Galactic Legacy Projects

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Outline

- Introduction: what “Legacy” projects can do for you
  - Recent Galactic legacy-type projects
- Possible future projects: positioning us for the SKA
  - NVSS with rotation measures
  - Galactic plane survey with full spectral polarization
    - VLA
    - GBT
  - Ammonia in star-forming regions
- What we need to make these happen
- Summary
Recent “Legacy” Projects

• “Legacy” Projects produce datasets with broad, lasting value and highly cited papers

• Some recent Galactic Legacy projects at radio frequencies:

  • International Galactic Plane Survey: CGPS (Taylor et al), VGPS, (Stil et al), SGPS (McClure-Griffiths et al, Haverkorn et al)
  • Multi-Array Galactic Plane Imaging Survey (Becker, Helfand et al)
  • Galactic All-Sky Survey (McClure-Griffiths et al)
    • Before 2005: LDS-IAR survey, Hartmann, Burton et al; Kalberla et al,
  • Boston University Galactic Ring Survey (Jackson et al)
\[ \begin{align*}
|b| & \leq 1.5^\circ, \quad l = 253^\circ - 358^\circ, 5^\circ - 20^\circ \\
|b| & \leq 5^\circ, \quad l = -5^\circ - 5^\circ \\
|b| & \leq 1.0^\circ, \quad l = 18^\circ - 44^\circ \\
|b| & \leq 1.5^\circ, \quad l = 44^\circ - 58^\circ \\
|b| & \leq 2.0^\circ, \quad l = 58^\circ - 67^\circ
\end{align*} \]
Why do the IGPS?

- Resolve the ISM simultaneously on scales of parsecs to kiloparsecs
- Hope to answer questions like:
  - What are the structural characteristics of the warm and cold HI
  - How is structure formed in the ISM?
  - What are the dynamics of the HI throughout the Galaxy?
  - What are the temperatures of the warm and cold HI?
  - What is the spiral structure of the Milky Way?
SGPS Galactic Centre Survey

- Extension to the SGPS to cover the Galactic Centre
  - Covers $-5^\circ \leq \ell \leq +5^\circ$ and $-5^\circ \leq \ell \leq +5^\circ$
  - Angular resolution of 100”
  - 967 pointings
  - Sensitivity: 1 - 2 K
- Probes the dynamics of HI in the central 3 kpc of the Galaxy
Galactic All-Sky Survey: GASS

- Survey all atomic hydrogen (HI) emission south of $\delta \ 0^\circ$
  - Uses the Parkes 13 beam 21 cm multibeam receiver
- Velocity range: -450 km/s to 400 km/s
  - Focuses on HI associated with the Milky Way
  - HIPASS was -1200 km/s to 12700 km/s
- Velocity resolution: 0.8 km/s
  - HIPASS was 13 km/s
- Angular resolution: 14.4 arcmin
- Stray radiation corrected
- ~1800 hours observing, started in Jan 2005 to be completed by November 2006

To do sky north of $\delta \ 0^\circ$ with the GBT would take ~10,000 hrs
Why do GASS?

- HI observed in all directions on the sky
  - Offers information about:
    - The structure and formation of the Milky Way and its halo
    - The interaction of the disk and halo
    - The nature of High Velocity Clouds

- Current HI surveys are:
  - High resolution (arcminute), but limited to +/- a few degrees around the plane (e.g. SGPS, CGPS)
  - All sky, but low resolution (~ degree)

- UV and optical absorption lines suggest that there is sub-degree structure but are limited to pinpointed lines of sight (e.g. Diplas & Savage 1994)

- Recent GBT and Arecibo observations also confirm sub-degree scale structure but they cannot survey the whole sky
A view of GASS
Possible Future Legacy Projects

- Focus on projects with direct lead-ins to the SKA, i.e. magnetic universe
- NVSS repeat with Rotation Measures
  - Constrain the magnetic field of the Galaxy
  - Search for variability
- Galactic Plane Surveys with full spectral polarimetry
  - HI Zeeman of tangent point
  - Faraday tomography of the magneto-ionic medium
- Ammonia in star-forming regions
Supply a rotation measure “grid”

With the EVLA capabilities of larger bandwidth and reduced system temperatures, it should be possible to repeat the NVSS with full polarimetric capabilities.
RM grid science

- Model the magnetic field of the Milky Way
  - Explore field reversals
  - Z-field strength
  - Probe dynamo theories
  - Complimented by pulsar surveys
- Search for magnetic fields/ionised gas in high velocity clouds

