ALFA Radio Recombination Line Survey

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1 Motivations and Background

A key feature of the GALFA consortium is to provide legacy data sets that are: more extensive than that achievable by an individual or a small group of investigators, rich enough to provide a wide range of science well beyond the specific science envisioned by the proposers that permits scientific horizons to be pushed beyond anything currently possible. We propose to produce THE MOST SENSITIVE RRL SURVEY EVER MADE. This survey will fully sample the entire Galactic plane observable from the Arecibo observatory in a carefully selected set of radio recombination lines (RRLs) that fall in the bandpass of the ALFA receivers to a well defined flux limit in a set of lines that permit a wide range of science.

RRLs provide a wide range of critical information on the physical state of ionized interstellar gas that is generally not obtainable through other observational means. Optical and near infrared spectroscopy can provide the physical properties of nearby ionized regions, but only RRLs can provide this information on a Galactic scale. What information do RRLs provide? For HII regions, planetary nebulae, young massive star formation regions, novae, ionized stellar outflows, and possibly the diffuse ionized interstellar medium (WIM), they provide: 1) the two dimensional velocity structure from RRL profile analyses, which can provide information on turbulent motions and bulk motions such as outflows, rotation, expansion, contraction, and shocks; 2) the electron density distribution (via non-LTE analysis); 3) a direct determination of the electron temperature distribution; and, 4) the distributions and relative abundances of ionized He, C, Mg and other heavier atoms. These are all critical properties required to understand the nature of nebulae and the environment in which they reside; properties that often can only be inferred from RRLs.

What science does RRLs enable? RRLs provide tools to study a host of important global astrophysical problems that would be very difficult or impossible to attack in any other way. Among these are: the physical properties (n_e, T_e, velocity structure, etc.) of HII regions, PNe, etc. as a function of their position in the Galaxy and local environments; the average electron temperature with galactocentric radius from which the relative abundances of coolants such as O/H, N/H, C/H, etc. can be inferred; the relative abundance of helium as a function of galactocentric radius from which, in principle, the stellar contribution to the cosmological abundance of helium can be determined and the helium abundance of the universe at the time of formation of the Galaxy may be obtained at large galactocentric radii where the interstellar medium has not been enriched by stellar nucleosynthesis. The enrichment of heavy elements such as O/H, N/H, C/H, etc. as a function of galactic radius is a measure of the stellar nuclear processing of the interstellar medium by each successive generation of stars in the Galaxy; these data provide the basis for determining the chemical evolution of the Galaxy as well as the distribution of stars responsible for the enrichment in the Galaxy. It has been known for some time that Carbon RRLs sample very different environments than H and He lines. C RRLs are formed in the transition zones between fully ionized regions and neutral gas. These regions are referred to as photodissociation regions (PDRs). Due to theoretical advances (e.g. Wolfire, Tielens, & Hollenbach 1990; Hollenbach & Tielens 1997) and observations in the infrared and optical it has become clear that PDRs occupy a significant volume of space and present some very interesting physics. C RRLs can make important contributions to our understanding of PDRs, but so far have not played a major role because of the intrinsic weakness of these lines and the high spectral resolution required to deconvolve them from the nearby He line. ALFA will provide both the sensitivity and spectral resolution needed for large-scale studies of PDRs via C RRL emission. Finally, we emphasize that a fully sampled survey obtained with a well defined spatial resolution and sensitivity limit enables a wide range of science that cannot be done with many limited observations of individual objects each with different spatial resolutions, sensitivity limits, and spectral lines.

Fully sampled surveys also strongly increase the probability of serendipitous discoveries.

The RRL GALFA sub-consortium proposes a fully sampled survey of the entire Galactic plane visible from Arecibo with sensitivity and resolution limits well beyond any currently available. All the science noted above can be achieved in such a survey by a judicious choice of lines to be simultaneously observed. The probability of serendipitous discoveries will be high in such a survey which may open new areas of investigation that cannot be anticipated at this time.

2 Scientific Programs Enabled by the RRL ALFA Survey

In the following, we discuss in more detail a few of the major scientific motivations for doing this survey.

2.1 Identification of Radio Sources

Thermal radio sources (HII regions, PNe, shocks, the warm ionized medium) produce RRLs, non-thermal radio sources (SNRs, pulsars, and other synchrotron sources) do not have RRL emission. Radio continuum surveys at a single frequency cannot distinguish the nature of the sources, but RRLs can distinguish between thermal and non-thermal sources with a single detection of line emission.

The majority of the HII regions, supernova remnants, and Giant Molecular Clouds (GMCs) in the Milky Way reside within the inner part of the galactic plane (see Fig 1). The L-band NRAO VLA Sky Survey (NVSS) has revealed thousands of continuum sources in that part of the first Galactic quadrant that is accessible from Arecibo, yet only a few hundred thermal HII regions have been identified to date in this zone (Altenhoff et al. 1979; Lockman 1989). The sensitivity of the work done by Lockman (1989) only goes down to sources with flux density greater than 1.0 Jy. Because the ALFA RRL survey will be almost twice as sensitive, it is expected to be able to detect the hydrogen line in sources with flux density down to ~ 0.5 Jy.

