The International Galactic Plane Survey (IGPS)

A Comprehensive View of the Galactic Interstellar Medium

Charles Kerton - NRC Canada - HIA - DRAO
The structure and evolution of a galaxy is controlled by the interplay between stars and the interstellar medium. The "ecosystem" of a galaxy includes processes such as infall from extragalactic space, supernovae and stellar winds disrupting and enriching with heavy elements, ultra-violet radiation, conversion to molecular clouds, and the formation of stars. Processes like disruption, tidal forces, shocks, young stellar outflows, and mass irretrievably locked up lead to low-mass stars, stellar remnants, black holes, and neutron stars.
The Milky Way Galaxy is the only galaxy close enough to see the details of the Galactic Ecosystem

Challenges

• The large angular size of the Galaxy
  - *A large area of sky must be observed*

• The Galaxy is a 3-dimensional object projected onto 2-dimensions
  - *Must untangle the third dimension*

• High angular resolution required to see details in larger context
  - *A very large database is required*

• Range of wavelengths required to observe all of the major ISM components
  - *Several different telescopes & techniques are required*
The International Galactic Plane Survey Consortium

**Canadian Universities**
- University of Calgary
- University of Alberta
- University of British Columbia
- University of Toronto
- University of Montreal
- University of Waterloo
- Queen’s University
- Université Laval
- University of Western Ontario
- University of Manitoba
- St Mary’s University

**International Organizations**
- California Institute of Technology
- University of California, Berkeley
- Five College Radio Astronomy Observatory
- University of New Mexico
- Cambridge University
- Hamburger Sternwarte
- Onsala Space Observatory
- University of Minnesota
- Harvard University
- University of Sydney
- Max Planck Institut fur Radioastronomie
- National Radio Astronomy Observatory

**NRC of Canada, Herzberg Institute of Astrophysics**
- Dominion Radio Astrophysical Observatory
- Canadian Astronomy Data Centre
Data from these telescopes are currently being obtained to construct a HI line and 1420 MHz continuum survey of almost the entire Galactic Plane.
International Galactic Plane Survey

cm-wavelength surveys:
CGPS I & II
VGPS
SGPS
IGPS – other surveys

Data from the cm-wavelength surveys are currently being combined with data from mm and infrared surveys.

FCRAO Outer Galaxy Survey
$^{12}\text{CO}$ – molecular gas

BU-FCRAO Galactic Ring Survey
$^{13}\text{CO}$ – molecular gas
IGPS – other surveys

**Midcourse Space Experiment**
Mid-infrared (8 microns) – PAH, hot dust

**IRAS – HIRES Processed Maps**
mid and far infrared data - dust
International Galactic Plane Survey

Northern Hemisphere HI and CO Surveys

- CGPS 2 Longitude Extension
- VGPS (phase I)
- Leiden/Dwingeloo HI Survey; \((l,b)\) total HI
- HI
- CO
- FCRAO OGS
- BU-FCRAO GRS
- Onsala CO Survey
The CGPS I Data Base

All data sets are at ~1 arcminute resolution.

A 73° x 9° section of the Galaxy has been observed and data are now available.

$74.2^\circ < l < 147.3^\circ$

$-3.6^\circ < b < 5.6^\circ$
Data from the various surveys included in the CGPS are processed at DRAO in Penticton and at the University of Calgary.

Data are registered to a common coordinate grid and made available to users in the form of overlapping 5 x 5 degree mosaics.
# DRAO Survey Summary

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Sensitivity (1σ)</th>
<th>Resolution (‘)</th>
</tr>
</thead>
<tbody>
<tr>
<td>408 MHz</td>
<td>3 mJy/beam</td>
<td>3.5x3.5 cosec(δ)</td>
</tr>
<tr>
<td>1420 MHz</td>
<td>0.2 mJy/beam</td>
<td>1x1 cosec(δ)</td>
</tr>
<tr>
<td>(IQUV)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HI line</td>
<td>3 K</td>
<td>1x1 cosec(δ)</td>
</tr>
<tr>
<td>Δv = 0.82 km/s</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Short spacing data**

- 408 MHz - Haslam survey
- 1420 MHz - Effelsberg
- HI Line - DRAO 26m
Milky Way at Radio (21 cm)

Atomic hydrogen gas
The 1 arcminute resolution of the CGPS is crucial for the detailed interpretation of structures observed at 21 cm.

