

## Chapter 4

### Results

This chapter presents the results of OH maser study in the region of OH 330.953-0.182. The intensities and spectra of OH maser features are presented in Section 4.1. The velocities and positions of OH features are presented in Section 4.2. Finally, the Zeeman analysis are presented in Section 4.3.

#### 4.1 Intensity and spectra

In the most channel, the rms noise ( $\sigma_{rms}$ ) was  $\sim 0.75$  mJy beam $^{-1}$  in 1665-MHz maps and 0.14 mJy beam $^{-1}$  in 1667-MHz maps. In the brightest channels the  $\sigma_{rms}$  levels were up to 1.4% and 5.2% of the peak fluxes for 1665- and 1667-MHz maps respectively. The emission in each channel which met the required criteria was fitted into Gaussian components. There is usually one component in each channel.

The OH maser emission in 1665- and 1667-MHz maps were measured using the 'JMFIT' task in the AIPS program to derive positions and flux densities. An example of each feature is shown in Figure 4.1. The main diagram show the velocity and peak flux of each channel. The upper frames show the contour maps produced from 'KNTR' task which are related to the spectra below. Fifty-three different spectral features in both 1665- and 1667-MHz OH maser emission were detected and listed in Table 4.1 and Table 4.2. The positional uncertainties of each feature were calculated from the standard deviation of the position of the components in that feature. According to equation in Section 3., the position offset (0, 0) at pixel (256, 256) is relative to R.A.(2000) =  $16^h 09^m 53^s.5$  and Dec(2000) =  $-51^\circ 54' 54''.0$

Figure 4.2 and Figure 4.3 show the velocity profiles of 1665- and 1667-MHz OH maser features corresponding to Table 4.1 and Table 4.2 respectively. The peak flux of each component measured from the contour maps were plotted against the Local Standard of Rest (LOS) velocity.

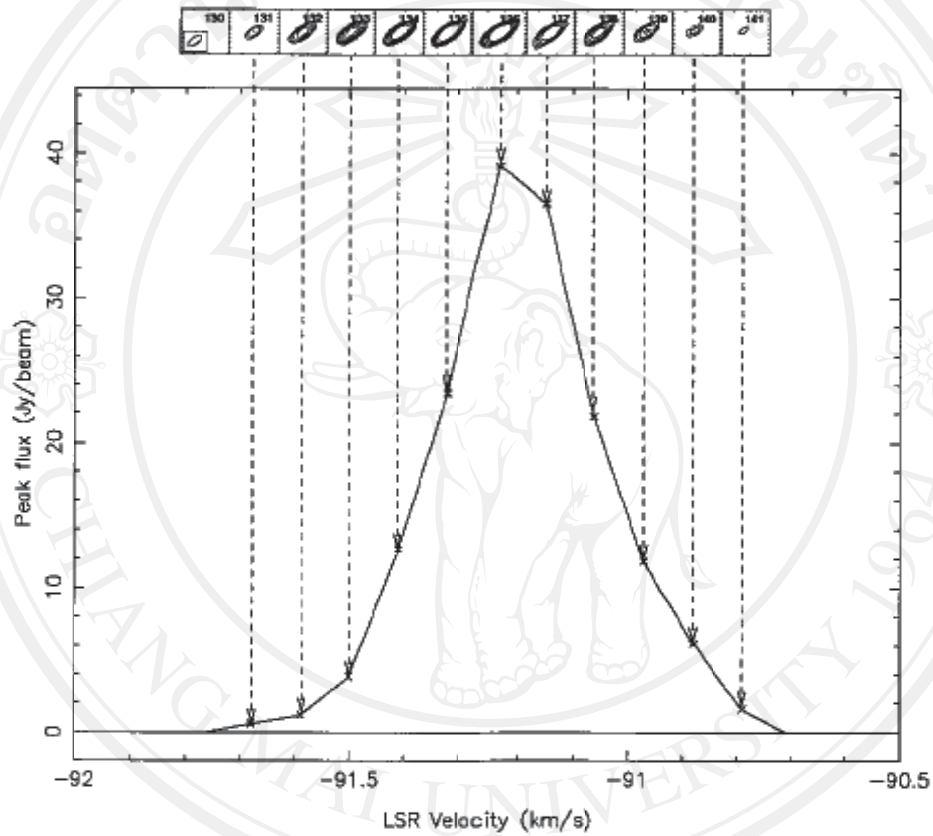


Figure 4.1: The line shape of feature i (RHCP, 1665 MHz). The upper frames show the contour maps corresponding with the spectra. The contour levels are 0.4, 0.8, 1.6, 3.2 and 6.4 Jy beam<sup>-1</sup>

For the LHCP 1665-MHz OH maser features, there are 19 features which the velocities ranging from  $-80.30$  to  $-98.28 \text{ km s}^{-1}$ . The maximum peak flux is  $25.18 \text{ Jy beam}^{-1}$  at velocity  $-83.02 \text{ km s}^{-1}$ . The features are divided into two groups, five features in the velocities ranging from  $-91.27$  to  $-85.25 \text{ km s}^{-1}$  and the features at the velocity  $-98.29$ ,  $-97.82$ ,  $-97.12$  and  $-95.46 \text{ km s}^{-1}$ .

For the RHCP 1665-MHz OH maser features, there are 23 features which the velocities ranging from  $-99.66$  to  $-85.18 \text{ km s}^{-1}$ . The maximum peak flux is  $39.16 \text{ Jy beam}^{-1}$  at the velocity  $-91.19 \text{ km s}^{-1}$  and the second maximum peak flux is  $31.99 \text{ Jy beam}^{-1}$  at the velocity  $-85.73 \text{ km s}^{-1}$ . The features are divided into two groups, five features in the velocities ranging from  $-91.78$  to  $-84.18 \text{ km s}^{-1}$  and the features at the velocity  $-99.66$ ,  $-98.30$ ,  $-97.89$ ,  $-97.15$ ,  $-92.64$  and  $-92.22 \text{ km s}^{-1}$ .

For the LHCP 1667-MHz OH maser features, there are six features which the velocities ranging from  $-97.85$  to  $-82.15 \text{ km s}^{-1}$ . The maximum peak flux is  $14.05 \text{ Jy beam}^{-1}$  at velocity  $-83.56 \text{ km s}^{-1}$ . The features are divided into two groups, 5 features in the velocities ranging from  $-82.15$  to  $-84.34 \text{ km s}^{-1}$  and a feature at the velocity  $-97.70 \text{ km s}^{-1}$ .

For the RHCP 1667-MHz OH maser features, there are five features which the velocities ranging from  $-91.75$  to  $-84.09 \text{ km s}^{-1}$ . The maximum peak flux is  $10.33 \text{ Jy beam}^{-1}$  at velocity  $-85.24 \text{ km s}^{-1}$ . The features are divided into two groups, 4 features in the velocities ranging from  $-86.56$  to  $-82.15 \text{ km s}^{-1}$  and a feature at the velocity  $-91.58 \text{ km s}^{-1}$ .

Table 4.1: The 1665-MHz OH maser features in OH 330.953-0.182 region. The polarizations flux weighted mean velocities and positions are given for each feature. The position offset (0, 0) are given relative R.A.(2000) =  $16^h 09^m 53^s.5$  and Dec(2000) =  $-51^\circ 54' 54''.0$  respectively.