2.2 The Large Scale Structure of the Milky Way

The spiral structure of the Milky Way galaxy is a controversial topic in Galactic astronomy. Vallee (1995) summarized the papers reporting spiral arm structure in the Galaxy that have been published since 1980. He listed

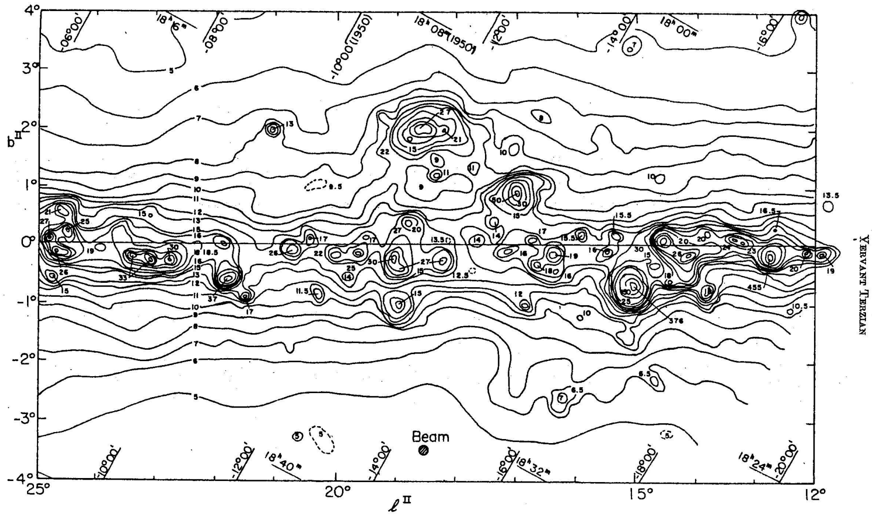

Figure 1: Contour map of the continuum emission of the galactic plane at 1.4 GHz for 12° $< l <$ 25° and $|b| < 4$ measured with Effelsberg 100-m telescope (Altenhoff et al. 1979). The image is in galactic coordinates, and the HPBW $\sim$ 10'.

15 models which are composed of two, three and four spiral arms and which show a variety of pitch angles. Regions of massive star formation, i.e. H II regions, are ideal tracers of the arm structure of spiral galaxies. Recently, Araya et al. (2002) and Watson et al. (2003) carried out a survey with the Arecibo Telescope to establish the distance to massive star formation regions, and with this, to explore the structure of our Galaxy (Fig. 2). They used the hydrogen recombination line H110α (4.87 GHz) to measure the velocity of ionized regions which, together with the velocity field of the Galaxy and simultaneous Formaldehyde observations, allowed them to establish kinematic distances to more than 60 regions of massive star formation in the first galactic quadrant. A similar method was used by Kuchar and Bania (1994). They used radio recombination lines from the Lockman (1989) catalog and H I spectra obtained with the Arecibo Telescope to obtain kinematic distances of galactic H II regions. The ALFA RRL survey will offer to the astrophysical community a large-area sample of galactic H II regions which, together with the ALFA H I survey of the galactic plane and complementary molecular-line surveys, will permit a comprehensive and unbiased study of the galactic structure and kinematics of the 32° $-$ 70° galactic longitude range. The ALFA RRL survey will also be useful to check the current velocity field models of the Galaxy since a rotation curve for the 4.5 to 8 kpc galactocentric-distance

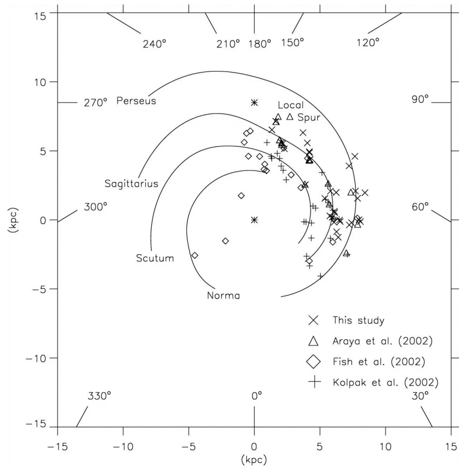

Figure 2: Distribution of ultra-compact HII regions compared with the spiral arm model of Taylor and Cordes (1993) (Watson et al. 2003). The resolution of the observations included in the plot is $\leq 1'$.

range can be derived from the data.

2.3 The Galactic Temperature and Abundance Gradients

Churchwell and Wamsley (1975) first determined that the average electron temperatures of HII regions gradually increase with galactocentric radius, as found in other spiral galaxies. They suggested that this gradient is probably the result of a gradient in the abundances of primary coolants such as O, N, Ne, etc. Shaver et al. (1983), in a classic paper, determined the temperature gradient more precisely than Churchwell and Wamsley (1975) and analyzed the abundance gradient in the Galaxy using RRLs and optical line measurements. Afflerbach et al. (1996) used high resolution RRLs to determine yet a more precise temperature gradient and predicted the gradient of O/H implied by this gradient. Afflerbach et al. (1997) used IR fine structure lines to measure the relative abundances of O/H, N/H, and S/H with galactocentric radius and compared the inferred temperature gradient with that found by Afflerbach et al. (1996) from RRL measurements; the inferred and directly measured gradients were in quite good agreement. However, even with these advances there is still a considerable scatter both in the temperature and abundance gradients. Some of this is surely intrinsic, but some is also due to small number statistics at each galactocentric radius which could be greatly improved by a more sensitive survey. The ALFA RRL survey would improve matters considerably, both because of the sensitivity and accuracy of these data and also because of the sheer increase in the number of sources. To constrain models of Galactic chemical evolution one needs to establish patterns across the Milky Way's disk. Shaver et al. (1983), Afflerbach et al. (1996, 1997) focused on the pattern revealed by RRLs in regard to nebular electron temperatures (Te) and the $\left[\frac{He}{H}\right]$ abundances (Y+) when these quantities are plotted as a function of galactocentric radius (Rgal). Because the RRLs give the nebular velocity, Rgal is known accurately from the Galactic rotation curve.

