Studies of the Galactic Magneto-Ionic Medium with the Canadian Galactic Plane Survey

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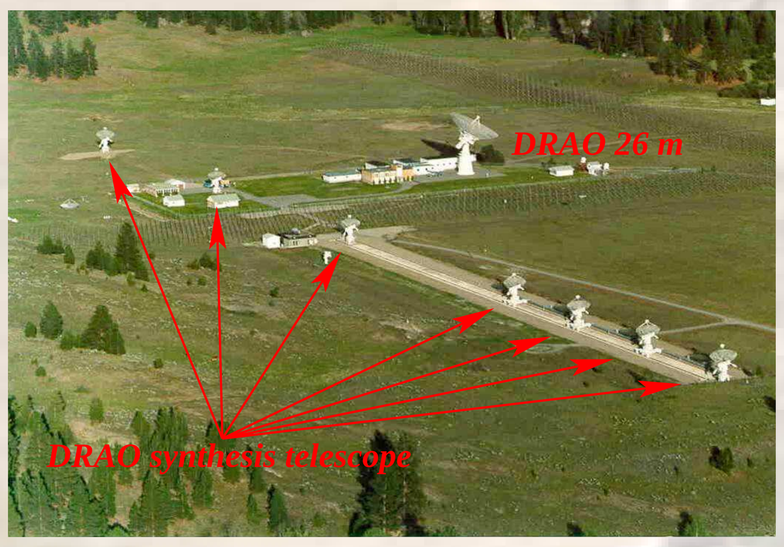
Abstract

The completion of the Canadian Galactic Plane Survey (CGPS) has given the astronomical community an incredibly broad view of the Interstellar Magneto-ionic Medium while preserving its spectacular details. Here, I would like to give a summary of the results of recent studies with the CGPS 1420 MHz radio continuum and polarization data.
A study of the effect of HII regions and supernova remnants on the background polarization signal gives a very detailed view of the "Polarization Horizon" and the relation between large-scale and turbulent magnetic fields. A comparison of pulsar dispersion measures (DM), foreground HI column densities (N_{HI}), and extragalactic rotation measures (RMs) of CGPS sources indicates that the large-scale magnetic field is part of the Warm Neutral Medium and provides information about the configuration of the Outer Galaxy large-scale magnetic field.

