such variations are indeed postulated as a possible cause of the different classes of source distinguished by Turner (1970).

Secondly, suppose that the inequalities of population are brought about by some collisional or chemical processes. The likelihood of such a process distinguishing between energy levels at only 50 MHz apart in ways that vary from place to place, seems very low. That does not mean, however, that such processes are to be excluded and radiation processes accepted, for it has been shown that the photon efficiency of the latter would most likely have to be improbably great.

Thus, the third possibility should be considered, that the inversion process does not itself distinguish between hyperfine states, and that the special inequalities are brought about by stimulated emission. No one has worked out such a scheme in detail because of its mathematical complexity, but Bromley (1971) has studied the simpler triplet system of the $^2\Pi_{1/2}$, $J = \frac{1}{2}$ rotational state, and on that basis suggests that the radiation observed from the $^2\Pi_{3/2}$, $J = \frac{3}{2}$ quartet would depend on the optical thickness in the Λ-doublet transitions, the 1667 MHz radiation being observed at the smaller thickness, then the 1665 MHz radiation and the 1720 MHz radiation at the greatest thicknesses. Thus in sources such as W3(OH) the optical thickness over most of the source would be that corresponding to 1665 MHz radiation with thickness corresponding to other radiations restricted to smaller regions.

4. A POSSIBLE FILTER

While the foregoing mechanisms might account for the single transitions, they do not seem to account for a unique sense of polarization; I therefore examine the idea of a filter in the source.

I suggest that within a source of given type (that is, one associated with an H II region or one associated with an infrared star) the pumping rates are generally similar throughout the source and that in particular, the different magnetic sub-levels are pumped at the same rates. In the absence of a filter, it would be expected that radiation would be emitted uniformly from the source and would be unpolarized. I now postulate that a filter so reduces the optical depth that stimulated emission occurs only along a few preferred lines of sight, with one sense of polarization and in one transition as is observed.

I have urged before (Cook 1968) that the optical depth along the line of sight to the Earth depends upon the scatter of molecular velocities projected on the line of sight, and it is probable that that factor determines the pattern of sources that is observed. The work of Baldwin, Harris & Ryle (1973) on the relation of the W3(OH) sources to the related compact H II source has given strong support to my earlier argument (Cook 1968) that OH sources (of Turner's Type I) are situated round the margins of H II regions, probably in the ionization front. Stimulated emission from such a thin spherical shell would be expected to appear, from the Earth, as a narrow illuminated rim to the H II region and the W3(OH) source spots do appear to lie within where such a rim would be, but radiation comes from spots which are only a very small fraction of the solid angle subtended by the rim at the Earth. Something inhibits stimulated emission from almost the whole of the potential source region and a very likely cause is that the optical thickness is almost everywhere reduced by the incoherence of velocities along the line of sight; only in a very few favoured directions are velocities sufficiently coherent to permit strong maser amplifications. I have also suggested (Cook 1966) that the reason why only one sense of polarization is observed is that a magnetic field in the source is correlated with mass velocity in such a way that the change of Zeeman shift along the line of sight for one sense of polarization corresponds to the change of Doppler shift, while for the other sense, it is in the opposite direction.

Let x be distance measured along the line of sight to the Earth and let u be the component of gas velocity along the line of sight and B the component of magnetic field. Then suppose u and B to change linearly with x:

$$u = u_0 + \partial u/\partial x,$$

$$B = B_0 + \partial B/\partial x.$$

The change of velocity in a distance x is then

$$x\frac{\partial u}{\partial x}.$$

In order that the transition frequency should be constant along the line of sight, as is required for maximum optical depth, the Doppler shift corresponding to this change in velocity must equal the change in Zeeman shift corresponding to the change in magnetic field. Let the Zeeman shift be γB. Then the condition to be satisfied is

$$\gamma \frac{\partial B}{\partial x} x = -\frac{\nu}{c} \frac{\partial u}{\partial x} x.$$

γ is positive for one sense of polarization ($\Delta m_F = +1$) and negative for the other sense, and thus the condition is satisfied either for right-handed or for left-handed polarization.

The factor relating the gradient of magnetic field to gradient of velocity is $\nu/\gamma c$.

$$\gamma \text{ is } (E_1 - E_2)/hB,$$

where E_1 and E_2 are the changes of the energies of the upper and lower levels respectively in a field B.