Features	Velocity ( $\text{km s}^{-1}$ )	R.A.offset (arcsec)	Dec. offset (arcsec)	$\sigma_{RA}$ (arcsec)	$\sigma_{Dec}$ (arcsec)	Peak flux ( $\text{Jy beam}^{-1}$ )
<i>1665LHCP</i>						
A	-98.28	2.664	-1.728	0.017	0.009	1.34
B	-97.82	2.639	-1.709	0.012	0.008	2.20
C	-97.12	2.585	-1.702	0.017	0.024	2.27
D	-95.46	2.663	-2.504	0.006	0.010	2.05
E	-91.97	0.621	-2.087	0.014	0.009	7.49
F	-88.12	-1.017	-4.701	0.008	0.007	7.30
G	-87.89	-0.918	-0.485	0.010	0.011	1.63
H	-87.68	-1.070	-4.921	0.006	0.002	3.17
I	-87.21	-1.070	-4.901	0.008	0.010	2.23
J	-86.92	-0.731	-0.754	0.007	0.011	12.58
K	-86.61	-0.736	-0.879	0.013	0.008	2.26
L	-85.85	-0.768	-0.873	0.017	0.006	4.49
M	-84.79	-0.351	-1.781	0.003	0.005	6.22
N	-83.86	-0.425	-1.403	0.021	0.009	1.17
O	-83.02	-0.449	-1.449	0.005	0.019	25.18
P	-82.58	-0.309	-1.663	0.005	0.009	10.10
Q	-81.83	-0.363	-1.599	0.004	0.009	5.11
R	-81.34	-0.325	-1.612	0.012	0.012	5.15
S	-80.30	-0.348	-1.548	0.008	0.011	1.96
<i>1665RHCP</i>						
a	-99.66	2.722	-2.414	0.015	0.005	0.67
b	-98.30	2.710	-1.769	0.000	0.006	1.26
c	-97.89	2.631	-1.692	0.006	0.027	1.65
d	-97.15	2.585	-1.706	0.008	0.005	2.47
e	-92.64	0.190	0.060	0.003	0.009	1.69
f	-92.22	0.271	0.163	0.014	0.011	1.26
g	-91.78	1.818	0.375	0.009	0.004	0.77
h	-91.76	0.704	-2.083	0.012	0.023	1.08
i	-91.19	0.000	0.000	0.010	0.011	39.16
j	-90.25	0.192	-0.019	0.002	0.009	5.08
k	-89.80	-1.069	-4.903	0.016	0.029	3.16
l	-89.69	0.203	-0.014	0.017	0.015	1.43
m	-89.37	-1.069	-4.899	0.014	0.007	2.81
n	-88.16	-1.019	-4.692	0.005	0.010	5.84
o	-88.05	-0.748	-0.770	0.013	0.010	1.32
p	-87.84	-0.381	-1.732	0.004	0.008	9.00
q	-87.01	-0.729	-0.754	0.027	0.019	4.65
r	-86.80	0.253	-0.323	0.017	0.005	13.51
s	-86.48	-0.434	-1.393	0.027	0.018	1.66
t	-85.82	-0.313	-1.659	0.015	0.006	10.64
u	-85.73	-0.447	-1.450	0.001	0.014	31.66
v	-85.27	-0.361	-1.596	0.034	0.053	1.05
w	-84.18	-0.357	-1.501	0.009	0.018	1.10

Table 4.2: The 1667-MHz OH maser features in OH 330.953-0.182 region. The polarizations flux weighted mean velocities and positions are given for each feature. The position offset (0, 0) are given relative R.A.(2000) =  $16^h 09^m 53^s.5$  and Dec(2000) =  $-51^\circ 54' 54''.0$  respectively.

Features	Velocity ( $\text{km s}^{-1}$ )	R.A.offset (arcsec)	Dec. offset (arcsec)	$\sigma_{RA}$ (arcsec)	$\sigma_{Dec}$ (arcsec)	Peak flux (Jy/beam)
<i>1667-LHCP</i>						
A	-97.70	2.921	-1.266	0.011	0.010	2.21
B	-84.34	-0.457	-1.421	0.019	0.003	0.91
C	-84.19	-0.698	-1.109	0.015	0.019	4.43
D	-83.64	-0.455	-1.458	0.015	0.015	14.05
E	-83.15	-0.428	-1.506	0.012	0.016	6.85
F	-82.36	-0.429	-1.568	0.010	0.007	4.61
<i>1667-RHCP</i>						
a	-91.58	0.053	0.153	0.016	0.005	10.25
b	-86.56	-0.391	-1.722	0.014	0.017	2.57
c	-85.30	-0.460	-1.450	0.004	0.005	10.33
d	-84.83	-0.427	-1.499	0.013	0.01	6.92
e	-84.15	-0.439	-1.554	0.008	0.013	1.53

Total intensity spectra of 1665- and 1667-MHz OH maser features are plotted in LHCP and RHCP as shown in Figure 4.4. The LHCP 1665-MHz spectra have the maximum peaks of 15.28 and 25.18  $\text{Jy beam}^{-1}$  at  $-86.91$  and  $-83.03 \text{ km s}^{-1}$  respectively. Those of the RHCP 1665-MHz spectra are 39.16 and 39.93  $\text{Jy beam}^{-1}$  at  $-91.15$  and  $-85.77 \text{ km s}^{-1}$ , respectively.

The LHCP 1667-MHz spectra have the maximum peaks of 14.05  $\text{Jy beam}^{-1}$  at  $-83.56 \text{ km s}^{-1}$ , respectively. Those of the RHCP 1667-MHz spectra are 10.25 and 10.35  $\text{Jy beam}^{-1}$  at  $-91.59$  and  $-85.24 \text{ km s}^{-1}$ , respectively.

## 4.2 Velocities and Positions

The velocity profiles of the 1665 and 1667-MHz OH maser features are shown in Figures 4.2 and Figure 4.3 respectively. All of the OH maser emissions at 1665-MHz extends from  $-100$  to  $-80 \text{ km s}^{-1}$  and those at 1667-MHz extends from  $-98$  to  $-82 \text{ km s}^{-1}$ .