The DRAO Synthesis Telescope

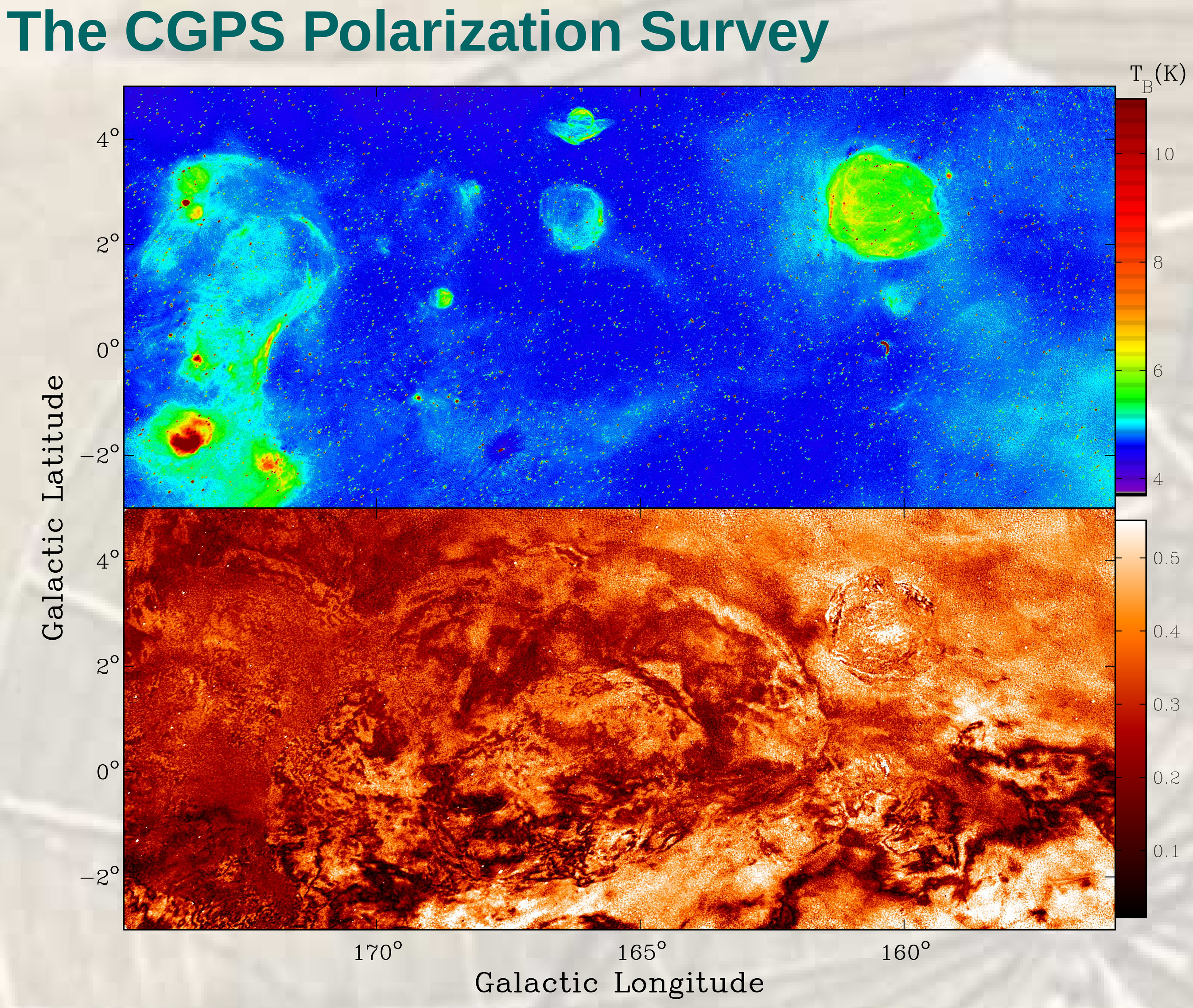


The DRAO ST (left) is a seven element interferometer providing full UV-coverage between a maximum spacing of 617 m and a minimum spacing of 12.9 m.

Frequencies	1420 MHz	408 MHz
Field of View	2.65°	8.22°
Angular Resolution	$58" \times 58" cosec(\delta)$	$2.8' \times 2.8' cosec(\delta)$
Spatial Frequencies	45' to 58"	2.6° to 2.8'
System Temperature	45 K	105 K + T_{sky}
Continuum Sensitivity	180 μJy/beam	3.0 mJy/beam
Rotation Measure Determination	4 bands, $\delta(f) = 7.5$ MHz see image below	
Mosaicking Sensitivity	45μJy achieved	confusion limited
HI sensitivity	$2.5 B^{-0.5} sin\delta$ K	
HI bandwidths	$B = 0.125, 0.25, 0.5, 1.0, 2.0, 4.0$ MHz	

