Multifrequency Study of Recombination Lines Toward W49A

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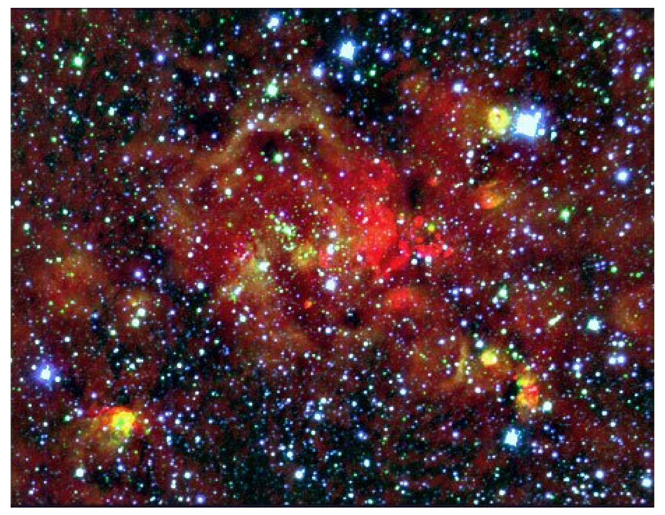
Introduction



- The molecular cloud W49 is the most luminous star forming region in our Galaxy with a luminosity several million times that of the sun, around $10^6 L$ and one of the strongest radio-emitting areas known in the Galaxy.
- W49A is a thermal source associated with an H II region approximately 11.4 kpc in size
- W49A is an active star forming region and therefore there exists the possibility of detecting molecular and atomic transition lines.

The NAIC Arecibo Telescope

- The NAIC Arecibo telescope is located in Arecibo, Puerto Rico. The 305m telescope is the largest single-dish radio telescope in the world. It operates at frequencies of 47 MHz - 10 GHz.

Arecibo Gregorian Dome Receiver System

Name	Freq. (GHz)	Beam (arcmin)	Gain (K/Jy)	T_{sys} K
327 MHz	0.312 - 0.342	14 x 15	11	130
430 MHz	0.423 - 0.438	10 x 12	11	40
610 MHz	0.6075 - 0.6115	7 x 8.5	11	110
L-wide	1.15 - 1.73	3.1 x 3.5	9-11	25-40
S-wide	1.8 - 3.1	2.0 x 1.8	8	40
S-narrow	2.33 - 2.43	2.0 x 1.8	10	25
S-high	3 - 4	1.5 x 1.35	7-10	31-37
C	3.85 - 6.00	1.0 x 0.9	4-8.5	29-40
C-high	5.9 - 8.1	0.75 x 0.65	2.5-7.5	26-29
X	7.8 - 10.2	0.57 x 0.5	2.0-5.5	28-32

Observations

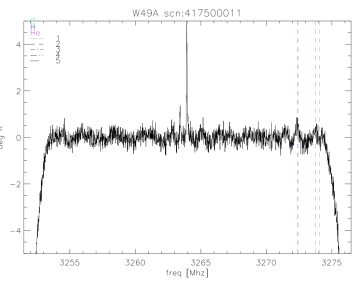
- We observed W49A located at R.A 19:10:15.7 and DEC +09:06:05. The observations took place June 23 and 24 of 2004 from 00:00:00 to 02:45:00 AST and 18:00 to 21:00 LST. We conducted spectral line observing using the Interim Correlator and observed across 327MHz-10GHz. Additional W49A data was taken on July 5 2004 using the WAPP spectrometer in the L band in the pulsar mode.

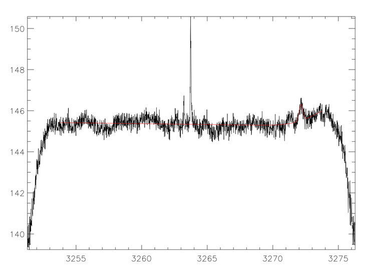
Abstract

Observations of the molecular cloud W49A with the 305-m Arecibo telescope were made across the frequency range 327 MHz to 10 GHz in order to identify molecular and recombination lines. In addition to the well-studied 1665.40 MHz and 1667.35 MHz OH masers and the 21-cm HI absorption line in the L-band, at higher frequencies (X and S-high bands) an abundance of Hydrogen and Helium recombination lines were observed. These included several high order ($\Delta n > 4$) transitions that were never detected before, for example, H167η, H157ζ, and H172θ. Estimates of the electron temperature (T_e) from the various lines are compared to examine possible departures from local thermodynamic equilibrium. An apparent dependence of T_e on Δn is understood as a result of systematic uncertainty in both, the line and the continuum intensities. This work was supported partly by the NAIC-REU program of the NSF.