Shaver et al. (1983), Afflerbach et al. (1996), and Afflerbach et al. (1997) found a gradient in Te with galactocentric distance which they interpreted as a metalicity gradient since the principal nebular coolants are fine-structure transitions of heavy elements. They were able to calibrate Te versus optically determined abundances of oxygen. Since RRLs probe transgalactic pathlengths, only another RRL survey can speak to this important constraint on Galactic chemical evolution models. ALFA RRL surveys will have more sources and more accurate RRL measurements. Furthermore, only Arecibo has the sensitivity to measure RRLs from heavy elements easily. For example, Figure 3 shows the recombination lines measurements at 5.0 GHz (C-band) of the compact HII region S88. Not only the main hydrogen, helium and carbon 109α transitions are detected but also the hydrogen and helium 137β lines are clearly visible. With the capabilities of the Arecibo telescope and with ALFA we will be able to measure the metalicity gradient for that part of the Galactic disk accessible from Arecibo *directly* without the need to use Te as a proxy which must be calibrated by optical measurements of the oxygen abundance of nearby HII regions.

The RRL Y+ vs Rgal analysis by Shaver et al. (1983), Churchwell et al. (1978); Churchwell at al. (1974) are also still the definitive constraints used by chemical evolution modelers. The Y+ values they used suffered from inaccuracies due to poor signal to noise in the spectra. ALFA will improve matters considerably, again both through improved sensitivity and also via the much larger number of HII regions in the sample.

Finally, GALFA will measure a large number of nebular Carbon RRLs. Only about 20 nebulae currently have carbon RRL measurements (Silverglate & Terzian 1978). A much larger sample will allow us to search for Galactic carbon abundance gradients which in turn will provide another, new constraint on Galactic chemical evolution.

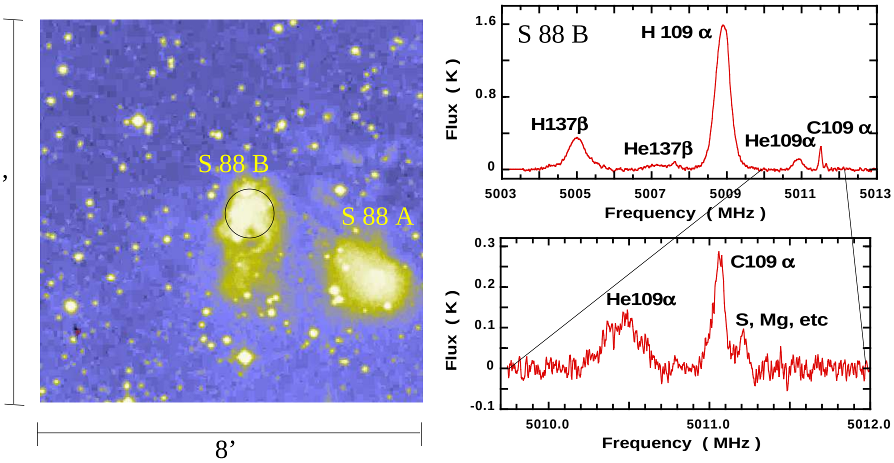

Figure 3: POSS image of the star-forming region Sharpless 88 (left). Radio recombination lines observations at 5 GHz toward the compact HII region S 88 with Arecibo telescope (right). Hydrogen, helium, and carbon 109α were clearly detected, and hydrogen and helium 137β as well. C109αline is clearly stronger than helium lines. Next to the carbon line is the heavy elements line. This spectra was taken in 45 minutes of integration (Terzian 2003).

2.4 Carbon Recombination Lines

Maps of Carbon RRL emission in a variety of sources can be used to probe the properties of the nebular photodissociation regions (PDRs) and to test PDR models. Carbon’s low 11.6 eV ionization potential means that the bulk of carbon RRL emission comes from the periphery of classical HII regions. Figure 4 shows the recombination line spectra from different HII regions. The hydrogen line comes from the HII region while the carbon line come from the PDRs outside the HII region. The carbon emission is dominated by the stimulated effects produced by the continuum emission of the HII region. The properties and structure of PDRs is thought to depend critically on metalicity. ALFA carbon RRL maps can make a unique contribution to PDR theory because, again, only Arecibo has the sensitivity to map carbon RRLs in a substantial number of sources with a wide range of metalicities.

This potential for carbon RRLs to enhance our understanding of PDRs becomes even more exciting if ALFA data are compared with [CII] 158 micron emission maps from, say, the ISO satellite or SOFIA. Natta et al. (1994) showed that a carbon RRL/[CII] 158 micron ratio can be used to measure the nebular electron densities and temperatures (Ne, Te) *independently*. The analysis compares two transitions of one ion, eliminating the difficult problem of adjusting for relative abundances of different species. Complete maps of the (Ne, Te) distribution surrounding HII regions with different metalicity and radiation fields will provide a powerful test of PDR theories.

2.5 The Galactic Diffused Ionize Medium

The extended low-density (∼1 to 10 cm^{-3}) warm (Te ∼ 3000 to 8000 K) ionized medium is found to be located in the galactic plane and halo. The diffuse ionized medium had been detected in radio recombination lines at the galactic plane but also at optical recombination lines outside of the plane. The sources of ionization are still unclear although massive stars can be accounting for most of the emission. The main controversy is how does the ionizing photons escape from the plane and ionize the gas outside of the galactic plane. One of the proposed methods is that supernova explosions generate cavities in the form of chimneys that permit UV radiation and ionized gas to flow from the plane to the galactic halo (Heiles et al. 1996). A clumpy ISM will also permit escape to the halo. With the proposed ALFA RRL survey it will be possible to study the diffuse medium and the chimney-like structures at $|b| > 1^\circ$ in RRL.

