Spectroscopic Observations of Bolocam Galactic Plane Survey Clumps

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The Bolocam Galactic Plane Survey (BGPS)

- 170 sq. deg.
- 1.1mm continuum
- 1 deg high strip
- 10.4m CSO 33” resolution
- Complete 1st quadrant
- Selected regions of 2nd quadrant

**ALL DATA & CATALOGS RELEASED!**

Aguirre et al. 2011
Rosolowsky et al. 2010
What are the properties of these newly discovered sources?

- SIZE, MASS, LUMINOSITY
- ALL DEPENDS ON KNOWING DISTANCE!

Over 8400 sources detected!

Bolocam 1.1 mm
Why Dense Molecular Gas?

$V_{lsr}$ of BGPS clump
HHT Spectroscopic Survey of Dense Molecular Gas in the BGPS

Beam matched at 1mm to BGPS continuum Survey
Observing Dense Molecular Gas

HCO⁺

Density $\times 10^4$

Temperature

$\log_{10} N/\Delta v = 13.5$
ALMA Band 6 (1mm) Prototype Receiver

**HCO⁺ 3-2 LSB**

- H\textsubscript{pol}

- V\textsubscript{pol}

**N₂H⁺ 3-2 USB**

- H\textsubscript{pol}

- V\textsubscript{pol}
HCO$^+$ vs. N$_2$H$^+$ Chemistry

- HCO$^+$ formed in gas phase from CO
  - $\text{H}_3^+ + \text{CO} \rightarrow \text{HCO}^+ + \text{H}_2$

- CO Freezes out of gas phase at low T

- N$_2$H$^+$ destroyed in gas phase by CO – abundant in cold dense regions
  - $\text{N}_2\text{H}^+ + \text{CO} \rightarrow \text{HCO}^+ + \text{N}_2$
Molecular Emission Maps

HCO$^+$ 3-2

N$_2$H$^+$ 3-2

Battersby et al. 2010
Initially Observed 1882 Sources

Schlingman et al. 2011
Detection Statistics

HCO\(^+\) Detection Statistics (1882 Sources)

- Single Detection: 59.5%
- Multiple Detections: 2.1%
- Line Wing: 3.6%
- Self Absorption: 11.6%
- No Detection: 23.2%

Schlingman et al. 2011
Molecular Correlations

\[ \text{Slope} = 1.15 \pm 0.01 \]
\[ \rho_{\text{Spearman}} = 0.80 \]

1 mm Flux

HCO$^+$ Detection
HCO$^+$ Upper Limit

Schlingman et al. 2011
$N_2H^+ / HCO^+$ - No Correlation

Shirley et al. in prep.

1 mm Flux
Tracing Spiral Arms in Dense Gas

Schlingman et al. 2011
Initially Resolving Distance Ambiguity

Association w/

(1) VLBA parallax
(2) Known region
(3) Tangent point
(4) IRDC assoc.

Total N~ 630

Schlingman et al. 2011
Typical Size = “Clumps”

R ~ 0.75 pc

Schlingman et al. 2011
Breakdown of Linewidth-Size Relation

\[ \rho_{\text{Spearman}} = 0.40 \]

(a)

\[ \Delta v \text{ km s}^{-1} \]

\[ \text{Radius (pc)} \]
Differential Mass Histogram

Compressible turbulent fragmentation:
\[ \frac{dN}{d\log M} = M^{-(1-(n-3/3))} \sim M^{-0.78} \]
for Kolmogorov (see Hennebelle+)

\[ \frac{dN}{d\log M} \sim M^{-\alpha} \]
\[ \alpha \sim 0.8 \]

Schlingman et al. 2011
Monte Carlo Simulations of $T_d$ variation

GBT NH$_3$ observations favor $T_k \sim 15$ K

Schlingman et al. 2011
GBT Ammonia Survey

Galactocentric Radius

Dunham et al. 2011b
Conclusions – Initial Analysis

• ¼ of BGPS sources observed – HCO$^+$ excellent unique dense gas tracer
  • Large variation in N$_2$H$^+/\text{HCO}^+$ ratio, but no significant trend with 1.1 mm flux
• Typical clump size (median) $\sim$ 0.75 pc, mass $\sim$ 300 $M_{\odot}$, $n \sim 2000$ cm$^{-3}$, and $\Sigma \sim 0.02$ g cm$^{-2}$
• Size-linewidth relationship breaks down
  • Linewidth dominated by supersonic turbulence
• $dN/d(\log M) \sim M^{-0.8}$
• Median Free-fall time $\sim 750,000$ yrs

Schlingman et al. 2011
A probabilistic approach to resolving the distance ambiguity

Bowes et al. 2012 in prep.
Full Spectroscopic Catalog: Over 6300 sources observed!
Future Plans – Analyzing BGPS

- Completed HHT observations of over 6300 BGPS sources $l > 7.5$ deg (Shirley et al.)
  - Catalog publically released Fall 2012 – ask Yancy if need in advance
- Release of v2.0 BGPS images and catalog by Ginsburg et al. Fall 2012
- Bowers et al. developing probabilistic method for distance ambiguity resolution to be applied to all BGPS source.
- Ultimately compare BGPS source properties with Galactic environment and evolutionary indicators
Embedded IR Sources

Identifying a pop. of starless clumps

Dunham et al. 2011a
Clump Mass with/without IR Sources

Dunham et al. 2011
L’ correlates well with Mass

Schenck et al. 2011