Data Reduction

- The OFF scans were read into the "corposonoff" routine. The two polarizations A and B were then averaged together using the "coravg" routine.
- "corblauto" was used to remove the baseline. This routine was used twice for all the data. The first time the parameter "fsin" was set to 5 and the second time it was set to 1. This parameter controls the order of the sin(nx) function used to fit the data.
- "recombsearch" was used to search for all the known recombination lines of species H, He, and C of Δn 1-8. Each spectra was then analyzed in order to determine if for each line identification there was an actual detection.
- The detections in our data exist only in the X and S-high bands. The L-wide and C-high bands were not reduced due to the fact that they were taken in the Stokes polarization mode and there does not exist any "pre-made" routines to analyze the spectra.
- The lower frequency bands, 327MHz and 610MHz, yielded only noise.





- When a line was determined to be an actual detection it was then fit to a gaussian profile using the "fitngauss" routine. For each line the routine returns an amplitude, center frequency and width.

Recombination Lines for S & X Bands

Band	Species	Δn	Amplitude (K)	ν_{rest} (MHz)	Sigma (MHz)
S-High	H 157	β	1.15	3334.70	0.449
	H 126	α	5.48	3248.89	0.29
	H 122	α	5.65	3577.47	0.35
	He 122	α	0.677	3579.02	0.3637
	H 158	β	0.597	3272.17	0.222
	He 158	β	0.3155	3273.55	0.288
	H 118	α	5.58	3952.12	0.377
X-Low	H 135	γ	0.218	7758.77	0.783
	H 94	α	1.964	7792.9	0.797
	H 118	β	0.441	7805.85	0.758
	H 157	ϵ	0.0407	8107.35	0.555
	H 133	γ	0.1514	8110.18	0.724
	H 146	δ	0.0849	8117.13	0.674
	H 116	β	0.3528	8213.07	0.8264
X-Mid	H 88	α	2.33	9487.9	0.932
	He 88	α	0.22	9491.75	0.619
	H 126	γ	0.192	9520.98	0.808
X-High	H 138	δ	0.0916	9590.06	1.084
	H 110	β	0.465	9618.41	1.000
	He 110	β	0.0488	9622.33	0.582
	H 148	ϵ	0.0353	9650.9	0.668
	H 167	η	0.0229	9630.64	1.131
	H 157	ζ	0.0182	9639.35	1.189
	H 172	θ	0.0204	9660.42	1.653

Pressure Broadening

- In the lower frequency regime, 327MHz and 610MHz, no recombination lines were detected. This systematic non-detection could be due to pressure broadening.
- The presence of high density charged particles in HII regions means that recombination lines may be broadened by pressure effects. This effect causes the spectral line to be spread out and weak which requires a very high level of sensitivity in order to detect such lines.
- The below equation gives the ratio relating line frequency to the Doppler frequency for a system undergoing pressure broadening.
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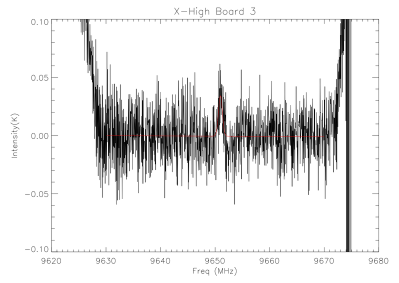
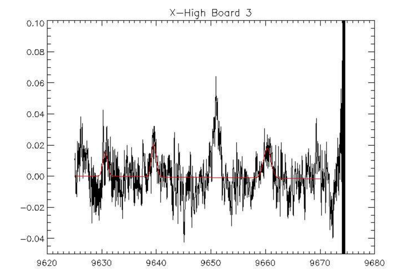
$$\frac{\Delta\nu_L}{\Delta\nu_D} = 0.14(\frac{n}{100})^{7.4}(\frac{10^4}{T_e})^{0.1}(\frac{N_e}{10^4})(\frac{M}{M_H})^{1/2}(\frac{2\times10^4}{T_D})^{1/2} \quad (1)$$