3 Other Surveys with which ALFA RRL can be Compared

MSX (Midcourse Space Experiment) – The MSX satellite observed the whole sky in the mid infrared band between 4.2 to 26 microns, with its maximum sensitivity at 8.3 microns. MSX covered the regions either missed by IRAS and COBE/DIRBE, or where the sensitivity of IRAS was degraded by confusion noise arising from regions of high source densities or structured extended emission. The MSX experiments mapped the entire Galactic Plane. The MSX results are very useful in the studies of the photodissociated regions that ALFA RRL will be detecting in through carbon RRL. The 8.3 microns band collects the continuum emission of the hot and warm dust but also included the emission from the PAHs, i.e. the emission of long molecules in photodissociated regions.

ISO (Infrared Space Observatory) – ISO experiments included four instruments: an infrared camera (CAM), a long-wavelength spectrometer (LWS), a photo-polarimeter (PHT), and a short-wavelength spectrometer (SWS). These experiments were dedicated to specific targets more than a survey but the results from the spectrometers, especially at low frequency (LWS), are relevant for carbon RRL studies. The LWS instrument covered a frequency

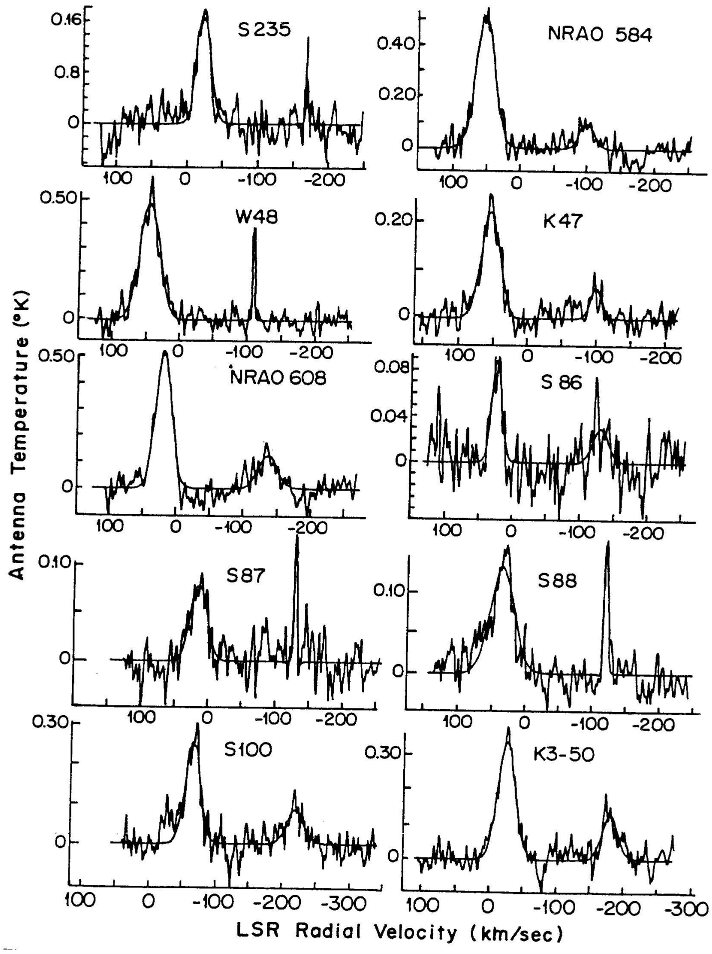

Figure 4: Radio recombination lines at 1.4 GHz measured with the Arecibo telescope (Silverglate & Terzian 1978). Each spectra took between 30 and 60 minutes of on-source time. The hydrogen line is clearly visible in all spectra, and the carbon line show up very bright in W48, S87, and S88.

range that includes the [CII] 158μ line, which is one of the main coolants of the PDRs and can be compared with carbon RRL.

2MASS (The Two Micron All Sky Survey) – 2MASS used two highly-automated 1.3-m telescopes, one on Mt. Hopkins, AZ, and one at CTIO, Chile. Each telescope was equipped with a three-channel camera, capable of observing the sky simultaneously at J (1.25 microns), H (1.65 microns), and Ks (2.17 microns). This survey covers the complete Galactic plane. The near infrared traces mainly the stellar emission but also shows the very embedded stellar clusters. This survey can be used to compare individual regions and identify the ionizing sources.

GLIMPSE (Galactic Legacy Infrared Mid-Plane Survey Extraordinaire) – A fully sampled survey of two thirds of the inner Galaxy at wavelengths 3.6, 4.5, 5.8, and 8.0 μm with a spatial resolution of 1.5" to 1.9" and a sensitivity 100 times greater than MSX. This survey is revealing many new regions of massive star formation, planetaries, and SNRs many of which were previously unknown either due to interstellar extinction or lack of sensitivity. The ALFA RRL survey will be very much complimentary with the GLIMPSE survey.

NVSS (NRAO VLA Sky Survey) – The NVSS is a 1.4 GHz continuum survey covering the entire sky north of -40° in declination. The NVSS is very useful for the identification of compact sources and determining their physical parameters. It can also be used for correcting beam dilution effects on compact sources.

