Physical Conditions of High-Mass Star-Forming Clumps in the BGPS

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Summary

Aims

High-mass stars play a key role in the physical and chemical evolution of the interstellar medium, yet the evolutionary sequence for high mass star forming regions is poorly understood. Recent Galactic plane surveys are providing the first systematic view of high-mass star-forming regions in all evolutionary phases across the Milky Way.

Observations

We present observations of the 22.23 GHz H_2O maser J(K_a,K_c) = 6(1,6)→5(2,3) transition toward **1398** clumps identified in the BGPS using the GBT. We detect **392** H_2O masers, **279** (71%) newly discovered. We simultaneously observe NH3 (1,1), (2,2), and (3,3) to derive T_K measurements.

We compare the physical properties of the clumps in the BGPS with observational diagnostics of star formation activity: *8 and 24 um emission, H_2O and CH_3OH maser emission, EGOs, and UCHII regions* (see survey list below).

Methods

We apply Monte Carlo sampling to *Distance Probability Distribution Functions* in order to marginalize distance and resolve the *Kinematic Distance Ambiguity* probabilistically. We then calculate distributions for derived properties for clumps in different evolutionary stages. We apply a neighbor matching system to apply DPDFs to neighboring clumps and increase the number of resolved KDAs by 30%.

Results

H_2O masers can identify the presence of protostars which were not previously identified by Spitzer/MSX Galactic plane infrared surveys: *25% of IR-dark clumps have an H_2O maser*.

Sub-sample of **400** clumps found with no star formation indicators, the largest sample of *Starless/Deeply-Embedded* clumps from an unbiased survey to date.

Evolutionary stages show s*trong separations* in Δv(HCO^+), I(HCO^+), Σ(H_2), and T_K. Marginalizing distance, Surface Area and M_{dust} show weak separations above > 2 pc^2 and > 3×10^3 M_{sol}.

Breakdown in size-linewidth relationship with no differentiation by evolutionary stage.

