RAMPS: The Radio Ammonia Mid-Plane Survey

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Collaborators

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Why is high-mass star formation important?

- Dominate the energetic input and chemical enrichment into the interstellar medium (ISM)
- Disrupt surrounding medium through outflows, H II regions, and supernovae
- ISM chemistry and kinematics is driven by the life cycle of high-mass stars

Credit: GLIMPSE/MIPSGAL
High-Mass Star Formation

Molecular clump (M ~ 200–5,000 M☉, R ~ 1 pc)
High-Mass Star Formation

Collapse of pre-stellar cores ($M \geq 1 \, M_\odot$, $R \sim 0.05 \, \text{pc}$)
High-Mass Star Formation

Cores collapse into protostars
High-Mass Star Formation

Protostars launch outflows

Credit: ALMA Observatory
High-Mass Star Formation

Begin fusion, ionize surrounding material
High-Mass Star Formation

H II regions expand and disrupt surrounding clump
High-Mass Star Formation

Supernovae inject turbulence into ISM
Early stages are hard to observe:
- Rare
- Form quickly
- Form within opaque gas and dust
Open Questions

• How do cluster-forming clumps evolve?
• How does gas flow along filaments?
• What is the distribution of high-mass star formation in the Galaxy?
• How does maser activity in star-forming regions evolve?
Continuum Surveys of the Galactic Plane

- 1.1 mm Bolocam Galactic Plane Survey (BGPS)
- 870 μm Apex Telescope Large Area Survey of the Galaxy (ATLASGAL)
- 70-500 μm *Herschel* Infrared Galactic Plane Survey (HiGAL)

ATLASGAL: Schuller, Menten, Contreras et al. 2009
Limitations of Continuum Surveys

- Blending of emission along line of sight
- Uncertain assumptions used to derive dust temperatures and column densities
- No kinematic information
- Unknown distances, thus size, mass, luminosity, and Galactic position are also unknown

ATLASGAL: Schuller, Menten, Contreras et al. 2009
RAMPS

- Molecular line survey of Galactic mid-plane
- Uses the Green Bank Telescope (GBT)
- Primary lines are $\text{NH}_3$ inversion lines and an $\text{H}_2\text{O}$ maser line
Advantages of NH$_3$

- Brightness ratios robustly indicate gas temperature
- Hyperfine lines are sensitive to optical depth
- Traces dense gas (~ $10^4$ cm$^{-3}$)
- Velocity yields kinematic distances and reveals internal motions

NH$_3$ inversion spectra of a dense molecular clump
Advantages of NH$_3$

- Brightness ratios robustly indicate gas temperature
- Hyperfine lines are sensitive to optical depth
- Traces dense gas (~ $10^4$ cm$^{-3}$)
- Velocity yields kinematic distances and reveals internal motions
Advantages of NH$_3$

- Main line brightness ratios robustly indicate gas temperature
- **Hyperfine lines are sensitive to optical depth**
- Traces dense gas ($\sim 10^4$ cm$^{-3}$)
- Velocity yields kinematic distances and reveals internal motions

Gives $\tau$
Advantages of NH₃

- Brightness ratios robustly indicate gas temperature
- Hyperfine lines are sensitive to optical depth
- **Traces dense gas (~ 10⁴ cm⁻³)**
- Velocity yields kinematic distances and reveals internal motions
Advantages of NH$_3$

- Brightness ratios robustly indicate gas temperature
- Hyperfine lines are sensitive to optical depth
- Traces dense gas (~10$^4$ cm$^{-3}$)
- **Velocity yields kinematic distances and reveals internal motions**
Advantages of H₂O Masers

Microwave Amplification by Stimulated Emission of Radiation

Credit: mwit.ac.th/~physicslab/hbase/mod5.html
Advantages of H$_2$O Masers

- Traces regions of active star formation
- Used to measure distances to star-forming regions across the Galaxy through parallax
- Associated with Asymptotic Giant Branch (AGB) stars
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Choi et al. 2014
RAMPS

- High density gas
- Gas temperature
- NH$_3$ column density
- Linewidths (turbulence)
- Kinematics (ordered flows)
- Kinematic distances

Credit: bonappetit.com
### RAMPS

- **20 deg² molecular line survey of Galactic mid-plane in 1ˢᵗ Quadrant**
- **Mapping in 13 lines**
- **NH₃ inversion transitions and H₂O maser line are most important**
- **Additional lines are CH₃OH maser lines and several high density tracers**