ALFA Continuum Survey – The ALFA continuum survey will provide continuum measurements for all the sources detected in ALFA RRL survey. This is necessary to obtain some physical parameters. The RRL survey will complement the ALFA continuum survey because the thermal or non-thermal nature of the continuum emission will be determined.

ALFA HI Survey – The ALFA HI galactic plane survey can be combined with the ALFA RRL survey to study the structure of the Galaxy and its kinematics. This survey covers the same latitude range of the RRL survey, and has the same spatial resolution.

IGPS (International Galactic Plane Survey) – The IGPS is an international cooperative effort to have a complete HI survey of the galactic plane with a spatial resolution of $1'$. The IGPS is composed of three HI surveys, the Southern Galactic Plane Survey (SGPS), the Canadian Galactic Plane Survey (CGPS) and the VLA Galactic Plane Survey (VGPS). The SGPS covers the galactic disk in the longitude range between 253° and 358°, the VGPS covers the range between 18° and 67°, and the CGPS covers the range between 74° and 147°. The latitude covered for each surveys varies from $\pm1^\circ$ and $\pm2^\circ$ for VGPS and SGPS, and from -3.6° to $+5.6^\circ$ for CGPS. These surveys are particularly useful for the RRL ALFA survey due to the $1'$ spatial resolution. For the very low galactic plane sources we will be able to use these HI data for the kinematical study of the RRL sources.

4 Line Selection

The IF bandwidth of ALFA is 300 MHz and it is possible to select up to 8 segments within the IF bandpass. Experience has shown that frequencies below about 1400 MHz are plagued more by interference than those above 1400 MHz. We, therefore, will confine our line selection to those with frequencies $\geq$ 1400 MHz. We also want to observe at least four sets of α lines which can be averaged to obtain a S/N twice that for a single line in the same integration time and spectral resolution. It is also important to have several higher order lines in the selected bandpasses as a check on departures from local thermodynamic equilibrium as well as a test for pressure broadening when the line full widths at half maxima are compared. Of course, He and C lines will be included in all selected bandpasses. To resolve the He, C , and heavier atomic lines it is necessary to have a velocity resolution of about 1 km s^{-1}. The bandpasses must be wide enough to include the whole range of Galactic rotation velocities along each longitude. Table 1 contains the lines that are of our interest in the RFI-free range of ALFA and also the required bandpasses. The lines with Δn$\geq$ 4 that fall within each frequency segment are not listed.

With this selection of lines, it will be possible to address all the science noted above and provide the possibility for serendipitous discoveries.

4.1 Instrumental Configuration

As we mentioned above in order to get the expected sensitivity in the RRL survey it is required to observe at least four hydrogen α transitions at the same time, with a spectral resolution of $\sim$ 1 km s^{-1}. The bandpass for each transition varies from 3 to 7 MHz (see Table 1 and below for details).

A possibility for the backends that we are proposing is to use the Wideband Arecibo Pulsar Processor (WAPP) backend with filters that isolate the different frequency ranges that are of our interest. Deshpande & Lebrón explored this possibility. Here we include a summary of their results. The details of this method can be found in the ALFA's memo web page located at *http : //alfa.naic.edu/memos/*. The title of the memo is: *A Possible Backend Solution for the ALFA Recombination-line Survey* (date 30th November 2004 and referenced here as Deshpande 2004).

