EDGES MEMO #019

RFI MEMO #034

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To: RFI Group

From: Judd D. Bowman
Subject: EDGES Sensitivity to Galactic Radio Recombination Lines

The detection of Galactic radio recombination lines (RRLs) is one possible additional use of the EDGES antenna and receiver system. This memo explores the feasibility of this idea. Mapping RRL emission has also been discussed for the MWA-LFD—see documentation by S. Doeleman and A. Rogers.

1. Background

Radio recombination lines are due to electron transitions between very large principle quantum state numbers in hydrogen, helium, and carbon atoms (heavier elements may also contribute to a much lesser extent). The frequencies of the lines are given by:

$$f = Z^2 \times R_x \times c \times \left[1/n - 1/(n + \Delta n) \right] GHz ,$$

where Z is the effective charge of the atomic nucleus as seen by the electron, R_x is the Rydberg constant, n is the principle quantum state number for the atom, and Δn is the change of quantum number for the transition.

$Z = 1$
$R_x = 10.97373 / (1 + m_s / M_x)$
m_e = electron mass
M_x = nuclear mass
$n \sim 300$
$\Delta n = 1$

At the frequencies of interest (80-250 MHz), RRLs typically occur every 1 to 3 MHz for a given species. These lines are observed in molecular clouds in the Galaxy and generally yield derived properties: $20 < T_e < 300$ K, $n_e = \sim 0.1$, and path lengths of order 1 pc. RRLs due to hydrogen tend to transition from emission to absorption with decreasing frequency around 150 MHz. RRLs due to carbon have been observed at frequencies below 100 MHz in absorption and above 300 MHz in emission (unsure about observations at intermediate frequencies?).

Erickson, McConnell, & Anantharamaiah (1995) detected strong (T_line/T_sky=~10^{-3}, T_line = ~1 K) absorption features due to carbon recombination lines in the Galactic plane at 76 MHz. These lines had a width corresponding to $5<\Delta v<20$ km/s, which is roughly equivalent to $1<\Delta f<5$ kHz. They were largely confined to $-20 < l < 20$ and $-4 < b < 4$ deg. The resolution of their observations was 4 x 4 deg.

Kantharia & Anantharamaiah (2001) observed additional carbon recombination lines at 34.5 MHz (absorption) and 328 MHz (emission) in the same region of the Galactic plane. These lines had comparable line-to-continuum ratios as those at 76 MHz lines $\left(T_{line}/T_{sys} \simeq 0.5\times10^{-3}\right)$, as well as comparable widths ($20<\Delta v<40$ km/s). The resolution of the observations was 21 arcmin × 25 deg at 34.5 MHz and 2×2 deg at 328 MHz.

The strength of RRLs is generally proportional to their optical depth and the background temperature. The optical depth for carbon recombination lines is probably $\tau \leq 10^{-3}$ and the background temperatures range from $T_{sky} \geq 1000$ K toward the Galaxy center to T_{sky} = ~100 K at high Galactic latitudes. Stimulated emission/absorption may also boost the strengths of the lines. While the strength of RRLs toward the Galaxy center is T_{line}= ~1K, at high Galactic latitudes could is probably T_{line}= ~1 mK, although no lines have every been detected in these regions.

2. Integration Times

The integration time, t, necessary for a radio antenna to detect a line is given by:

$$t = SNR^2 \times \left(T_{sys}/T_{ant}\right)^2 \big/ \left(2\times B\times N\right),$$

where SNR is the desired signal-to-noise ratio, T_{sys} is the system temperature seen at the antenna, T_{ant} is the antenna temperature due to the signal, B is frequency channel size, and N is the number of lines averaged together. The antenna temperature is:

$$T_{ant} = f \times T_{line} ,$$

where $f = f_{beam} \times f_{channel}$ is the combined beam and frequency filling factor of the emitting/absorbing region. The EDGES receiver nominally has 32 kHz frequency channels over a band spanning 80-250 MHz (although the sample rate is 1 GS/s). The field of view of the antenna is greater than π str.