Now

$$\frac{E}{hB} = \frac{\mu_0 g_J}{h}\left[\frac{F(F+1)+J(J+1)-I(I+1)}{2F(F+1)}\right] m_F,$$

where μ_0 is the Bohr magneton ($9{\cdot}2732 \times 10^{-24}$ J/T) and g_J is the Landé splitting factor, equal to 0·935 for the upper levels of the Λ-doublet and to 0·936 for the lower levels (Radford 1961). μ_0/h is 13 997 MHz/T and so γ is found to have the values given in Table VIII and the corresponding values of $\nu/\gamma c$ are, in units of 10^{-10} Ts m^{-1}

1720 MHz: $\pm 17{\cdot}78$, $\pm 5{\cdot}85$, $\pm 3{\cdot}50$

1667 MHz: $\pm 5{\cdot}67$ (mean of four values)

1665 MHz: $\pm 3{\cdot}38$ (mean of two values)

1612 MHz: $\pm 16{\cdot}48$, $\pm 5{\cdot}48$, $\pm 3{\cdot}28$.

On the face of it, the values for the four transitions are quite different, but the differences of frequency to which they give rise should be compared with the widths of the lines arising from the thermal velocities of the gas, generally somewhat less than $\pm 0{\cdot}5$ km s^{-1}.

The range of mass velocities in the sources is of the order of 20 km s^{-1}, the corresponding Doppler shifts are about 100 kHz and the required range of magnetic

TABLE VIII

Zeeman shifts in the ground-state quartet of hydroxyl

Frequency (MHz)	m_F	(γ) (GHz/T)						
1720	+1		−16·37		−9·80		−3·23	
	−1		3·23		9·80		16·37	
1667	+1	−9·82		−9·81		−9·80		−9·79
	−1	9·79		9·80		9·81		9·82
1665	+1			−16·37		−16·36		
	−1			16·36		16·37		
1612	+1		−3·26		−9·81		−16·36	
	−1		16·36		9·81		3·26	

fields is of the order of $5 . 10^{-6}$ T (50 mG). The closest values of $\nu/\gamma c$ are 5·67 for 1667 MHz and 5·85 for 1720 MHz or 5·48 for 1612 MHz. At a field of 10^{-5} T, the corresponding velocities for matching the Doppler and Zeeman shifts would be 17·63, 17·06 and 18·21 km s^{-1} respectively. The differences between these values are of the order of the half-width of the thermal distribution of velocities, and it may therefore be concluded that if the gradient of velocity and magnetic field are matched for one transition, they will not be matched for any other, given the observed range of mass velocities and the magnetic fields corresponding to them. A range of magnetic field of 10^{-5} T may seem large in relation to other galactic fields, but a much smaller range of field would suffice to discriminate between the 1667 and 1665 MHz transitions, and to a large extent between those and the 1712 and 1620 MHz transitions.

Thus, the mechanism previously suggested for producing polarization of one sense also ensures that only one transition can radiate, and so provides a filter which selects radiation of one Doppler shift and one sense of polarization in one transition along a given line of sight within a single source region. At the same time it should be borne in mind that differences between sources of different type may well arise from differences in the pumping mechanism, for Litvak (1969) has argued that a scheme depending on absorption of far infrared radiation may account for the dominance of the 1612 MHz transition in sources associated with infrared stars, while on the other hand, the pumping mechanism in the sources associated with H II regions could be driven by ultraviolet radiation or energetic particles.

It is true that in the absence of detailed solutions of the equations of radiative transfer, it remains speculative to attribute much of the observed structure of sources like W3(OH) to variations of optical thickness at the 18-cm radiation, and then to variations of mass velocities along the line of sight; on the other hand, if the line of sight velocities are incoherent, the optical thickness will certainly be reduced and stimulated emission will be reduced or suppressed, and furthermore, it seems very likely that in an ionization front expanding at some 10 km s^{-1} and also, it seems, rotating, there will be turbulent motions on a large scale, as indeed is strongly suggested by the scatter of Doppler shifts of the observed radiation. Some effect of mass motions on the structure of hydroxyl maser sources seems inescapable, whether or not the particular features of the structure of W3(OH) and similar objects have been correctly attributed in this article.

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