HI Image from a Single Antenna Radio Telescope ~ 30 arcminute resolution

25 m Radio Telescope, Dwingeloo
Netherlands Foundation for Radio Astronomy

10 degrees
The 1 arcminute resolution of the CGPS is crucial for the detailed interpretation of structures observed at 21 cm.

HI Image from an interferometer ~ 1 arcminute resolution

7 Element Interferometer, Penticton
Dominion Radio Astrophysical Observatory

Equivalent diameter equals 600 m

10 degrees
A 21cm mosaic in Cygnus: MM1
The common grid and resolution facilitates multiwavelength comparisons.

Stellar Birth and Death in Eastern Cygnus

2 degrees

Red: 74 cm
Green: 21 cm
Blue: Infrared
Cygnus radio/IR composite

Featured in July 2002 S&T
The W3/4/5 Region of the Perseus Arm

5 degrees

Composite Image: Hydrogen, Dust, and Ionised Gas
The CGPS is more than just spectacular images of the ISM.

- A population of newly formed intermediate-mass stars.
- A new technique for determining distances to molecular clouds.
- Studies of sequential star formation surrounding HII regions.
- Very old “merger-stage” SNR’s studied in HI emission.

IRAS 00556+6048 – a newly formed Intermediate-mass star (Kerton AJ, 124, 3449, 2002)
Embedded Intermediate Mass Stars

5 – 10 Msun stars (optically visible – HERBIG Ae/Be stars)
Disruption of molecular clouds due to photodissociation / winds
Boundary between high & low mass star formation

Observational Properties

Expected to form small weak HII regions
Can form large HI photodissociation regions – direct detection difficult
Expected to be a strong IR emitter
Embedded Intermediate Mass Stars – Search Technique

MSX – 8.3 μm

HI ON, OFF & ON-OFF Spectra
Embedded Intermediate Mass Stars – Search Technique

Integrated HI

CO Spectrum
Embedded Intermediate Mass Stars – Search Technique

Integrated CO

1420 MHz continuum
Embedded Intermediate Mass Stars – IR Colours
Embedded Intermediate Mass Stars – IR Colours
Embedded Intermediate Mass Stars – IR Colours + CO
Embedded Intermediate Mass Stars – IR Colours + CO + MSX
Embedded Intermediate Mass Stars – Final Sample

### Summary of IRAS Sample Subsets

<table>
<thead>
<tr>
<th>Sample</th>
<th>Objects</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>IRAS</em> ................</td>
<td>165</td>
<td>Objects meeting the <em>IRAS</em> color criteria</td>
</tr>
<tr>
<td><em>IRAS-CO</em> .............</td>
<td>148</td>
<td><em>IRAS</em> objects associated with CO</td>
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<tr>
<td><em>IRAS-CO-MSX</em> ........</td>
<td>100</td>
<td><em>IRAS-CO</em> objects with MSX5C source</td>
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<tr>
<td><em>IRAS-CO-LUM</em> ..........</td>
<td>110</td>
<td><em>IRAS-CO</em> objects with $L &gt; 10^{2.3} L_\odot$</td>
</tr>
<tr>
<td><em>IRAS-CO-LUM-MSX</em> .....</td>
<td>86</td>
<td><em>IRAS-CO</em> objects with MSX5C source and $L &gt; 10^{2.3} L_\odot$</td>
</tr>
</tbody>
</table>

Why so few directly detectable?

a) Confusion due to Galactic emission

b) Detectable HI zone is short-lived due to action of winds/outflows

To do: spectral classification

high resolution HI around Herbig Be stars

deep NIR (start with 2MASS)
Small HII Regions

KR 140 – Submm Mapping
KR 140 – Gravitational Stability
KR 140 – Column Density Threshold
Molecular Cloud Distances

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Molecular Cloud Distances = HII Region Distances

IC 1848 (W5)  \( d = 2.35 \text{ kpc} \)
Kinematic Distances

Double-valued in Inner Galaxy

Model Dependent

Non-circular Motions

R = 8.5 kpc  V = 220 km/s
A new cloud catalog has been created for the OGS
OGS Cloud Catalog

Step 1. - simple thresholding to define basic structure

Step 2. - modified CLUMPFIND applied to step 1 objects

Final catalog has data on 14595 objects
Size-Line Width Relation

Larson 1981

Brunt 2002
Angular Size-Line Width Relation

\[ \delta v \text{ - independent of distance} \]