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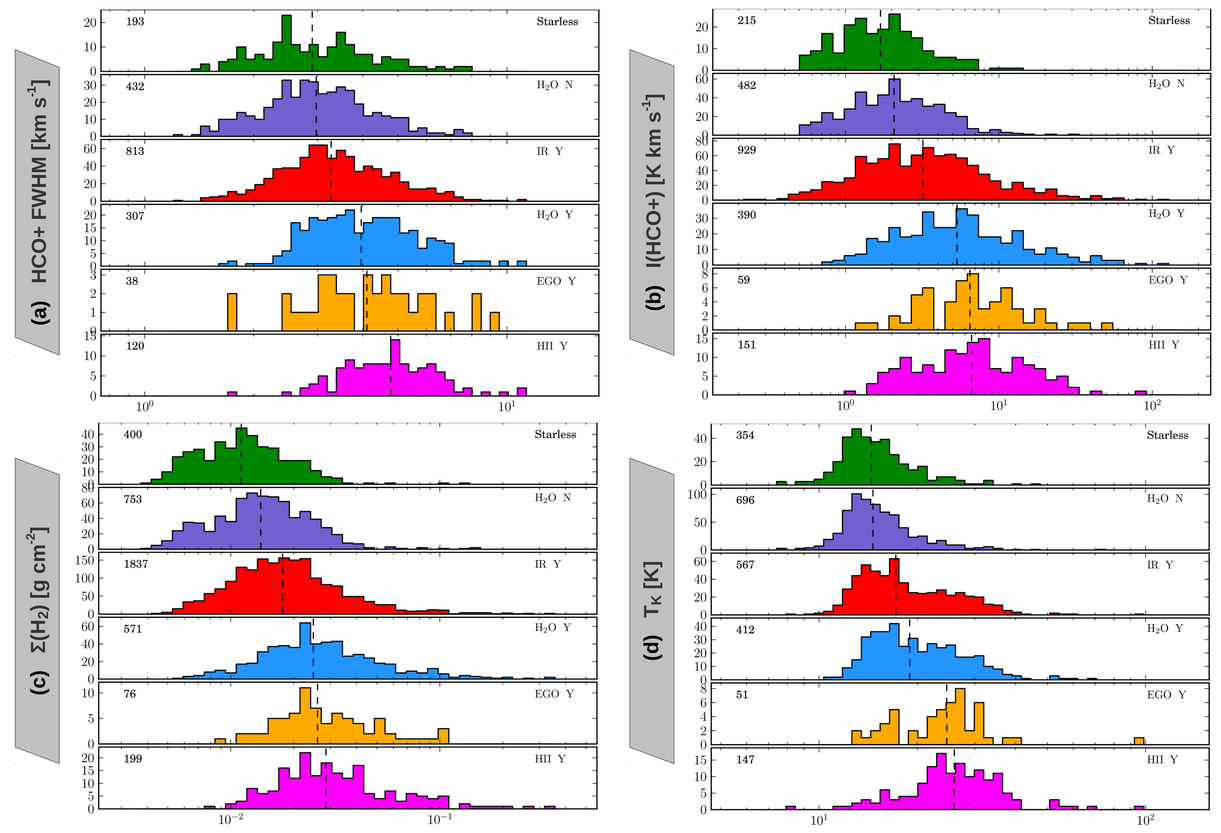
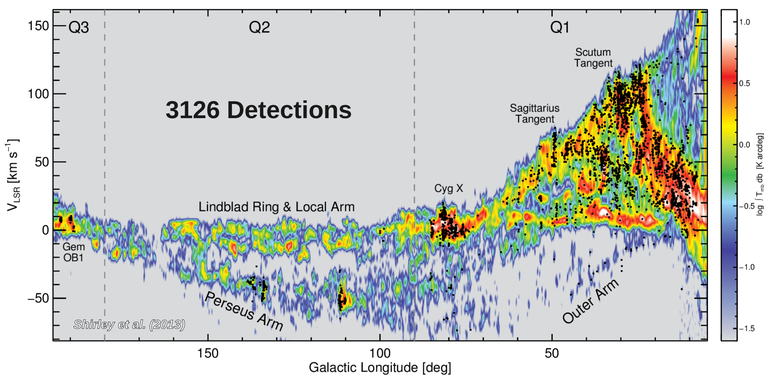
Future work includes adding evolutionary indicators (MIPSGAL, HiGal, MMB) and expanding DPDF priors (HI self-absorption, Galactic structure) to expand well-resolved KDAs.

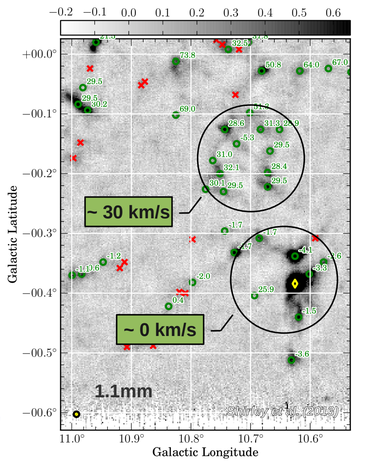
Distance-Independent Results



F5 Distance independent and observed properties of BGPS Molecular Cloud Clumps associated with evolutionary indicators: Starless/Deeply-Embedded, H_2O No, IR Yes, H_2O Yes, EGO Yes, UCHII Yes. The categories are not mutually exclusive. Trends are observed in nearly all observed and derived clump properties. The **(a)** HCO^+ linewidth, **(b)** HCO+ integrated intensity, **(c)** mass surface density, and **(d)** kinetic temperature all show strong separations by evolutionary stage.

BGPS HCO^+ / $N2H^+$ Kinematic Survey





F1 The *Bolocam Galactic Plane Survey* (BGPS) HCO^+ / N_2H^+ Kinematic Survey has observed the complete v1.0.1 catalog of **6194** *Molecular Cloud Clumps* ("clumps") between 7.5° < lon < 193°: the largest such targeted, kinematic survey (Shirley et al. 2013). These velocities provide the requisite data to calculate clump *distances* and *physical quantities*.