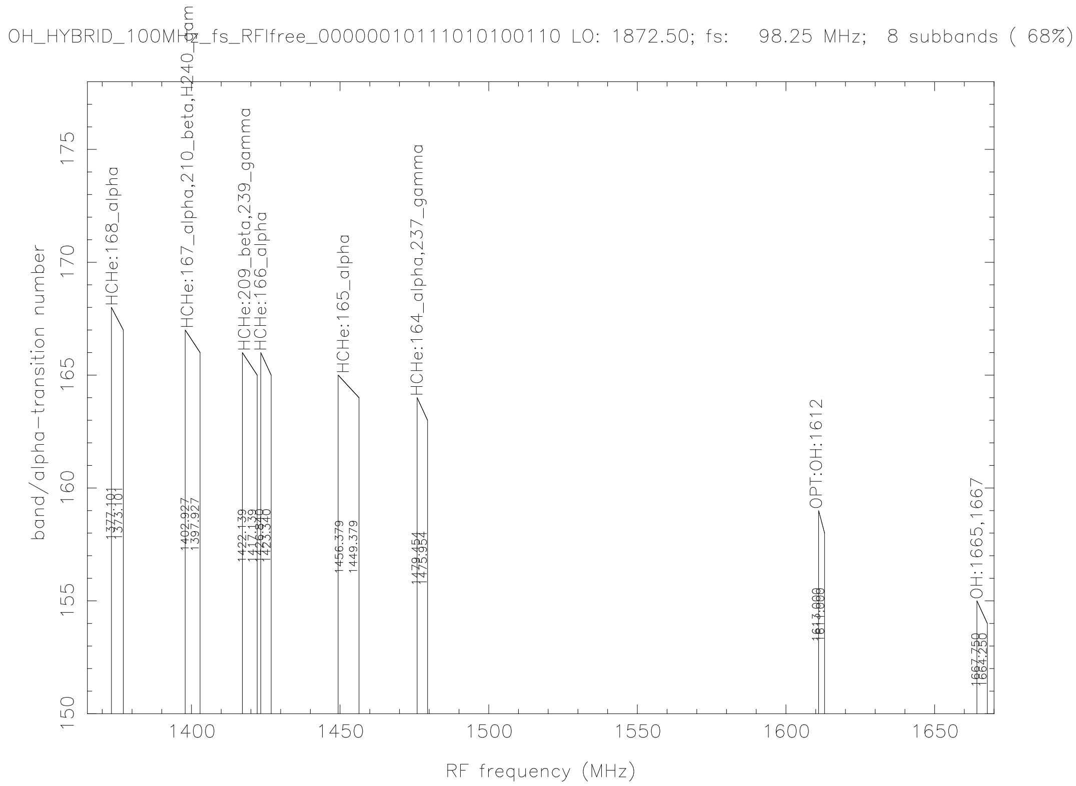

Figure 5: The selected RF bands associated with the indicated RRL transitions. The y-axis scale is somewhat arbitrary, and the higher-rise edge in each band corresponds to the its lower RF frequency end. The LO and sampling clock frequencies found most appropriate are indicated in the top text.

The desired bands are appropriately filtered (defined) by using a single filter with multiple (closely harmonic) responses, the compact packing may be achieved by exploiting (the otherwise undesirable) “aliasing”. In this method the apparent folding of the input bands with respect to the harmonics of the sampling frequency is exploited to compactly pack together otherwise well-separated bands.

The existing IF/LO system for the ALFA (or for any single-pixel receiver) presents signals to the WAPP at an IF frequency of 250 or 275 MHz, depending on whether the BW is 100 MHz or ≤50 MHz, respectively. Noting this, we define the allowed IF extent to be within the window 200-300 MHz for using the presently available WAPP-input paths. The sampling frequencies of the WAPP are normally fixed; however we assume that these can be varied if needed.

In the following example, 6 key bands of varying bandwidths, including one OH band, were specified as the "must-include" bands. All the known RFI-prone bands were excluded from the list of bands to be considered. The IF bandwidth was left unrestricted (corresponding to a possibility of bypassing the WAPP filters), and the range of sampling clock frequency was limited to 95-105 MHz, to ensure ready compatibility with existing WAPP usage.

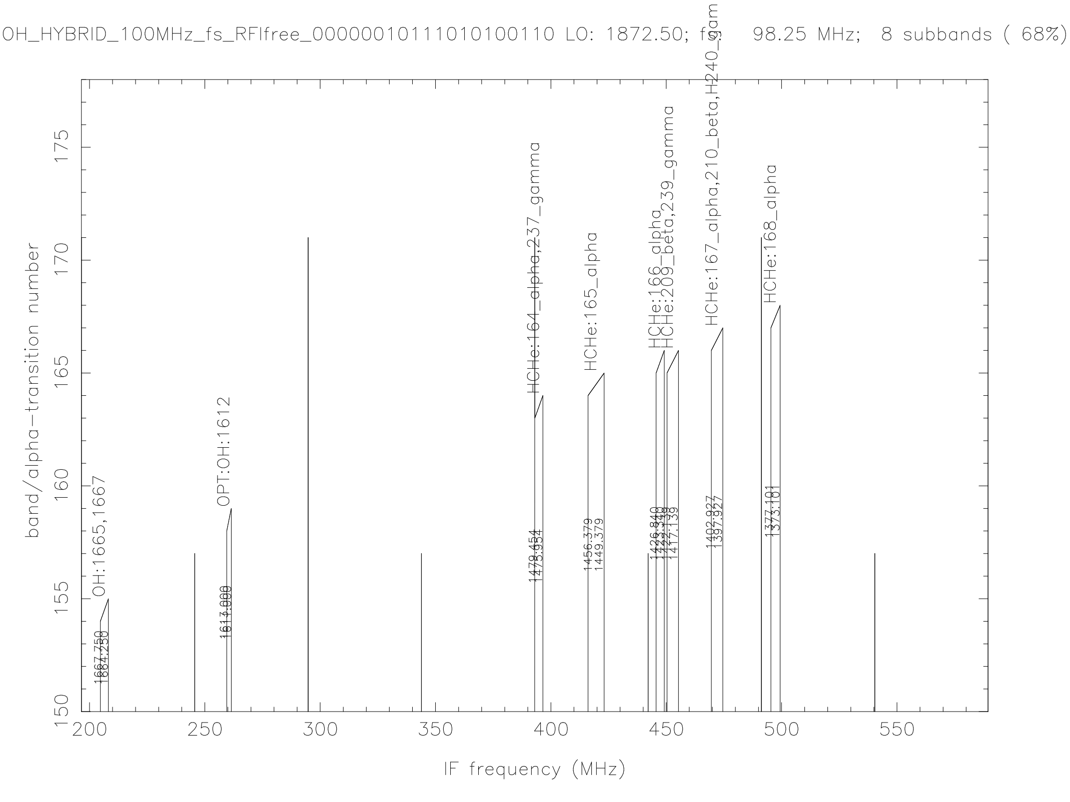

Figure 6: The selected bands associated with the indicated RRL transitions after the first down-conversion, i.e. their respective locations at IF. The start and end frequencies (at the left and the right edges) are harmonics of the sampling frequency and the tall vertical lines mark the locations of the harmonics within the plotted range. The other harmonics of half of the sampling frequency are marked by the 'short' vertical line. The individual bands are not flipped relative to each other at IF, but the flips about the 'short' and 'tall' markers would be apparent at baseband (figure 5).