<table>
<thead>
<tr>
<th>Molecule</th>
<th>Transition</th>
<th>Frequency [MHz]</th>
<th>$E_{\text{upper}}/k$</th>
<th>Number of Receivers</th>
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<tbody>
<tr>
<td>NH₃</td>
<td>(J,K) = (1,1)</td>
<td>23694.47</td>
<td>23</td>
<td>7</td>
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<td>NH₃</td>
<td>(J,K) = (2,2)</td>
<td>23722.60</td>
<td>64</td>
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<td>NH₃</td>
<td>(J,K) = (3,3)</td>
<td>23870.08</td>
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<td>7</td>
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<tr>
<td>NH₃</td>
<td>(J,K) = (4,4)</td>
<td>24139.35</td>
<td>201</td>
<td>7</td>
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<tr>
<td>NH₃</td>
<td>(J,K) = (5,5)</td>
<td>24532.92</td>
<td>295</td>
<td>7</td>
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<tr>
<td>CH₃OH</td>
<td>$J_Kp = 10_1 - 9_2 \ A^-$</td>
<td>23444.78</td>
<td>143</td>
<td>7</td>
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<tr>
<td>HC₅N</td>
<td>$J = 9 - 8$</td>
<td>23963.90</td>
<td>6</td>
<td>7</td>
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<tr>
<td>HC₅N</td>
<td>$J = 8 - 7$</td>
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<td>5</td>
<td>1</td>
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<tr>
<td>HC₇N</td>
<td>$J = 19 - 18$</td>
<td>21431.93</td>
<td>10</td>
<td>1</td>
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<tr>
<td>CH₃OH</td>
<td>$J_Kp = 12_2 - 11_1 \ A^-$</td>
<td>21550.34</td>
<td>479</td>
<td>1</td>
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<td>HNCO</td>
<td>$J(K_p, K_o) = 1(0,1) - 0(0,0)$</td>
<td>21981.57</td>
<td>1</td>
<td>1</td>
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<tr>
<td>H₂O</td>
<td>$J(K_p, K_o) = 6(1,6) - 5(2,3)$</td>
<td>22235.08</td>
<td>644</td>
<td>1</td>
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<td>CCS</td>
<td>$J = 2 - 1$</td>
<td>22344.03</td>
<td>2</td>
<td>1</td>
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The Green Bank Telescope

• Large collecting area (100 meter dish)

• K-band Focal Plane Array (KFPA; 18-27.5 GHz) is a 7-element array

• VEGAS spectrometer has multi-line capabilities and works with receiver arrays

• Fast/sensitive K-band mapping ($T_{\text{rms}} \sim 0.15 \text{ K in 0.2 km/s channels}$), high spatial resolution (32” beam), and high spectral resolution (0.02 km/s)
Current Status

- RAMPS was allocated 210 hours of GBT time for a pilot study to test the feasibility of the project and to help commission the VEGAS spectrometer.
- Pilot survey completed (Hogge et al. 2018), mapped 6.5 deg².
- Allocated >400 hours to complete the survey.
- Use gbt-pipeline and gbtgridder software to reduce data, custom pipeline for processing.
- Data to be released publicly after verification at sites.bu.edu/ramps (only NH₃(1,1), (2,2), and H₂O pilot data currently available).
Results from RAMPS Pilot Survey

NH$_3$(1,1) integrated intensity map of RAMPS fields L23 and L24

Hogge et al. 2018
NH₃ Modeling with PySpecKit

**Fit Parameters**
- Temperature
- Column density
- Linewidth
- Velocity
- Filling Fraction

Hogge et al. 2018
Temperature

L23-24 Rotational Temperature

Hogge et al. 2018
Column Density

L23-24 NH3 Column Density

Hogge et al. 2018
Linewidth

Hogge et al. 2018
Filling Fraction

Hogge et al. 2018

L23-24 Filling Fraction

Galactic Latitude

Galactic Longitude

Hogge et al. 2018
Comparison with HOPS – NH$_3$

Hogge et al. 2018
• RAMPS detected 82 masers in L23-24, while HOPS detected 15.
• RAMPS detected 325 in 6.5 deg$^2$, HOPS detected 540 in 100 deg$^2$. 
Clump Evolution

- Classify evolutionary state with MIR images
- NH$_3$ data will give temperature, column density, and kinematics
- Look for trends as a function of evolutionary state
Classify with MIR Data

Quiescent

Protostellar

H II Region

Color is GLIMPSE and MIPSGAL 3.6 µm (blue), 8 µm (green), and 24 µm (red). Contours are RAMPS NH$_3$(1,1) integrated intensity.
NH$_3$ Rotational Temperature

Quiescent

Protostellar

H II Region

Temperature in K
NH$_3$ Column Density

Quiescent

Protostellar

H II Region

$10^{15}$ cm$^{-2}$

$10^{16}$ cm$^{-2}$
Linewidth

Quiescent Protostellar H II Region

km/s
Linewidth of G23.33-0.30 is ~20 km/s, 10 X larger than typical NH$_3$-emitting clumps. Rare NH$_3$(3,3) maser may be associated with high-mass star formation.
VLA data reveals multiple NH$_3$(3,3) masers - are they tracing outflows?

Hogge et al. (in prep)
NH₃ kinematics reveal velocity gradient across filament
SNR W41 interacting with 77 km/s filament?

Hogge et al. (in prep)
Is 60 km/s component accelerated gas?

Hogge et al. (in prep)
SMA and ACA detect cores: is the star formation process being triggered, inhibited, neither?

Hogge et al. (in prep)
Summary

• Many open questions, only partial answers from continuum surveys
• Molecular lines provide additional information, RAMPS and GBT offer significant improvements in mapping NH₃ and H₂O
• RAMPS pilot detected ~500 clumps and can measure temperature, column density, line width, and velocity
• Large surveys are critical for the study of high-mass star formation and allow for the discovery of rare and unique sources
• Publicly available RAMPS dataset will support many future scientific investigations
Questions?
Velocity Corresponds to Distance

L23-24 NH$_3$(1,1) Velocity Field