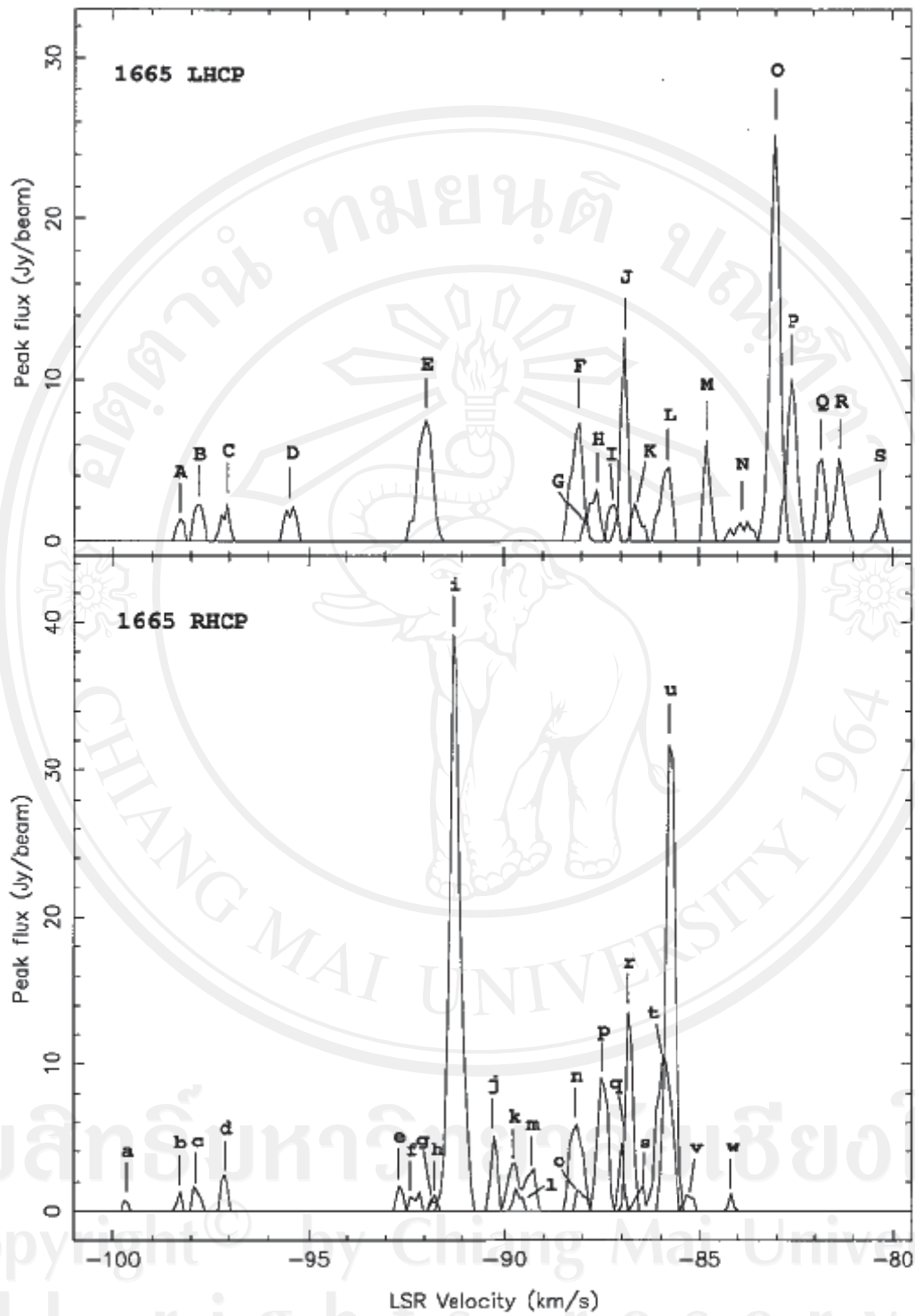


Figure 4.2: Velocity profiles of the 1665-MHz OH masers in OH330.953-0.182. The peak flux of each feature is plotted against the LSR velocity. The labeled features are listed in Table 4.1.

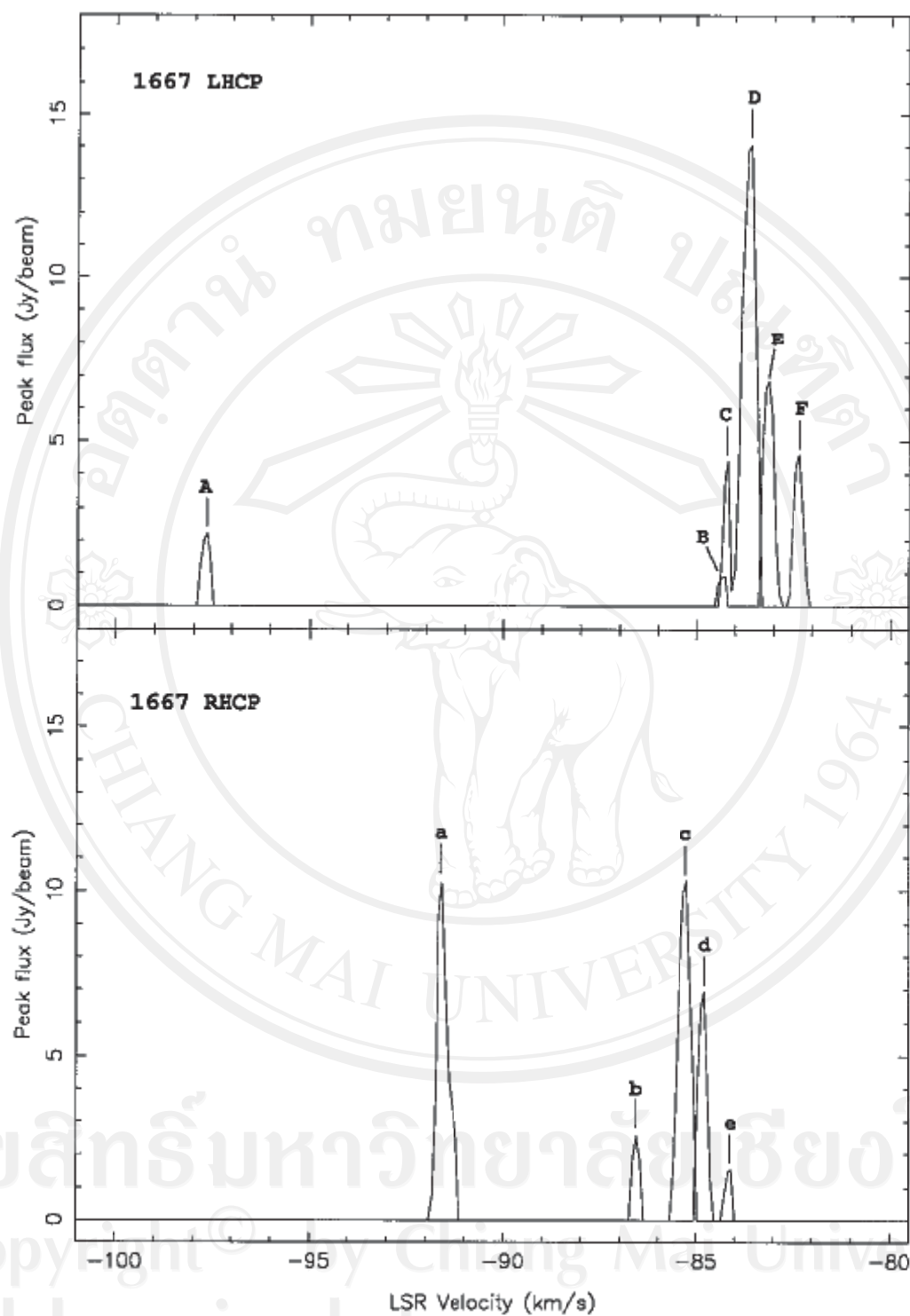


Figure 4.3: Velocity profiles of the 1667-MHz OH masers in OH330.953-0.182. The peak flux of each feature is plotted against the LSR velocity. The labeled features are listed in Table 4.2.