Figures 5, 6 and 7 show the selected bands as a function of RF, IF and baseband frequencies, respectively. In this case, 8 bands (which include 2 OH-bands) could be packed in a bandwidth slightly under 50 MHz. The packing efficiency (65 to 68%) is somewhat lower here, as a consequence of

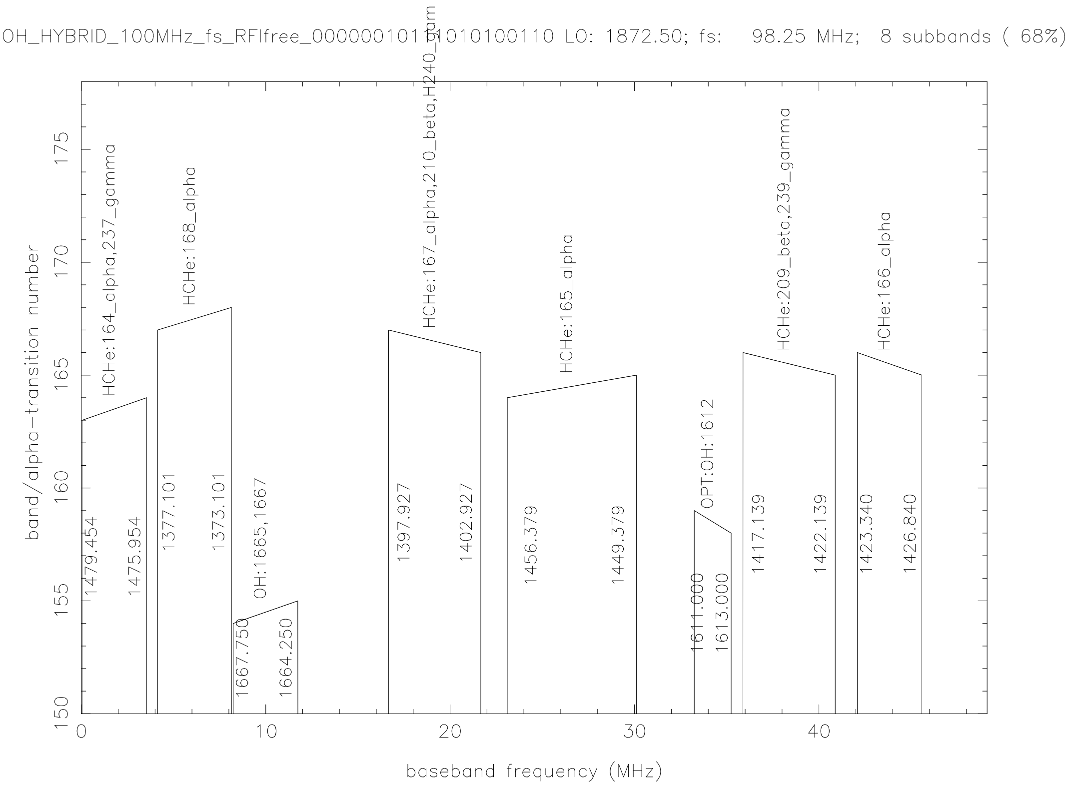

Figure 7: The resultant packing in the baseband, i.e. over the range 0 to half of the sampling frequency. Note the flips and the shifts apparent in individual band version associated with baseband. The efficiency of packing is indicated at end of the top label, and is be considered as near optimum, given the variety in spacing and the widths of the RF bands.

the limits on the sampling frequency, than in the case where 6 bands were selected as "must-include" (see details in ALFA memo Deshpande 2004). Noting that two of the selected 8 bands can be treated as one (i.e. 1417-1427), only seven distinct band-pass windows need to be considered. Using the WAPP in its "3-level, 2-channel auto-correlation" mode, we estimate the spectral resolution to be ∼6 kHz (a little over 1 km s^{-1} in velocity).

Implementation of these cases (shown in figures 5-7 and memo Deshpande 2004) does not require any significant change in the WAPP sampling setup, and so the existing boards would not need any fine tuning. According to Bill Sisk, it would be easier to provide a direct IF path to the WAPP digitizers (by-passing the existing 50/100 MHz filters), than to change the WAPP clock frequencies by a large factor. So, a setup with a by-pass IF-path would enable use of the WAPPs as an attractive back-end for ALFA surveys of the

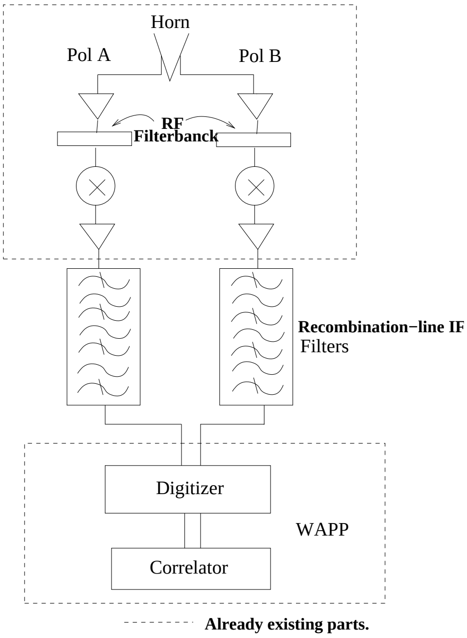

Figure 8: Flow-chart of a single ALFA beam including the filters proposed for the RRL backend option using the WAPPs. The dashed-line area indicate parts that already exist in ALFA and the WAPPs.

several RRLs and OH-lines together, if suitable IF filters (e.g. with band-pass windows as shown in figure 6) can be obtained/made. Figure 8 shows a flow chart for one of the ALFA beams indicating where the filters are required. All the parts surrounded by dashed lines already exist in the ALFA and WAPP systems.