see also: Landecker et al, 2000, A&AS 145, 509

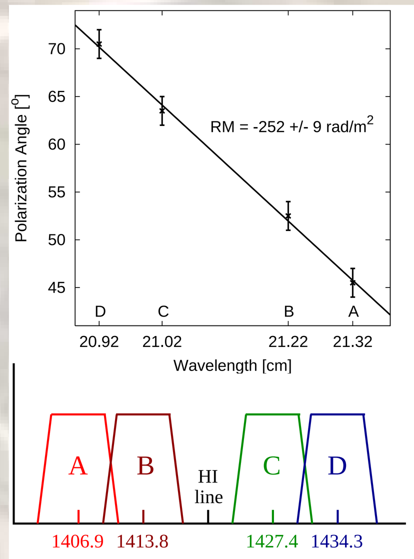
The CGPS Polarization Survey



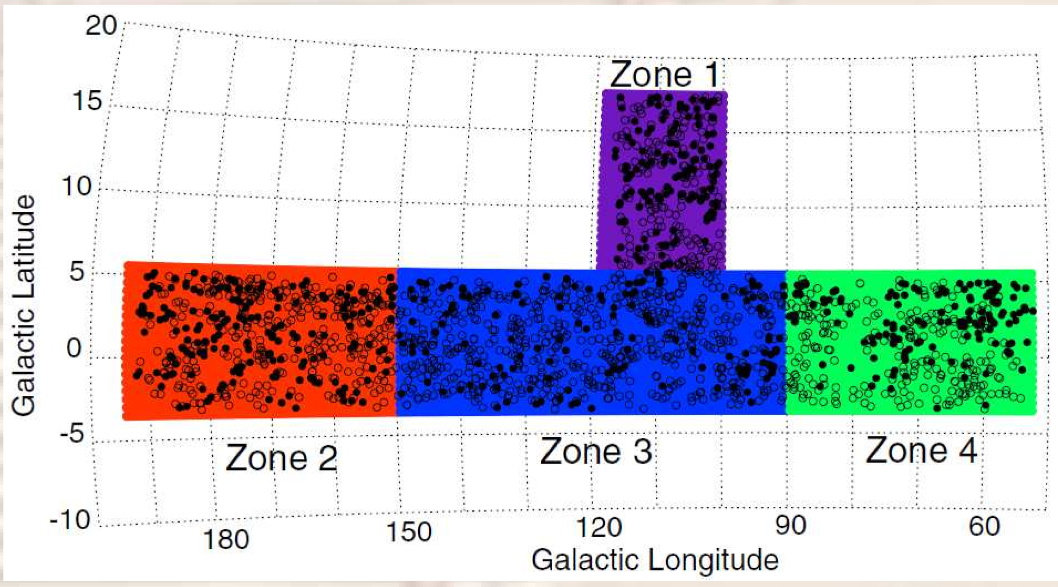
CGPS Stokes I image (top) and polarized intensity (bottom) at 1420 MHz taken from the Canadian Galactic Plane Survey (Taylor et al., 2003, AJ 125, 3145; Landecker et al., 2010, A&A 520, 80). Both images combine data from the DRAO ST with single antenna observations to truly represent all structure from the largest scales down to the resolution limit. 1420 MHz is close to the ideal frequency for radio polarization imaging, showing emission and Faraday rotation features. The DRAO ST is THE world's leading telescope for imaging polarized emission through unique capabilities to correct for instrumental polarization and accurately combine single antenna and aperture synthesis data.
(CGPS data is available at: http://www.cadc-ccda.hia-iha.nrc-cnrc.gc.ca/)

RMs of Extragalactic Sources

At 1420 MHz the DRAO ST provides four 7.5 MHz wide frequency bands with full Stokes (I,Q,U,V) parameters.

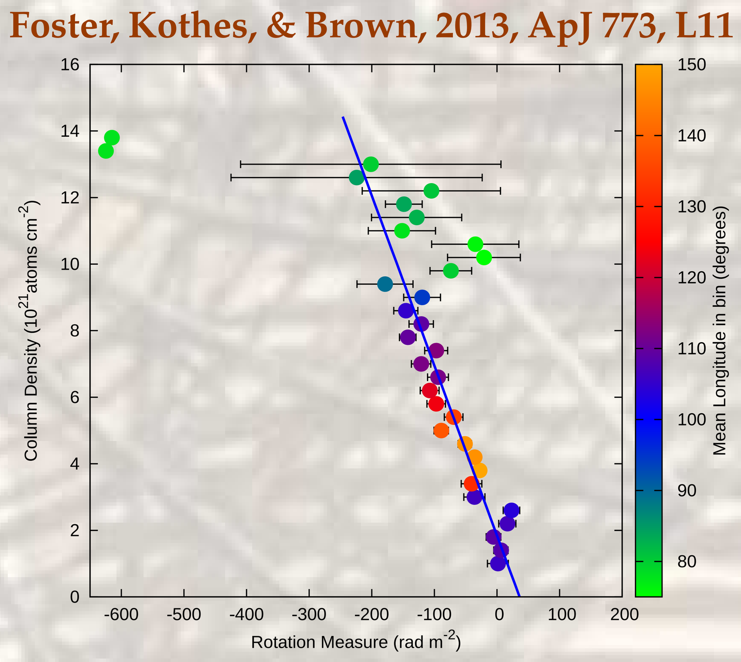


This gives the opportunity to calculate rotation measures (RMs) at very high precision (left). There have been several studies of RMs of extra-galactic background sources with data from the CGPS (Brown & Taylor, 2001, ApJ 563, L31; Brown, Taylor, & Jackel, 2003, ApJS 145, 213; Brown et al., 2003, ApJ 592, L29; Van Eck et al, 2011, ApJ 728, 97; Brown et al., 2015, in prep) providing a list of 1970 RMs over the entire CGPS sky (right).