Angular size - varies with distance
ASLW Plots
OGS Fields

23 complexes

Size & linewidth from cloud catalogue

Bisector fits $\log(s) = \log(s_0) + \kappa \log(\delta v)$
Cam OB 1

$-18 < V_{\text{lsr}} < -5$ km/s

$\sim 600$ clouds

d = 0.8 +/- 0.3 kpc
ASLW - Local Complex

Cam OB 1

$\log(s) = 0.59 \quad \kappa = 1.26$
Sh 2 - 156

-60 < V_{lsr} < -35 \text{ km/s}

\sim 75 \text{ clouds}

d = 6.4 +/- 2 \text{ kpc}
ASLW - Distant Complex

Sh 2 - 156

\[ \log(s) = 0.29 \quad \kappa = 1.04 \]
HII Region Calibration

\[ \log(D) = 1.418 - 2.7 \log(s) \]
HII Region Calibration
Comparison with HII Region Distances

![Graph comparing $V_{lsr}$ (km/s) vs. $D$ (kpc)]
14 cloud complexes identified in the region:

$$39.9 < l < 44.1 \quad -0.54 < b < 0.53 \quad -5 < V_{\text{lsr}} < 80 \text{ km/s}$$

Calibrated using W49 (11.4+/- 1.2 kpc) and OGS slope
ASLW Plots
GRS Fields

Size & linewidth from cloud finding algorithm
GRS Distances
Conclusions

Distances derived using the ASLW relation are consistent with expected local cloud velocities and known non-circular motions in the Perseus Arm.

Future applications include Galactic structure studies using CGPS II and GRS data, and the determination of distances to far outer Galaxy molecular clouds.
Positive Intermediate Velocity Gas in the Canadian Galactic Plane Survey

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Lewis B. G. Knee
Lloyd Higgs

NRC Canada - HIA - DRAO
Deviation Velocity

\[ V_{\text{dev}} = V_{\text{lsr}} - V_{\text{max}} \]

\[ V_{\text{max}} + 10 < V_{\text{dev}} < 50 \text{ km/s} \]

CGPS Velocity Coverage

\[ -150 < V_{\text{lsr}} < 50 \text{ km/s} \]

Positive Intermediate Velocities

\[ b = -2.8 \]

LRDS (Higgs & Tapping 2000 AJ 120, 2471)
IVC G 92.0-3.5+50

Visible in Leiden/Dwingeloo

Not found in previous HVC catalogues

Not in Braun & Burton studies of isolated compact HVCs


58D pc x 9D pc
IVC G 92.0-3.5+50
IVC G 92.0-3.5+50

- ZOAG 092.11-3.91
- Variable continuum source
- B9 Ia star - LS III+46 64

- No IRAS features
- No CO in correct V range
- No large-scale continuum feature

+65.2 to +32.2 km/s
IVC G 92.0-3.5+50

“Shock-like” morphology

“HVC-like” structure

+65.2 to +32.2 km/s
IVC G 92.0-3.5+50

$\Delta V \sim 4-8 \text{ km/s}$

$T_b \sim 4-7 \text{ K}$

$\sim 4 \text{ arcmin scale (1.2D pc)}$
ICV G 92.0-3.5+50

Extragalactic Object - very large, little velocity structure

Galactic Halo Infall - unlikely due to positive $V_{\text{dev}}$

Distant Galactic
- HI cavity at -67 km/s ($d_{\text{kin}} \sim 8.5$ kpc)
- $E_{\text{kin}} \sim 1.4 \times 10^{51}$ ergs

Close Galactic
- no non-thermal SNR emission
- $E_{\text{kin}} \sim 3.5 \times 10^{48} D^2$ ergs
Other IGPS Projects

• disk-halo interactions in our Galaxy

• Magnetic field structure of our Galaxy

• Detection and analysis of new SNR

• Interpretation of continuum polarization images

• Identification of variable compact radio sources

• HI power spectrum and morphological analysis
Summary

• The IGPS is an unprecedented database for galactic studies
• All components at high angular resolution
• High spatial dynamic range -- there are ISM components that can only be seen with high resolution over large areas
• Wide range of scientific projects possible using entirely IGPS data or using IGPS data as a starting point

www.ras.ucalgary.ca/IGPS
cadcwww.hia.nrc.ca