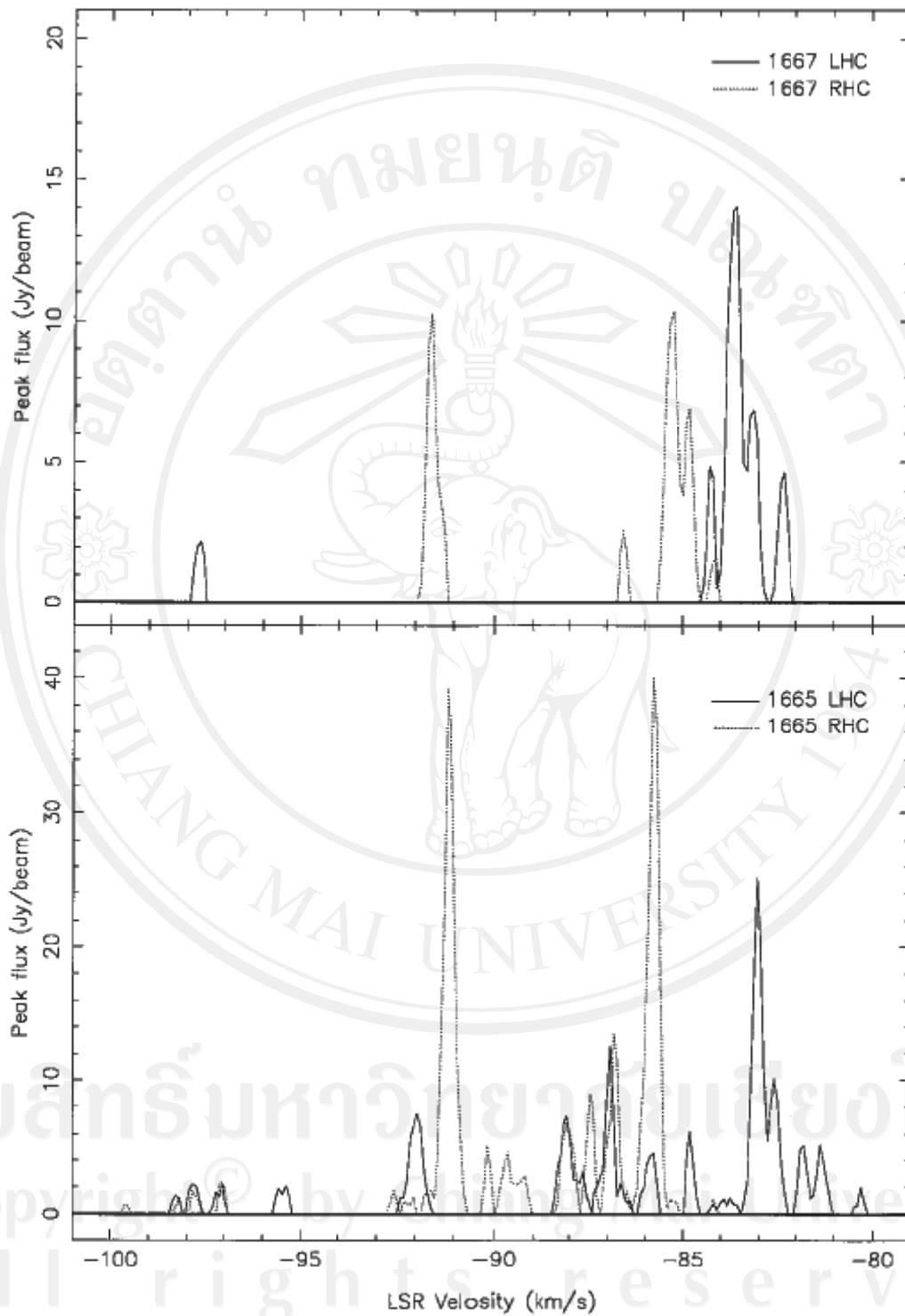


Figure 4.4: Total intensity spectra of OH masers at 1665- and 1667-MHz transitions.

According to Figure 4.5, the 1665-MHz maser features are clustered into seven groups (a1 to a7). Cluster a1 has the velocities ranging from  $-87.89$  to  $-80.30$   $\text{km s}^{-1}$ . This group, called group a1, have the velocity between  $-88.05$  and  $-80.30$   $\text{km s}^{-1}$ . At the north group of the map, at the position (0 arcsec, 0 arcsec) offset, called group a2, have the velocity ranging from  $-92.22$   $\text{km s}^{-1}$  to  $-86.80$   $\text{km s}^{-1}$ , are only the LHCP features. At the west of the map, near position (2.5 arcsec, -2 arcsec) offset, called group a3, have the velocity ranging from  $-95.49$   $\text{km s}^{-1}$  to  $-98.30$   $\text{km s}^{-1}$  and are expected to be the features of OH330.954-0.182. The a4 group at the south of the map have the velocity ranging from  $-87.21$   $\text{km s}^{-1}$  to  $-89.79$   $\text{km s}^{-1}$  are expected to be the features of the third site of the cluster. At the position (0.7 arcsec, -2 arcsec) offset, there are two features, velocity  $-91.76$   $\text{km s}^{-1}$  of the RHCP and  $-91.97$   $\text{km s}^{-1}$  of the LHCP, called group a5. The velocity  $-91.78$   $\text{km s}^{-1}$  at the northernmost of the map are the feature of the RHCP.

The positions and velocities of the 1667-MHz maser features are shown in Figure 4.6 similar to 1665-MHz, the maser features are clustered into three groups. The cluster b1 has velocities ranging from  $-86.56$  to  $-82.36$   $\text{km s}^{-1}$ . The cluster b2 has velocity  $-91.58$   $\text{km s}^{-1}$ . The last cluster, b3, has velocity  $-97.70$   $\text{km s}^{-1}$ . The clusters b1, b2 and b3 at 1667-MHz coincide with clusters a1, a2 and a3 at 1665-MHz respectively.

### 4.3 Zeeman Analysis

From Section 2.3.2, Zeeman splitting of the OH lines gives rise to pairs of  $\sigma$ -components of opposite circular polarizations. The split in velocity of each Zeeman pair allows the magnetic field strength and magnetic field direction to be derived. The features of opposite circular polarization which coincide within the positional uncertainties were identified as Zeeman pairs. Table 4.3 gives details of Zeeman pairs. The OH maser feature names refer to Table 4.1 and Table 4.2. The negative signs indicate the magnetic field direction towards us.