Observing Toward the Galaxy Center:

If EDGES were located such that it could observe the Galaxy center, the beam filling factor for the carbon RRLs observed by Erickson et al. would be approximately

$$f_{beam} = 0.1 str / 3.14 str = 0.03,$$

and the dilution due to frequency channel size would add an additional factor of

$$f_{channel} = 3 kHz / 32 kHz = 0.1.$$

Using the combined efficiency f = 0.003, T_{sys} = 2000 K, T_{obj} = 2 K, and B=32 kHz, and setting the desired SNR=1 and N=1, gives:

t = ~480 hours

to reach the required sensitivity to observe a single RRL toward the Galaxy center. If the EDGES channel size could be reduced by a factor of 10 (to nearly perfectly match the ~3 kHz line widths seen by Erickson et al.), then f = 0.03 and

t = ~4.8 hours.

Performing one such observation would result in a simultaneous measurement of all the line strengths between 80 and 250 MHz (but with no spatial resolution, limited line-width information, and the effects of the frequency dependence of the antenna power response pattern folded in).

Another possibility is to use the EDGES backend with the MWA-LFD prototype antenna tiles at Mileura from the Early Deployment campaign. This would provide a better match between the FOV and the size of the RRL region near the Galaxy center. The FOV for the antenna tiles is ~1 str, thus f = 0.01 for B=32 kHz, and **t =~ 43 hours**. Again, reducing the channel size to B=3 kHz would yield f = f_{beam} = 0.1 and **t = ~0.4 hours**.

Observing Toward High Galactic Latitudes:

Away from the Galactic center, T_{sys}=200 K, T_{obj} = 1 mK, B=32 kHz, and

$$f = f_{channel} = 0.1$$

is due only to the frequency channel dilution (assuming a faint diffuse signal filling the sky). In this case,

t = ~17,000 hours

to reach the sensitivity to observe a single RRL. If the lines remain relatively narrow at high Galactic latitudes, then, as before, reducing the frequency channel size of the EDGES system by a factor of 10 to 3 kHz, would result in

t = ~170 hours.

Additional sensitivity could be gained by adding multiple lines together. At best, N=100 lines will be present across the band. Thus, the integration time could be reduced by a factor of up to 100 by summing all RRL frequencies in order to simply "detect" the signal. A first-ever "detection" of RRLs at high Galactic latitude could be achieved (very optimistically) in as little as

t = ~1.7 hours.

Since the signal is expected to be diffuse, replacing the EDGES antenna with the MWA-LFD antenna tiles would provided little advantage in this case (unlike toward the Galaxy center).

NOTE: In all cases described above, the need to switch between antenna and calibration loads in the EDGES system will double the actual time for the measurements. Also, for 3-sigma detections, add another factor of ~10 to the integration time.

3. Conclusion

Due to its large field of view, EDGES (and also the MWA-LFD prototype antenna tile) is not able to isolate individual RRL regions. Thus any measurement would be an aggregate of many regions. Its primary novelty would be a simultaneous measurement of many lines (toward the Galaxy center) or detecting any RRL signal from high Galactic latitudes. Both of these applications warrant further consideration.

From Erickson, McConnell, and Anantharamaiah (1995):