The MIM in the Outer Galaxy: RM vrs. N_{HI}

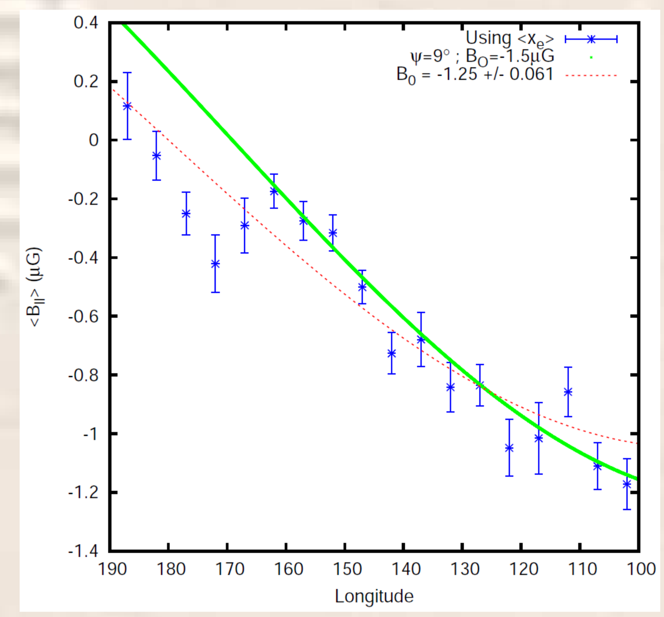
Foster, Kothes, & Brown, 2013, ApJ 773, L11



A comparison of RMs and the foreground N_{HI} towards 1970 extragalactic sources (see above) with data from the CGPS indicates a linear relationship of RM/N_{HI} $= -23.2 \pm 2.3$ rad m^{-2} 10^{21} cm^{-2} (left). This slope gives a mean magnetic field of $B_{\|} \approx -1\,\mu$Gs assuming a typical value of 8 % for the ionization fraction. The remarkable consistency between our $B_{\|}$ and B_{tot} of $-1.2\,\mu$Gs by Van Eck et al. (2011, ApJ 728, 97) suggests that the Galactic magnetic field may be supported by the partly ionized WNM.

The MIM in the Outer Galaxy: B_{tot}

Jang, Kothes, & Foster, 2015, in prep.



To get a more accurate distribution of free electrons in the CGPS area we compared DMs from 210 pulsars and their foreground N_{HI}. This resulted in a remarkably constant ionization fraction in the Outer Galaxy between Galactic Longitude of about 100° and the anti-centre. Combining this with the distribution of RM/N_{HI} gives $B_{\|}$ as a function of Galactic Longitude (Figure above).
The fit of a spiral pattern to this magnetic field gives a pitch angle of 0° and a total field strength of $-1.25\,\mu$Gs (red dotted line). This would represent a circular magnetic field as indicated by many previous studies. A spiral magnetic field with a pitch angle of about 9° and a field strength of $-1.5\,\mu$Gs (green line) fits the data below a Galactic Longitude of 160° much better. In this case the observations indicate a local anomaly beyond 160°. Please, have a look at the PI image (top left) and be your own judge.

The Polarization Horizon

The term "Polarization Horizon" (PH) defines the maximum distance from which linearly polarized radio continuum emission is still detectable. Synchrotron emission generated more distant than the PH is depolarized by Faraday rotation effects. This is typically caused by either turbulent magnetic fields (beam depolarization) or linearly polarized emission generated at different distances along the same line of sight suffer from different Faraday rotation (depth depolarization).
We can probe the location of the polarization horizon by studying the polarization characteristics of supernova remnants (SNRs) and the effects that HII regions have on background polarization. Hereby SNRs, being the dominant source of synchrotron emission along their line of sight, probe a PH caused by turbulent magnetic fields, while HII regions, not being synchrotron emitters themselves, probe the depth depolarization of the smooth, large-scale synchrotron emission of the Galaxy.
All SNRs and HII regions, that have reliable distance information, are displayed in the Figure (right) with their polarization characteristics indicated.
All SNRs except for those behind Cygnus X and W 80 and those along the line of sight through Sagittarius arm (behind Sagittarus arm) are polarized. This indicates that beam depolarization by turbulent fields is not significant in the general ISM, only in HII regions and when the line of sight through a spiral arm is very long and along its embedded field. This leads to a SNR polarization window between Galactic longitudes of 57° and 77° in which SNRs at more than 12 kpc are still polarized.
For HII regions there is a tendency that the PH becomes more distant with Galactic Longitude. That is to be expected, since HII regions are mostly affected by depth depolarization and the angle between the line of sight and the large-scale magnetic field becomes smaller with lower longitudes. Therefore no HII regions are "polarized" in the SNR polarization window.
(Kothes, Landecker, Brown, & Ordog, in prep.)