There are five Zeeman pairs detected in 1665 MHz (Z1 to Z5) and three Zee-

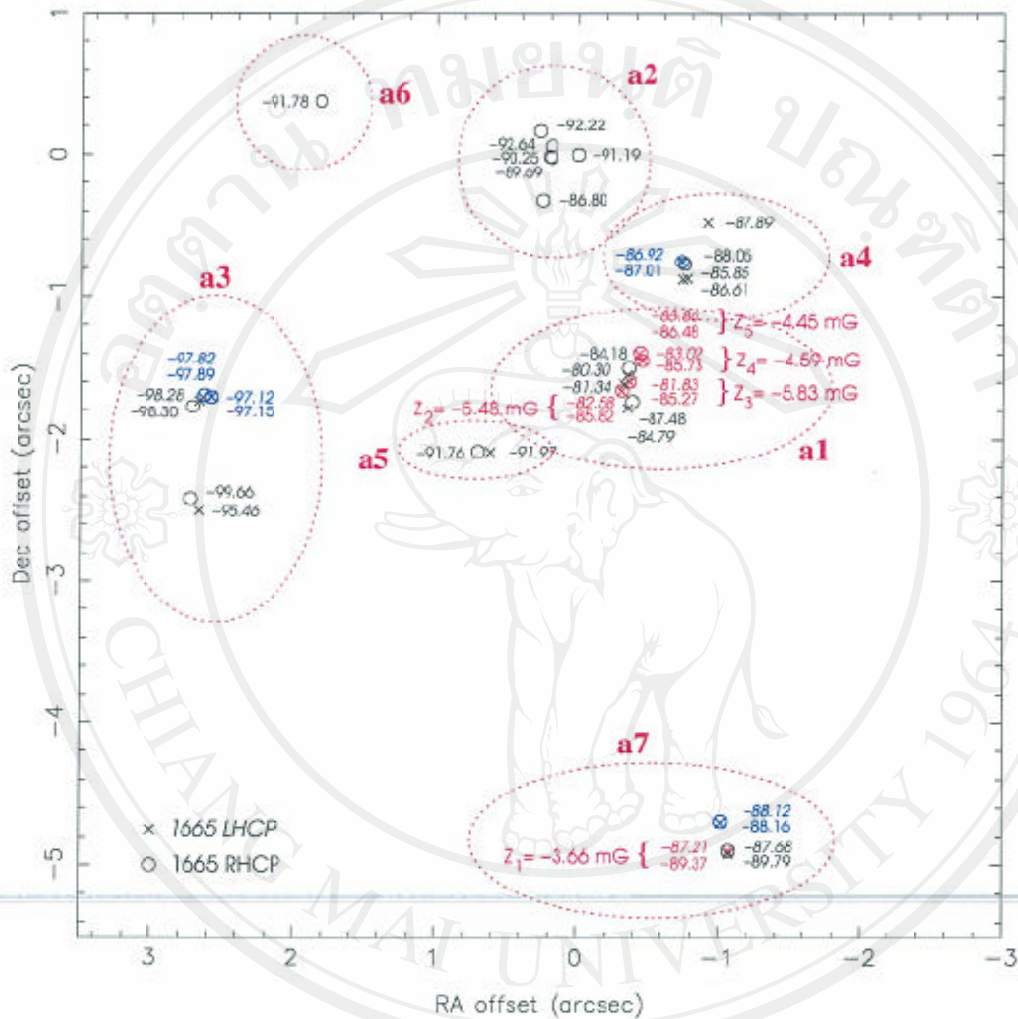


Figure 4.5: Positions and velocities of the 1665-MHz OH masers in OH 330.953-0.182. The positions are offset from (256,256) at R.A.(2000) =  $16^h 09^m 52^s.71$ , Dec(2000) =  $-51^\circ 54' 54''.58$ . The velocity of each feature is given in  $\text{km s}^{-1}$ . The red, blue and black labels are features of Zeeman pairs, linear polarization pairs and single polarization respectively.

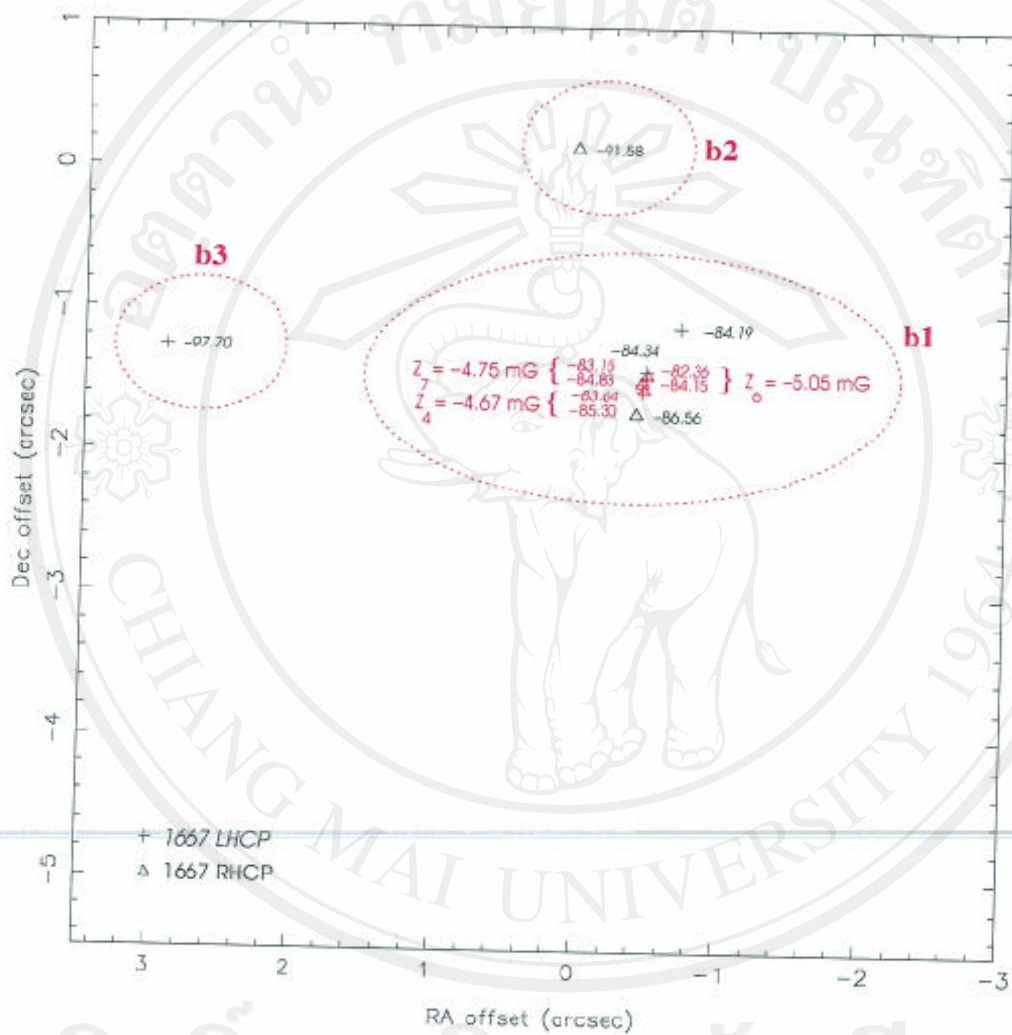


Figure 4.6: The positions are offset from  $(256,256)$  at R.A.(2000) =  $16^h 09^m 52^s.71$ , Dec(2000) =  $-51^\circ 54' 54''.58$ . The velocity of each feature is given in  $\text{km s}^{-1}$ . The color labels are coincide with Figure 4.5.

man pairs in 1667 MHz (Z4, Z6 and Z7). Among these pairs, Z4 in both 1665 and 1667 MHz are coincided in position, see Figure 4.5. In Figure 4.5, Zeeman pairs were plotted in red color. The RHCP and LHCP features which coincide in positions and velocities were identified as linear pair and plotted in blue color. Isolated single feature in RHCP and LHCP were plotted in black.

Figure 4.7 to Figure 4.14 show the positions of Zeeman pairs and their velocity profiles. The Zeeman pairs Z1, Z2, Z4 and Z7 are well defined. However, the Zeeman pairs Z3 and Z5 are less defined. As seen in Figure 4.9, the RHCP component of Z3 has large positional uncertainty, however its mean flux weighted mean position still coincides with that of LHCP component, therefore they are considered to be a Zeeman pair. In case of the Zeeman pair Z5, in Figure 4.11 complicated velocity profiles as seen component has two peaks at velocity  $-86.47$  and  $-86.38$  km s<sup>-1</sup> and the LHCP component has three peaks at velocity  $-84.28$ ,  $-83.47$  and  $-82.19$  km s<sup>-1</sup>. Therefore, the magnetic field value of Z5 in Table 4.3 were estimated from the total flux weighted mean velocities of both components. However, it is possible that there may be several features coincide in positions. Table 4.4 gives values of magnetic field strength derived from six possible Zeeman pairs included in Z5.

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In overall picture, the magnetic field derived from both 1665 and 1667 MHz is toward us (negative) and ranges from  $-3.36$  to  $-5.83$  mG, with mean value of  $-4.81$  mG.

Table 4.3: Zeeman Pair Masers in this cluster.