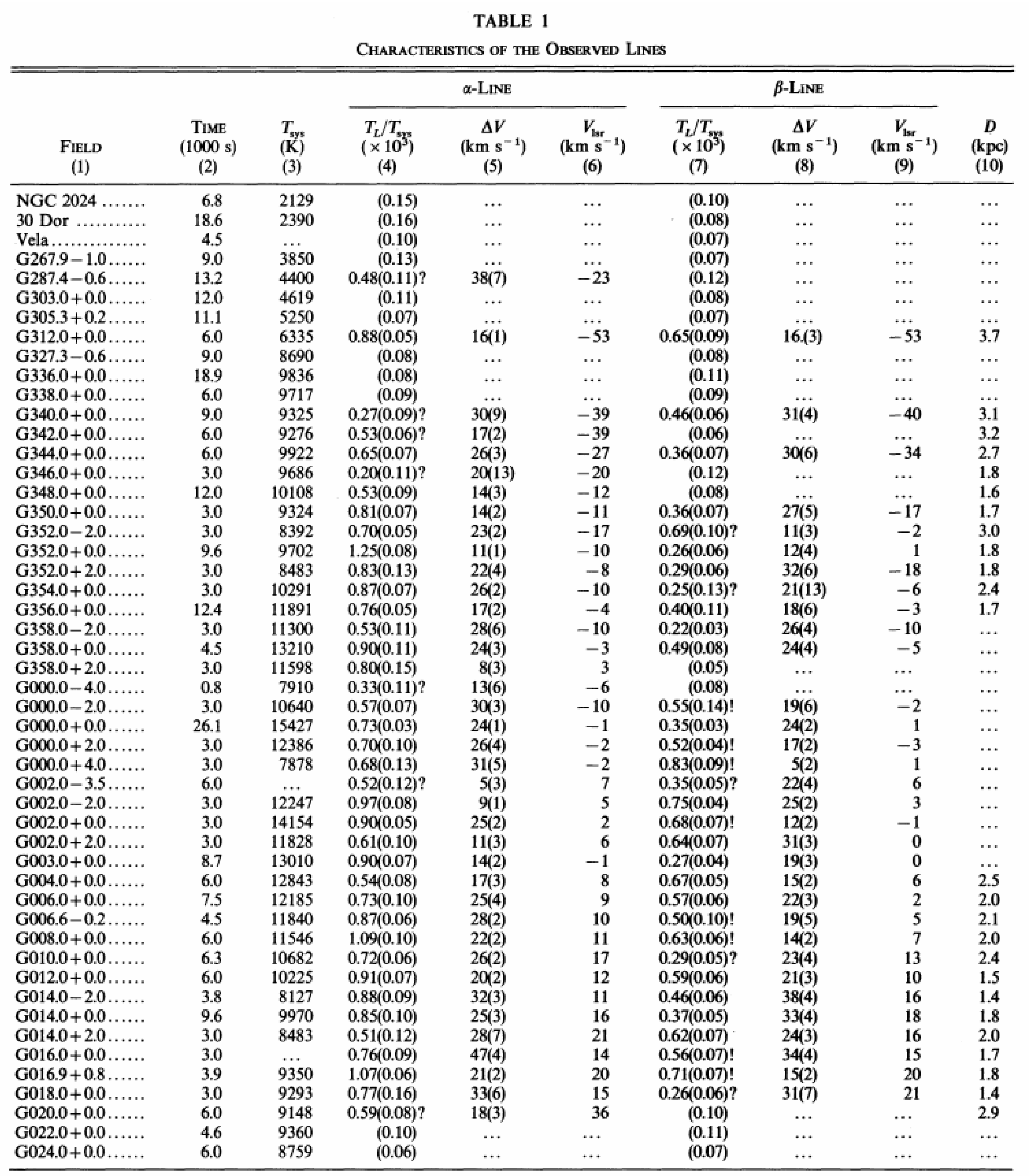

TABLE 1

CHARACTERISTICS OF THE OBSERVED LINES

			α-LINE			β-LINE			
FIELD (1)	TIME (1000 s) (2)	T_{sys} (K) (3)	T_L/T_{sys} ($\times 10^3$) (4)	ΔV (km s^{-1}) (5)	V_{lsr} (km s^{-1}) (6)	T_L/T_{sys} ($\times 10^3$) (7)	ΔV (km s^{-1}) (8)	V_{lsr} (km s^{-1}) (9)	D (kpc) (10)
NGC 2024	6.8	2129	(0.15)	…	…	(0.10)	…	…	…
30 Dor	18.6	2390	(0.16)	…	…	(0.08)	…	…	…
Vela	4.5	…	(0.10)	…	…	(0.07)	…	…	…
G267.9−1.0	9.0	3850	(0.13)	…	…	(0.07)	…	…	…
G287.4−0.6	13.2	4400	0.48(0.11)?	38(7)	−23	(0.12)	…	…	…
G303.0+0.0	12.0	4619	(0.11)	…	…	(0.08)	…	…	…
G305.3+0.2	11.1	5250	(0.07)	…	…	(0.07)	…	…	…
G312.0+0.0	6.0	6335	0.88(0.05)	16(1)	−53	0.65(0.09)	16.(3)	−53	3.7
G327.3−0.6	9.0	8690	(0.08)	…	…	(0.08)	…	…	…
G336.0+0.0	18.9	9836	(0.08)	…	…	(0.11)	…	…	…
G338.0+0.0	6.0	9717	(0.09)	…	…	(0.09)	…	…	…
G340.0+0.0	9.0	9325	0.27(0.09)?	30(9)	−39	0.46(0.06)	31(4)	−40	3.1
G342.0+0.0	6.0	9276	0.53(0.06)?	17(2)	−39	(0.06)	…	…	3.2
G344.0+0.0	6.0	9922	0.65(0.07)	26(3)	−27	0.36(0.07)	30(6)	−34	2.7
G346.0+0.0	3.0	9686	0.20(0.11)?	20(13)	−20	(0.12)	…	…	1.8
G348.0+0.0	12.0	10108	0.53(0.09)	14(3)	−12	(0.08)	…	…	1.6
G350.0+0.0	3.0	9324	0.81(0.07)	14(2)	−11	0.36(0.07)	27(5)	−17	1.7
G352.0−2.0	3.0	8392	0.70(0.05)	23(2)	−17	0.69(0.10)?	11(3)	−2	3.0
G352.0+0.0	9.6	9702	1.25(0.08)	11(1)	−10	0.26(0.06)	12(4)	1	1.8
G352.0+2.0	3.0	8483	0.83(0.13)	22(4)	−8	0.29(0.06)	32(6)	−18	1.8
G354.0+0.0	3.0	10291	0.87(0.07)	26(2)	−10	0.25(0.13)?	21(13)	−6	2.4
G356.0+0.0	12.4	11891	0.76(0.05)	17(2)	−4	0.40(0.11)	18(6)	−3	1.7
G358.0−2.0	3.0	11300	0.53(0.11)	28(6)	−10	0.22(0.03)	26(4)	−10	…