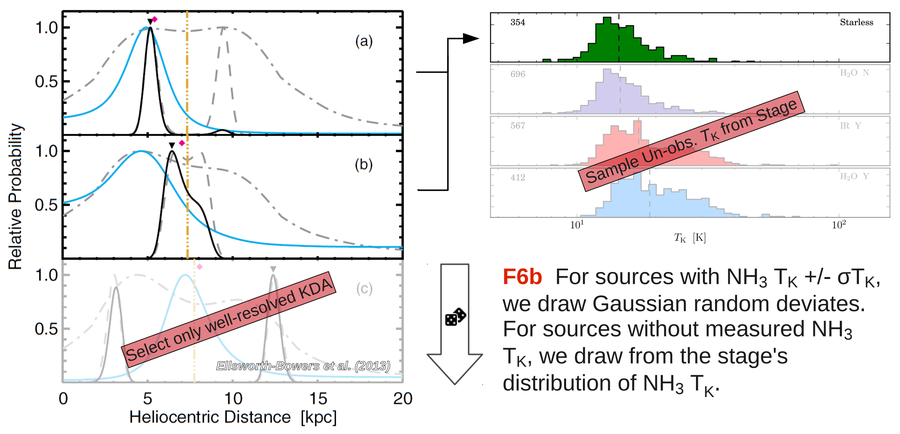
○ **Detection** ✕ **Non-detection**

Monte Carlo Sampling

We resolve the *Kinematic Distance Ambiguity* (KDA) using Bayesian priors from Ellsworth-Bowers et al. (2013) which include:

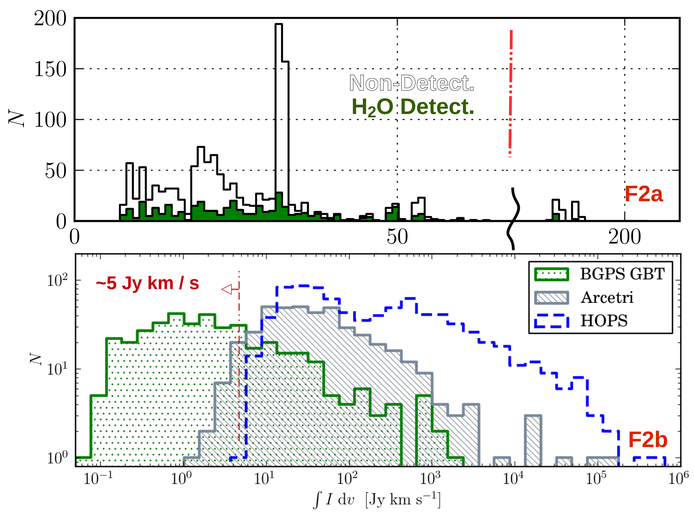
- 8 um Absorption Morphological Matching
- H_2 Wolfire et al. Model

We Monte Carlo sample the resultant posteriors or *Distance Probability Distribution Functions* (**F6a**; DPDFs), to marginalize distance for *dust mass*, *size*, and *surface area* calculations.



F6b For sources with NH_3 T_K +/- σT_K, we draw Gaussian random deviates. For sources without measured NH_3 T_K, we draw from the stage's distribution of NH_3 T_K.