Feature	Velocity ( $\text{km s}^{-1}$ )	RA offset (arcsec)	Dec.offset (arcsec)	$\sigma_{RA}$ (arcsec)	$\sigma_{Dec}$ (arcsec)	Peak flux (Jy/beam)	B (mG)
<i>1665-MHz</i>							
Z1:							
LHCP - l	-87.21	-1.070	-4.901	0.008	0.010	2.23	-3.66
RHCP - m	-89.37	-1.069	-4.899	0.014	0.007	2.81	
Z2:							
LHCP - p	-82.58	-0.309	-1.663	0.005	0.008	10.10	-5.48
RHCP - t	-85.82	-0.313	-1.659	0.015	0.006	10.64	
Z3:							
LHCP - q	-81.83	-0.363	-1.599	0.004	0.009	5.11	-5.83
RHCP - v	-85.27	-0.361	-1.596	0.034	0.054	1.05	
Z4:							
LHCP - o	-83.02	-0.449	-1.449	0.005	0.019	25.18	-4.59
RHCP - u	-85.73	-0.448	-1.450	0.001	0.014	31.66	
Z5:							
LHCP - n	-83.86	-0.425	-1.403	0.021	0.009	1.17	-4.45
RHCP - s	-86.48	-0.434	-1.393	0.027	0.018	1.66	
<i>1667-MHz</i>							
Z4:							
LHCP - d	-83.64	-0.455	-1.458	0.015	0.105	14.05	-4.67
RHCP - c	-85.30	-0.460	-1.450	0.004	0.005	10.33	
Z5:							
LHCP - f	-82.36	-0.429	-1.568	0.010	0.007	4.61	-5.05
RHCP - e	-84.15	-0.439	-1.554	0.008	0.013	1.53	
Z7:							
LHCP - e	-83.15	-0.428	-1.506	0.012	0.016	6.85	-4.75
RHCP - d	-84.83	-0.427	-1.499	0.013	0.013	6.92	

Table 4.4: The six possible Zeeman pairs include in Z5. The features L1, L2, R1, R2 and R3 refer to each component in Figure 4.11.

Case	Polarisation	l No.	Velocity ( $\text{km s}^{-1}$ )	B (mG)
1	LHCP	$L_1$	-84.18	-3.88
	RHCP	$R_1$	-86.47	
2	LHCP	$L_1$	-84.18	-3.73
	RHCP	$R_2$	-86.38	
3	LHCP	$L_2$	-83.91	-4.34
	RHCP	$R_1$	-86.47	
4	LHCP	$L_2$	-83.91	-4.19
	RHCP	$R_2$	-86.38	
5	LHCP	$L_3$	-83.74	-4.63
	RHCP	$R_1$	-86.47	
6	LHCP	$L_3$	-83.74	-4.47
	RHCP	$R_2$	-86.38	

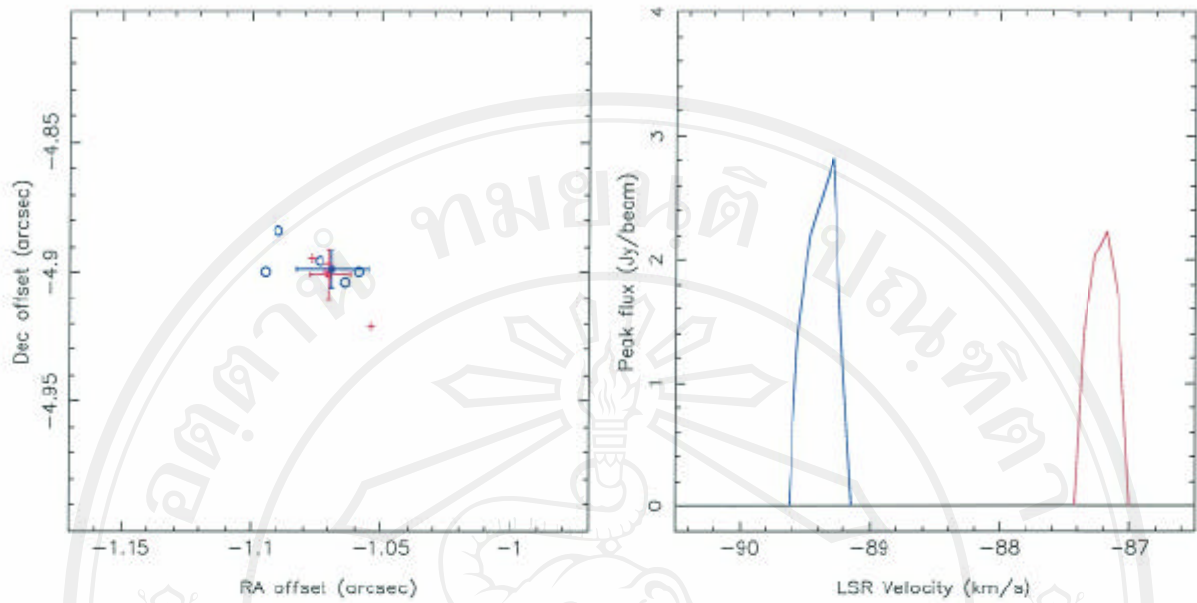


Figure 4.7: Position and velocity profiles of the Zeeman pair Z1. Plus and circle signs indicate RHCP and LHCP respectively.

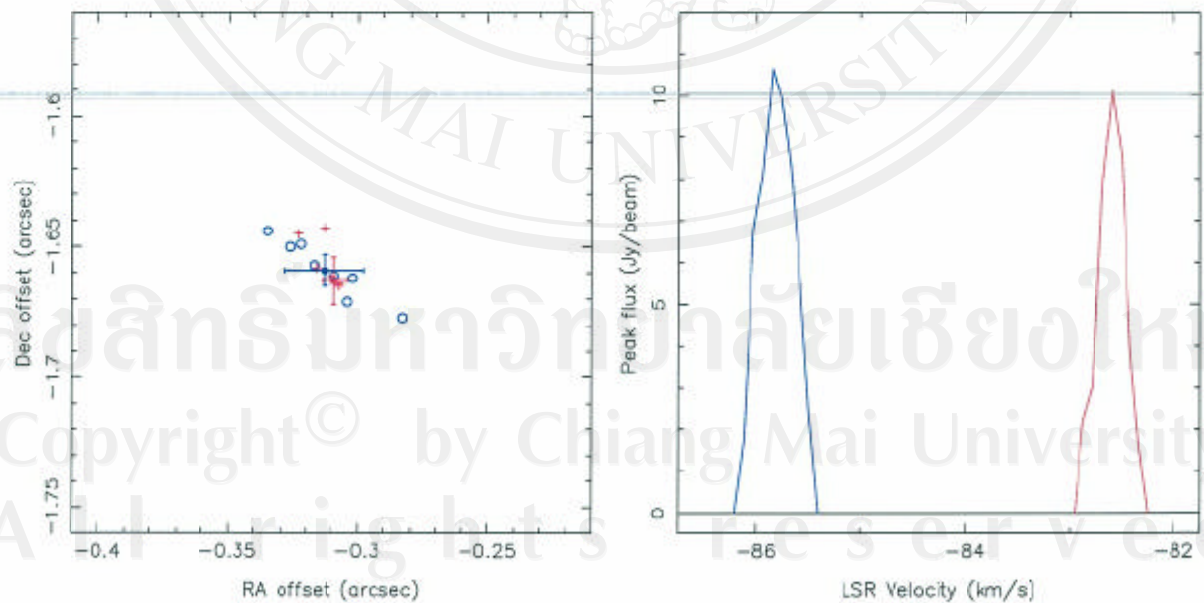


Figure 4.8: Position and velocity profiles of the Zeeman pair Z2.