Brown et al, in prep
Milky Way Magnetic field

Han et al. (2006): Plus signs and crosses represent positive RMs, squares and circles represent negative RMs
RM Grid with the EVLA

- Use bandwidth of 500 MHz, with full polarization in ~0.5 MHz channels

\[ \Delta RM = \frac{1}{2L} \frac{1}{\lambda \Delta \lambda} \]

- For \( \Delta RM > 5 \text{ rad m}^{-2} \), require S/N, \( \mathcal{L} \sim 6 \) (Beck & Gaensler 2004)
- For the same integration time per pointing as the NVSS, expected rms is \( \sim 0.05 \text{ mJy/Bm} \)
- Anticipated number of RM sources is \( \sim 120,000 \), 100 times the number known now!
Zeeman survey of the Tangent Point

- HI Zeeman observations provide in situ measurements of the B-field
  - Depends on the derivative of the spectrum
- The terminal velocity at the tangent point in the inner Galaxy provides a steep spectrum at a known distance
- Zeeman peak-to-peak signal:

\[ \Delta T_{pp} = 3 \times 10^{-4} \times \left( \frac{B_{\mu G}}{\sigma_v^2} \right) \times T_b \]

- If \( B \sim 6 \, \mu G \) (Heiles & Troland 2005), \( T_b \sim 120 \, K \), \( \Delta T_{pp} \sim 0.2 \, K \)
- GBT survey of \( l=10 - 90 \), \( |b|<0.5 \), with 9’ resolution to 20 mK in 900 hrs
An HI Galactic Plane Survey?

- The EVLA correlator might offer the opportunity to do a full polarization survey with HI and continuum

- Multiple options:
  - Improve the sensitivity of the IGPS: \( \sigma = 1 \, \text{K} \rightarrow 0.1 \, \text{K} \)
    - Requires the E-array
  - Improve the resolution of the IGPS: \( \theta = 1' \rightarrow 30'' \)
    - Requires lots of time on the C array (mapping speed \( 0.025 \, \text{deg}^2/\text{hr} \): 5200 hrs just for VGPS area!)
  - Improve the coverage of the IGPS
    - Extend to higher latitudes - requires better sensitivity (E-array)
  - Redo the IGPS with full spectro-polarimetry
    - Faraday Tomography of the Galactic plane: feasible with EVLA + GBT
Faraday Rotation Measure Synthesis

- Different frequencies trace different Faraday depths, $\phi$:
  \[
  \phi = 0.81 \int_{\text{there}}^{\text{here}} n_e B \cdot dl \text{ rad m}^{-2}
  \]

- By imaging the polarized continuum over a large frequency range with good spectral resolution, we can probe the magneto-ionic medium as a function of Faraday depth
  - Follow-up with HI absorption towards polarized background for distances to emitting regions

- Channel width determines the RM range and the total BW determines $\Delta RM$
The GBT need

- Interpreting RMs without large scale structure is dangerous!
  - Imaging of the diffuse polarized background requires single dish data as well as the interferometric data
  - Need spectro-polarimetric imaging capabilities with the GBT (software)
- Most large scale surveys of diffuse emission will require GBT data to accompany VLA data
Ammonia survey with the GBT+VLA

• The GBT could do a survey of ammonia in the Galactic plane, tracing densities of $n \geq 10^5 \text{cm}^{-3}$
• Use GLIMPSE IR survey as a finder map of star forming regions
  • Derive kinematic distances to the regions
  • Explore temperature and density structure of star forming regions
• Angular resolution of 30” will complement the HI GPS (1’-2’), the Boston University GRS CO survey (46”)
  • Follow-up with EVLA for matching resolution to GLIMPSE (1”)
What we need

- EVLA to achieve polarization purity of -25 dB across the field
- EVLA to achieve correlator goals, i.e. $\Delta \nu > 500$ MHz at 1.4 GHz, full polarization in >1000 channels
- The E-Array for surface brightness sensitivity
- Software:
  - Spectro-polarimetric imaging for the GBT
  - Efficient large-scale mosaic imaging for the VLA
- Support for producing VO compliant public release data products?
Summary

• Legacy projects provide highly cited papers, general purpose datasets for large community use

• Possible Galactic projects for the future include:
  • RM grid with the EVLA
  • HI Zeeman at the tangent point with the GBT
  • Ammonia in star-forming regions with the GBT+EVLA

• Future HI surveys (Galactic Plane and high latitude) with the VLA would require the E-array

• An all-sky HI survey with the GBT will need a multibeam
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