G358.0+0.0	4.5	13210	0.90(0.11)	24(3)	−3	0.49(0.08)	24(4)	−5	…
G358.0+2.0	3.0	11598	0.80(0.15)	8(3)	3	(0.05)	…	…	…
G000.0−4.0	0.8	7910	0.33(0.11)?	13(6)	−6	(0.08)	…	…	…
G000.0−2.0	3.0	10640	0.57(0.07)	30(3)	−10	0.55(0.14)!	19(6)	−2	…
G000.0+0.0	26.1	15427	0.73(0.03)	24(1)	−1	0.35(0.03)	24(2)	1	…
G000.0+2.0	3.0	12386	0.70(0.10)	26(4)	−2	0.52(0.04)!	17(2)	−3	…
G000.0+4.0	3.0	7878	0.68(0.13)	31(5)	−2	0.83(0.09)!	5(2)	1	…
G002.0−3.5	6.0	…	0.52(0.12)?	5(3)	7	0.35(0.05)?	22(4)	6	…
G002.0−2.0	3.0	12247	0.97(0.08)	9(1)	5	0.75(0.04)	25(2)	3	…
G002.0+0.0	3.0	14154	0.90(0.05)	25(2)	2	0.68(0.07)!	12(2)	−1	…
G002.0+2.0	3.0	11828	0.61(0.10)	11(3)	6	0.64(0.07)	31(3)	0	…
G003.0+0.0	8.7	13010	0.90(0.07)	14(2)	−1	0.27(0.04)	19(3)	0	…
G004.0+0.0	6.0	12843	0.54(0.08)	17(3)	8	0.67(0.05)	15(2)	6	2.5
G006.0+0.0	7.5	12185	0.73(0.10)	25(4)	9	0.57(0.06)	22(3)	2	2.0
G006.6−0.2	4.5	11840	0.87(0.06)	28(2)	10	0.50(0.10)!	19(5)	5	2.1
G008.0+0.0	6.0	11546	1.09(0.10)	22(2)	11	0.63(0.06)!	14(2)	7	2.0
G010.0+0.0	6.3	10682	0.72(0.06)	26(2)	17	0.29(0.05)?	23(4)	13	2.4
G012.0+0.0	6.0	10225	0.91(0.07)	20(2)	12	0.59(0.06)	21(3)	10	1.5
G014.0−2.0	3.8	8127	0.88(0.09)	32(3)	11	0.46(0.06)	38(4)	16	1.4
G014.0+0.0	9.6	9970	0.85(0.10)	25(3)	16	0.37(0.05)	33(4)	18	1.8
G014.0+2.0	3.0	8483	0.51(0.12)	28(7)	21	0.62(0.07)	24(3)	16	2.0
G016.0+0.0	3.0	…	0.76(0.09)	47(4)	14	0.56(0.07)!	34(4)	15	1.7
G016.9+0.8	3.9	9350	1.07(0.06)	21(2)	20	0.71(0.07)!	15(2)	20	1.8
G018.0+0.0	3.0	9293	0.77(0.16)	33(6)	15	0.26(0.06)?	31(7)	21	1.4
G020.0+0.0	6.0	9148	0.59(0.08)?	18(3)	36	(0.10)	…	…	2.9
G022.0+0.0	4.6	9360	(0.10)	…	…	(0.11)	…	…	…
G024.0+0.0	6.0	8759	(0.06)	…	…	(0.07)	…	…	…