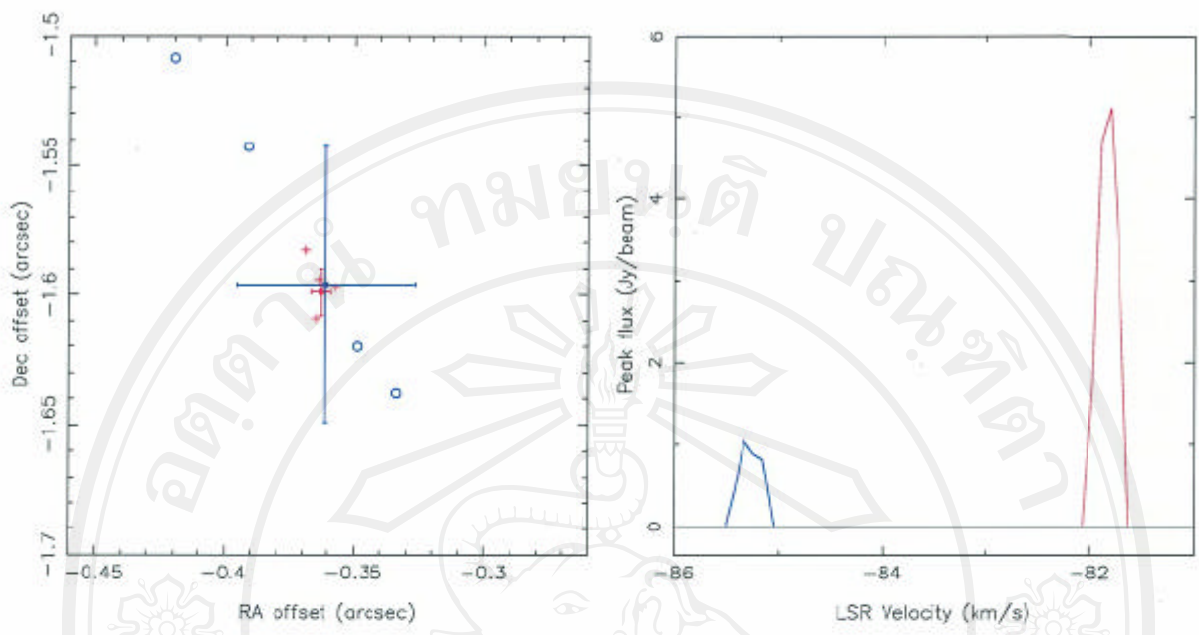


Figure 4.9: Position and velocity profiles of the Zeeman pair Z3.

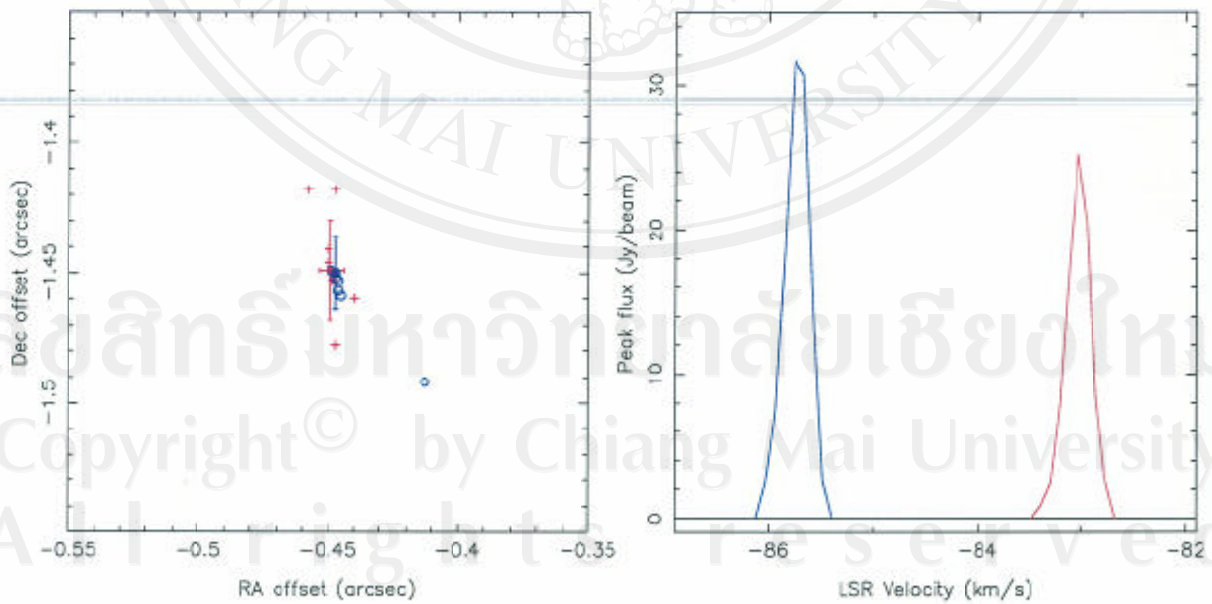


Figure 4.10: Position and velocity profiles of the Zeeman pair Z4 (1665 MHz).

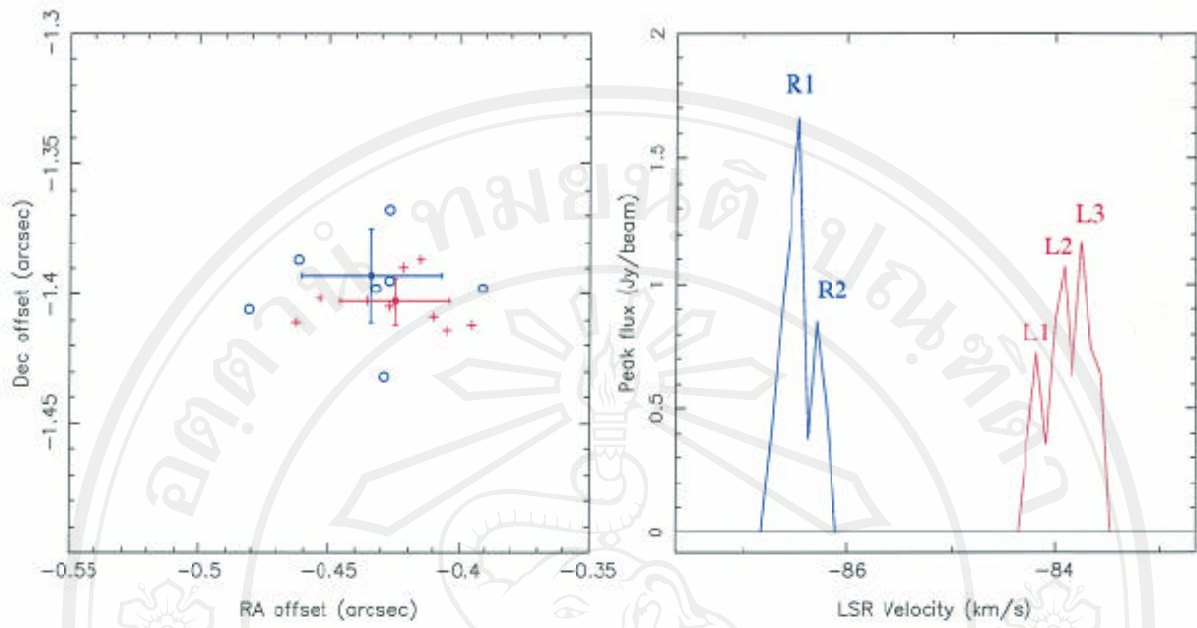


Figure 4.11: Position and velocity profiles of the Zeeman pair Z5.