BGPS GBT Water Maser & Ammonia Survey



Total Observations: **1398** in 22.23 GHz H_2O & NH_3

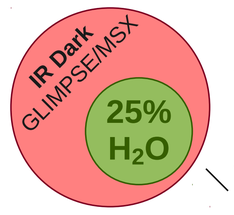
Lon. **7.5-65.0°**, **188-193°**

Detections: **392** (28%)

Discoveries: **279** (71%)

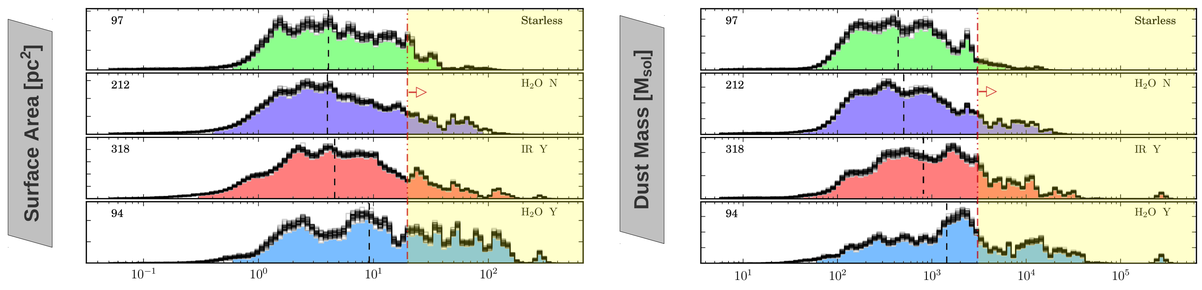
5× Detection rate of HOPS towards BGPS clumps

Representative sample of H_2O masers towards high-mass SFR.

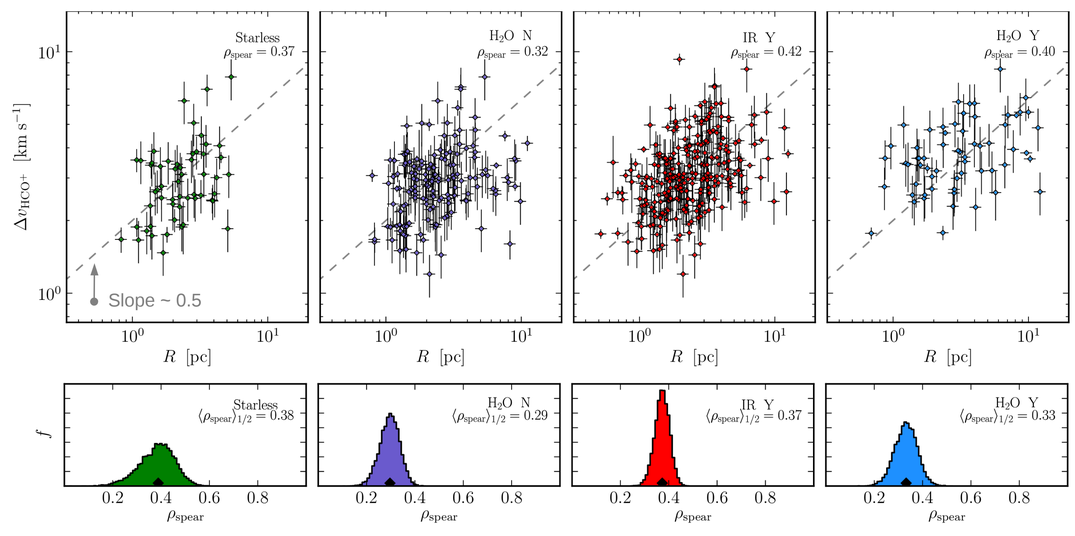


***25%** of clumps IR-Dark in GLIMPSE/MSX have a H_2O detection (**146**).*

Distance-Marginalized Results



F7 The majority of clumps occupy the same parameter space of surface areas and dust masses regardless of evolutionary stage. For an upper tail approximately **> 2 pc^2** and **> 3×10^3 M_{sol}** we find that Starless/Deeply-Embedded clumps are *more frequently smaller and less massive* than H_2O Yes clumps.