From Kantharia & Anantharamaiah (2001):

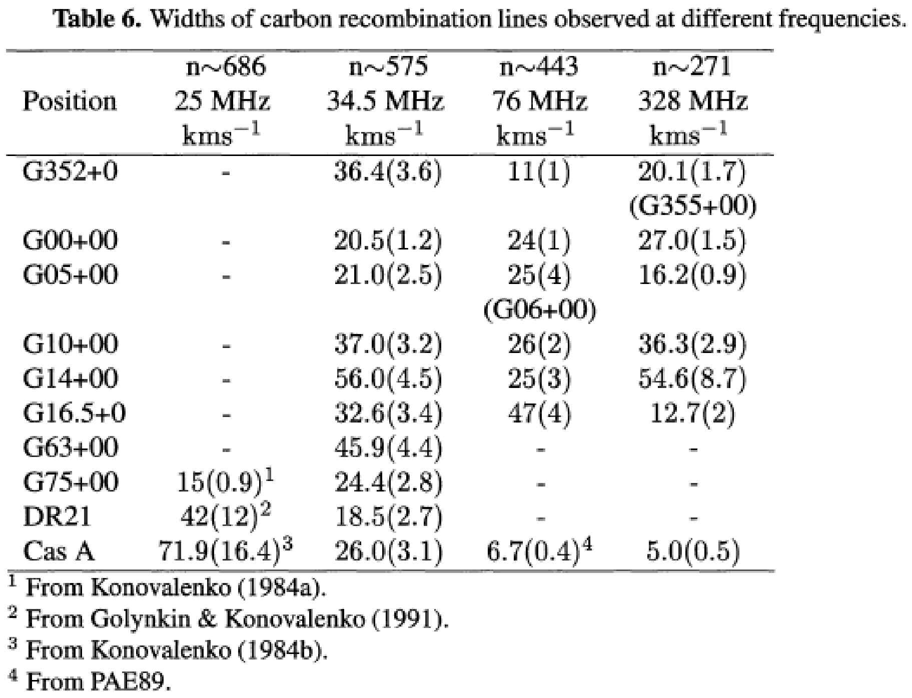

Table 6. Widths of carbon recombination lines observed at different frequencies.

Position	$n{\sim}686$ 25 MHz kms^{-1}	$n{\sim}575$ 34.5 MHz kms^{-1}	$n{\sim}443$ 76 MHz kms^{-1}	$n{\sim}271$ 328 MHz kms^{-1}
G352+0	-	36.4(3.6)	11(1)	20.1(1.7) (G355+00)
G00+00	-	20.5(1.2)	24(1)	27.0(1.5)
G05+00	-	21.0(2.5)	25(4) (G06+00)	16.2(0.9)
G10+00	-	37.0(3.2)	26(2)	36.3(2.9)
G14+00	-	56.0(4.5)	25(3)	54.6(8.7)
G16.5+0	-	32.6(3.4)	47(4)	12.7(2)
G63+00	-	45.9(4.4)	-	-
G75+00	15(0.9)[1]	24.4(2.8)	-	-
DR21	42(12)[2]	18.5(2.7)	-	-
Cas A	71.9(16.4)[3]	26.0(3.1)	6.7(0.4)[4]	5.0(0.5)

[1] From Konovalenko (1984a).

[2] From Golynkin & Konovalenko (1991).

[3] From Konovalenko (1984b).

[4] From PAE89.