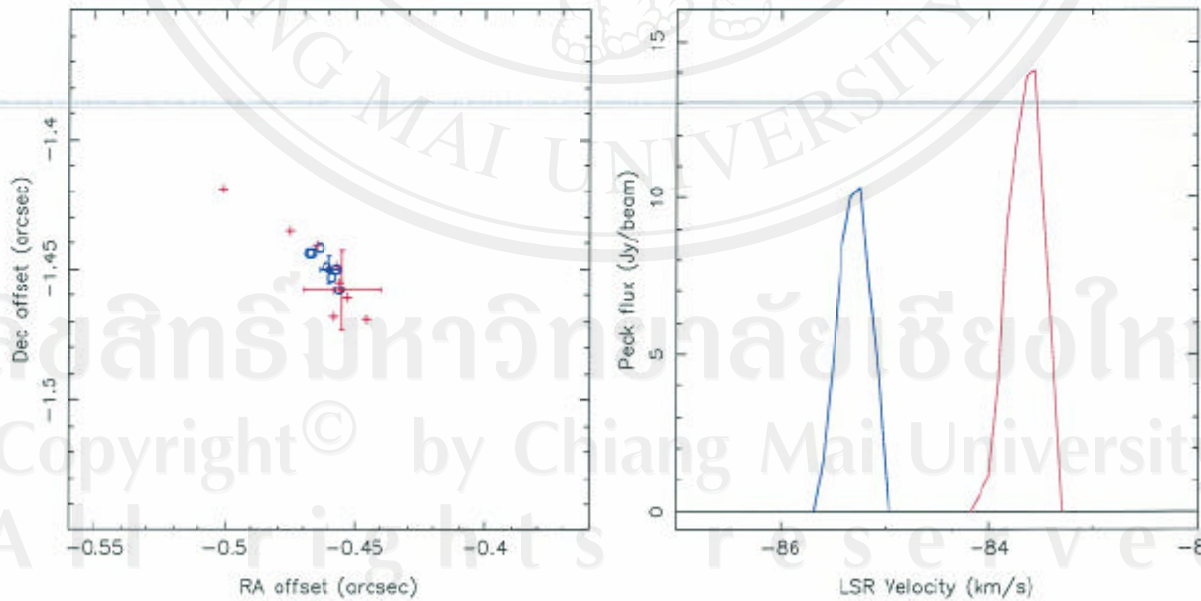


Figure 4.12: Position and velocity profiles of the Zeeman pair Z4 (1667 MHz).

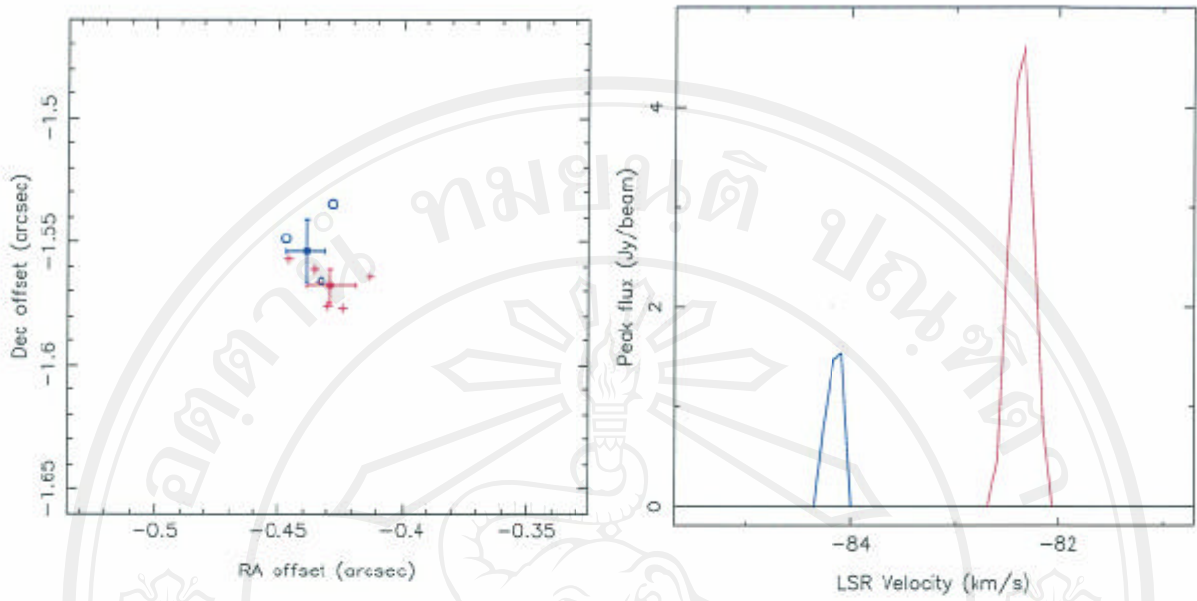


Figure 4.13: Position and velocity profiles of the Zeeman pair Z6.

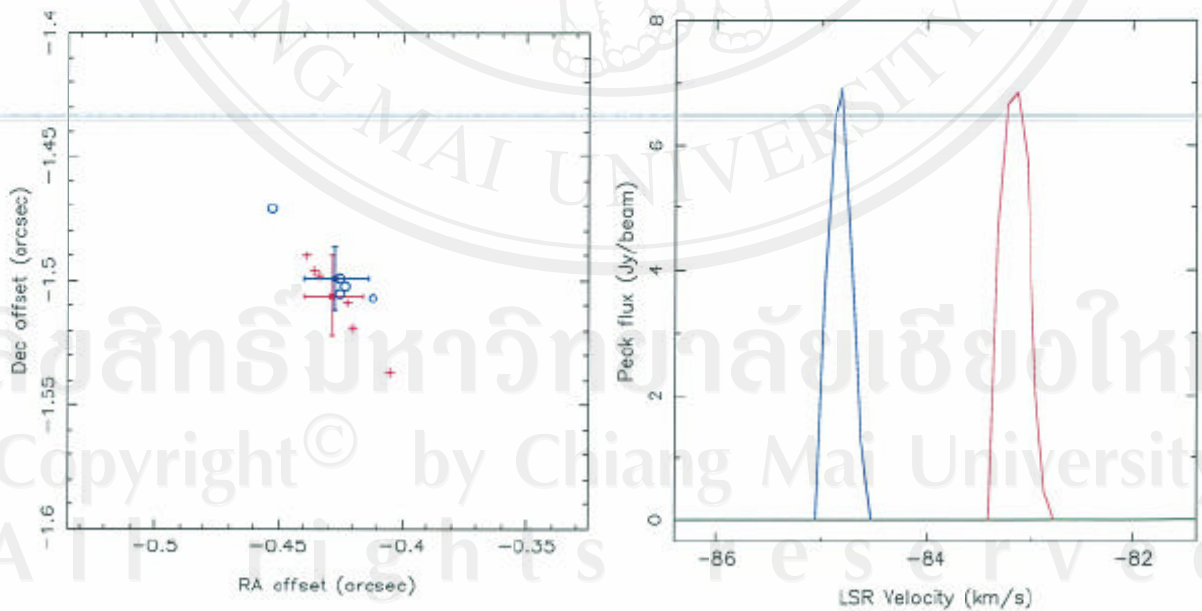


Figure 4.14: Position and velocity profiles of the Zeeman pair Z7.