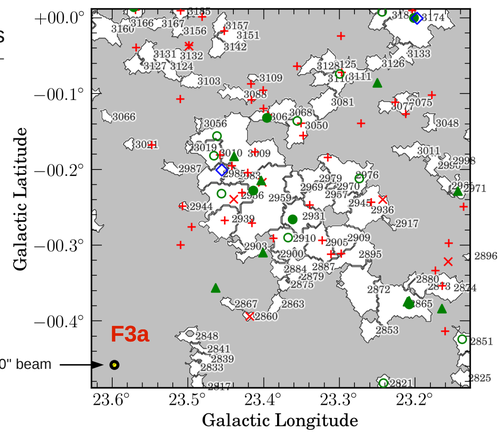


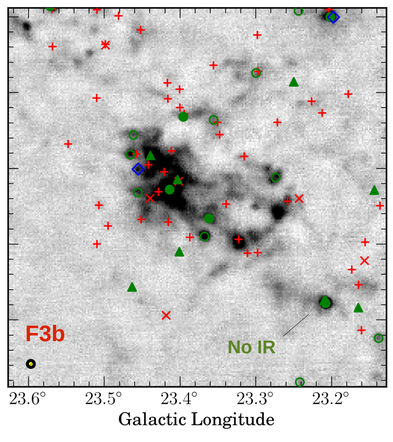
F8 Breakdown of size-linewidth relationship R vs. Δv(HCO^+) at observed smaller size scales and higher densities probed by HCO^+. The correlation does not improve when moving to younger evolutionary stages without internal feedback sources. Larson's Law with slope 0.5 is visualized and not a fit. We compute distributions of Spearman rank correlation-coefficients marginalizing over distance, showing FWHM approximately 0.1-0.2.

Evolutionary Stages and Sign-Posts of Star Formation

Evolutionary Indicators

- HII — CORNISH
- EGO — 4.6 um Outflow
- IR — Red Spitzer IRAC
- IR — Red MSX
- H_2O — GBT N
- H_2O — GBT Y
- H_2O — Arcetri/Hops/RMS
- CH_3OH — MMB



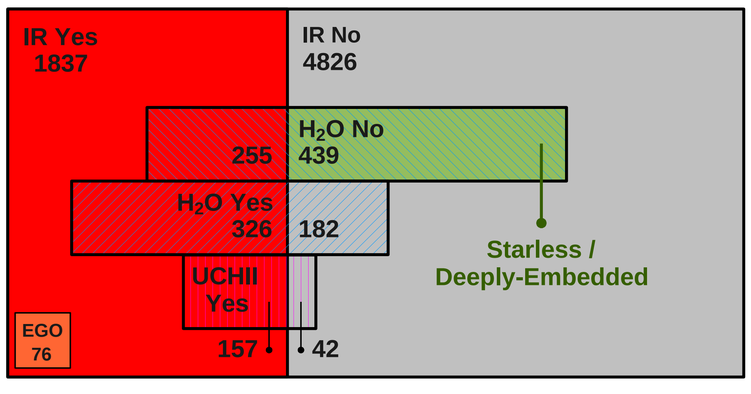


Evolutionary Stages

F3 We match available observations of star-formation indicators to BGPS clumps based on the label-mask returned by Bolocat. This more accureately accounts for a clumps extended structure.

F4 Categorization by evolutionary indicators into "evolutionary stages" are not mutually exclusive. The stages are ordered with the proposed evolutionary sequence by Battersby et al. (2010) in mind.

Starless / Deeply-Embedded → H_2O No → IR Yes → H_2O Yes → EGO Yes → HII Yes



Future Work

1. Include additional evolutionary indicators to differentiate stages and reveal deeply-embedded protostellar sources.
   - MIPSGAL 24 um
   - HiGAL 70 um
   - MMB CH_3OH
   - Shocked H_2
   - Broad SiO or Chem.
2. Increase the number of sources with well-constrained DPDFs in order to more robustly calculate derived clump properties: add and expand DPDF priors.
   - HI absorption
   - Galactic struct.
   - Dendrogram analysis and broadcasting

Acknowledgments:

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