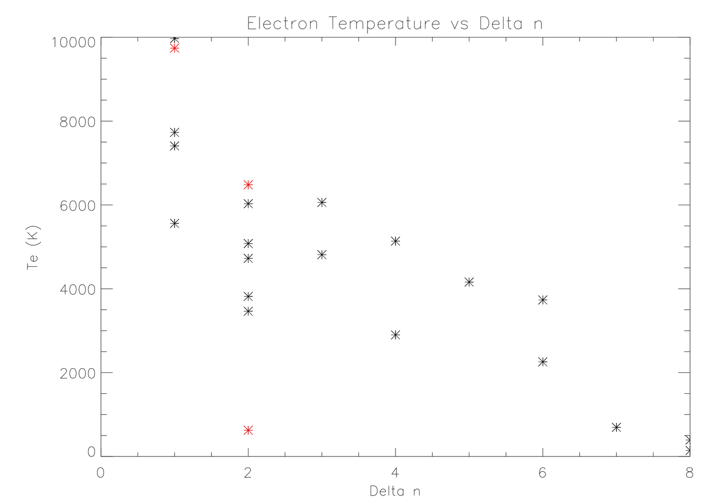
- A "back of the envelope" calculation using the H 273 α at 321.43 MHz with a typical $\Delta\nu_D$ of about 30 km/s gives a $\Delta\nu_L$ of 7080 km/s. A line-width of such magnitude would appear flat and spread-out and would be undetectable given the sensitivity of the Arecibo telescope.

Electron Temperature





- On the left are the results from the fsin parameter set to 5 and on the right the fsin parameter set to 1. This illustrates that the more accurate the baseline fit, the smaller the signal to noise ratio. On the left the H 148 ϵ line at 9650.9 MHz is shown. On the right the higher order δ n lines are shown: H 167 at 9630.64 MHz, H 157 ζ at 9639.35 MHz and H 172 θ at 9660.42 MHz



- Electron temperature was found assuming local thermodynamic equilibrium. We see that electron temperature increases with Δ n. This is believed that this discrepancy, in terms of underestimations of electron temperatures for high n, is due to to a break down in LTE at high Δn regimes.

Electron Temperature

Species Name	n	Δn	ν_0 (MHz)	T_e (K)
H	134	6	7758.7728	2256.1740
H	94	1	7792.9098	5560.2141
H	118	2	7805.8551	3817.4677
H	157	5	8107.3548	4160.4987
H	133	3	8110.1831	6059.1865
H	146	4	8117.1301	5135.6329
H	116	2	8213.0781	4724.8959
H	88	1	9487.9243	7730.4013
He	88	1	9491.7817	9740.0808
H	126	3	9521.0105	4813.6974
H	167	7	9630.6549	694.45887
H	157	6	9639.5601	3733.7677
H	172	8	9660.3308	143.49845
H	157	2	3334.7649	3462.9307
H	158	2	3272.1554	6029.7251
He	158	2	3273.5509	625.46907
H	138	4	9590.0609	2899.8364
H	110	2	9618.4114	5078.1050
He	110	2	9622.3948	6480.4683
H	126	1	3248.8923	9969.8671
H	122	1	3577.4705	7407.3233
He	122	1	3579.0295	392.61764

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Summary

- Observations of W49A have yielded detections of recombination lines spanning the S-high and X bands. Out of the 24 Hydrogen and Helium recombination lines observed, it is the high Δn lines such as H 167 η, H157 ζ, and H 172 θ that are of particular interest.
- Because higher Δn lines are much weaker they are, therefore, harder to detect and fit to a gaussian profile. Due to the inability to properly estimate high Δn recombination lines, we may have a systematic underestimation of electron temperature.
- A possibility for the discrepancy in electron temperature may be due to the fact that we have assumed LTE. Since it is understood that at high quantum number, n, LTE is less valid, in order to properly estimate electron temperature, we need to identify the regimes where LTE breaks down.

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