4.2 Proposed Survey

Region to Survey: We propose to survey the entire Galactic plane visible from Arecibo, i.e. the longitude range from 32° to 77° in the inner Galaxy and 168° to 214° in the anticenter region and latitudes $|b| \leq 5°$. This will be the FIRST FULLY SAMPLED RRL survey of the galactic plane ever made. (We assume that the ALFA RRL survey will make commensal observations with the ALFA Pulsar survey that requires $|b| \leq 5°$, and has the same integration time per beam as the RRL survey).

Survey Parameters: The following list summarizes the parameters for the proposed RRL Galactic Plane survey.

- Integration time per position, 300s

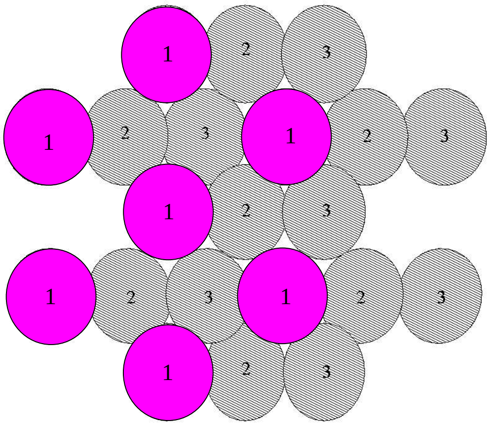

Figure 9: Example of the dense sampling method. Taken from the Pulsar tiling observing mode. Each circle indicates the points for which the sensitivity is half of what it is in the center. Each ellipse depicts a sensitivity level of -3 dB compared to the center of the beam. Beams with the same number belong to the same ALFA pointing. This figure was taken from: *http* : *//www2.naic.edu/ pfreire/tiling/*.

- Dump time, 1 sec
- Total bandwidth, 100 MHz
- Velocity resolution, ~ 1 km s^{-1}
- Number of filters per beam, 14
- Bandpass for each filter from 3 to 7 MHz (see table 1 for details)
- Sensitivity limit in the line ~ 0.1 Jy

We propose to use the WAPP spectrometers. For the inner and outer Galaxy we will use 300s total dwell time per sky position.

Pointing Strategies: We will sample the sky, pointing on each position with a *dense-sampling* approach.

Dense Sampling: Figure 9 shows an example of the dense sampling. Sets of three pointings one next to the other covers a continues area. The dense sampling is a mode that the Pulsar consortium are planning to achieve ultimately in their PALFA survey. For the RRL Survey it is fundamental to cover the sky systematically in a dense mode because we are expecting many sources to be more extended than one ALFA beam, and in some cases the sources could be even bigger than the complete ALFA ARRAY. In this mode the survey will be covering sections of the sky of approximately 22 by 25 arcmin every hour. With the dense sampling we can obtain results from the survey as soon as the survey starts.

Another point to considerate in the survey is if it is better to do a single pointing of 300s per position or to do multiple passes with a total integration time of 300s. Because the sources we are considering are not variable, and we also are expecting to have a minimum of RFI in our bandpass, one single pass of 300s is desirable. On the other hand if the total integration time is divided in two or more passes the results will eventually be the same. In such a case it is important for the multiple passes not to be separated by a very long period of time.

To summarize, for the survey proposed here, our plan is to adopt a dense, single-pass pointing strategy. This plan may change depending on discussions with other commensal surveys. The skim of Deshpande (2004) also allows to record the OH (1665, 1667 MHz) main lines and the OH (1612 MHz) satellite line. These will also be recorded through appropriate filters. We propose that the ALFA RRL survey make commensal observations with the ALFA Pulsar surveys, the proposal submitted last October 2004 titled "An ALFA Pulsar Survey of the Galactic Plane", P.I. Jim Cordes, and any other future surveys. Because the ALFA RRL will use the WAPP spectrometers, commensality with the pulsar group will only be possible after the PALFA spectrometer is available.

4.3 Sensitivity Limits

Basically this will be determined by the assumption of a total of 20 minutes integration per position. Since we will be able to average all 4 alpha lines, the S/N will be twice what one would expect for a single alpha line. The beta and gamma higher order lines will only be possible to average if they do not differ very much in principal quantum levels or if pressure broadening is demonstrably unimportant. The high order lines are useful mostly for non-LTE effects and pressure broadening.

4.4 Survey Data Format and Archiving

To the existing FITS data format it is necessary to add a *tag* that contains the information of the frequency for each spectral channel. That is necessary because we will not be using the complete band, and it will not be possible to calculate the frequency during data processing. This will also be useful to avoid any confusion during the line analysis.

The Standard BDFIT format is required. All RRL data and OH data will be archived appropriately. Arrangements will be made for the community to have access to the data.

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Table 1: Recombination lines in the L-Band (MHz)

Line set	Bandwidth (MHz)	Central Freq. (MHz)	1 km s^{-1} (kHz)	Lines Included
H164α-C164α	3.50	1477.704	4.93	H164α, He164α, C164α
H165α-C165α	7.00	1452.879	4.84	H165α, He165α, C165α H237γ, He237γ, C237γ
H166α-C166α	3.50	1425.09	4.75	H166α, He166α, C166α
H167α-C167α	5.00	1400.427	4.67	H167α, He167α, C167α H210β, He210β, C210β H240γ
H209β-C209β	5.00	1419.639	4.73	H209β, He209β, C209β H239γ, He239γ, C239γ

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