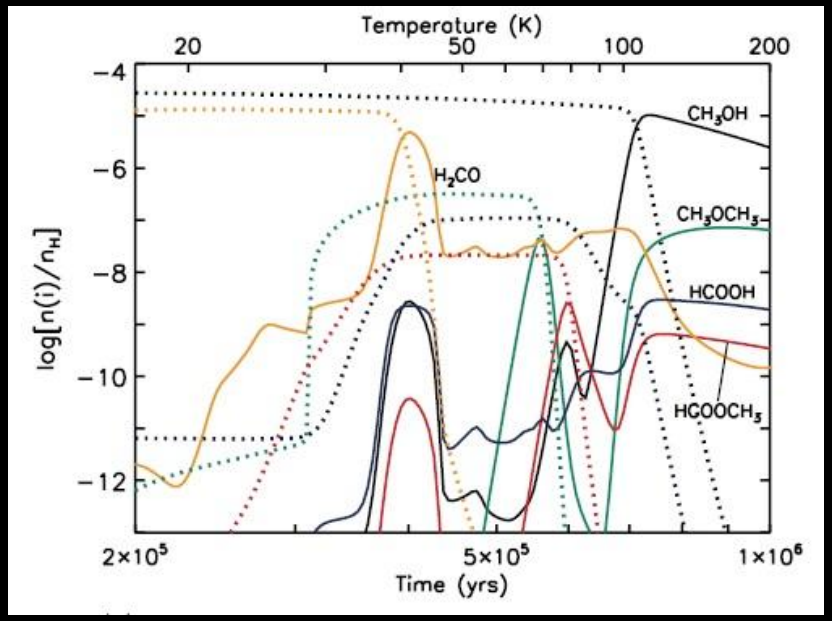
CSO BROADBAND MOLECULAR LINE SURVEYS II: INITIAL CORRELATION ANALYSIS RESULTS FOR COMPLEX ORGANIC MOLECULES

James L. Sanders, Mary L. Radhuber, Jacob C. Laas,
Brian M. Hays, Trevor N. Cross, Susanna L. Widicus Weaver
Department of Chemistry, Emory University, Atlanta, GA 303222
Darek C. Lis
Division of Physics, Mathematics, and Astronomy, California Institute of Technology, Pasadena, CA 91125

Unbiased Molecular Line Surveys

- Probe multiple transitions in a broad energy window and overlap multiple molecules
- Test models with complete chemical and physical understanding of sources and compare with observations
- Quantify formation pathways of complex organic species



Garrod, Widicus Weaver, Herbst, ApJ 2008

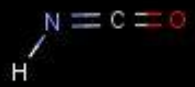
Molecular Targets

- Complex organic molecules (COMs) with specific functional groups that trace formation pathways and physical conditions
- Products of Gas Phase and Grain Surface Chemistry
- Initial constraints of formation pathways associated can be determined through these molecules

Dimethyl Ether

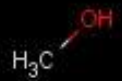
Ethanol

Ethyl Cyanide



Isocyanic Acid

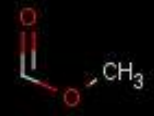
Sulfur Dioxide



Methanol

Methyl Cyanide

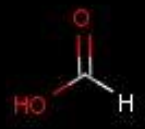
Formaldehyde



Methyl Formate

Glycolaldehyde

Vinyl Cyanide



Formic Acid

Grain Surface Radical Chemistry

$H_2O + h\nu \rightarrow OH + H$

$H_2O + h\nu \rightarrow H_2 + O$

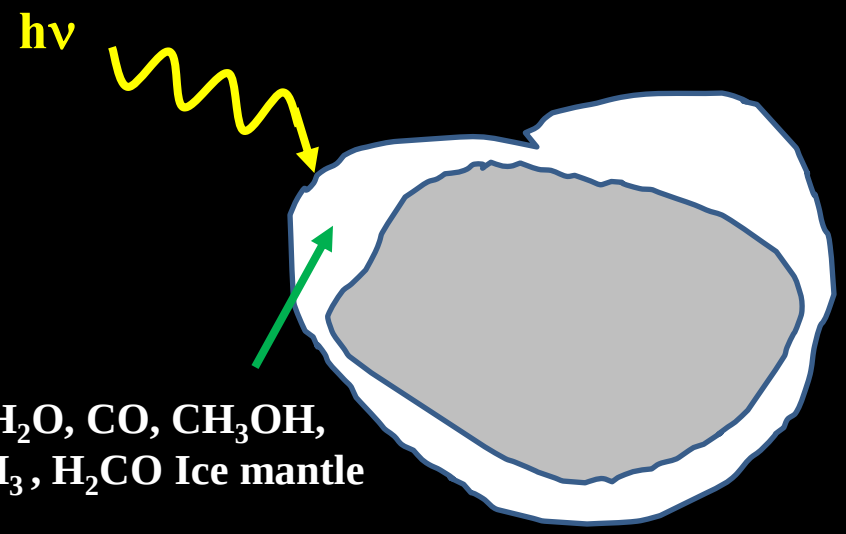
$CH_3OH + h\nu \rightarrow CH_3 + OH$

$CH_3OH + h\nu \rightarrow CH_3O + H$

$CH_3OH + h\nu \rightarrow CH_2OH + H$

$NH_3 + h\nu \rightarrow NH_2 + H$

$H_2CO + h\nu \rightarrow HCO + H$



$HCO + CH_2OH \rightarrow$	$HOCH_2CHO$	Glycolaldehyde
$HCO + CH_3O \rightarrow$	CH_3OCHO	Methyl Formate
$HCO + OH \rightarrow$	$HCOOH$	Formic Acid
$HCO + CH_3 \rightarrow$	CH_3CHO	Acetaldehyde
$HCO + NH_2 \rightarrow$	H_2NCHO	Formamide
$CH_3 + CH_3O \rightarrow$	CH_3OCH_3	Dimethyl Ether
$CH_3 + NH_2 \rightarrow$	CH_3NH_2	Methyl Amine
$CH_3 + CH_2OH \rightarrow$	CH_3CH_2OH	Ethanol
$CH_2OH + CH_2OH \rightarrow$	$HOCH_2CH_2OH$	Ethylene Glycol

Sources

- Shocked Regions, Hot Cores, Hot Corinos, Quiescent Clouds
- Integration to ~ 30 mK maximum, ~ 20 mK average , 1 MHz resolution
- Frequency Coverage Ranges from 30 GHz to 50 GHz for a total of 1.3 THz of spectral data

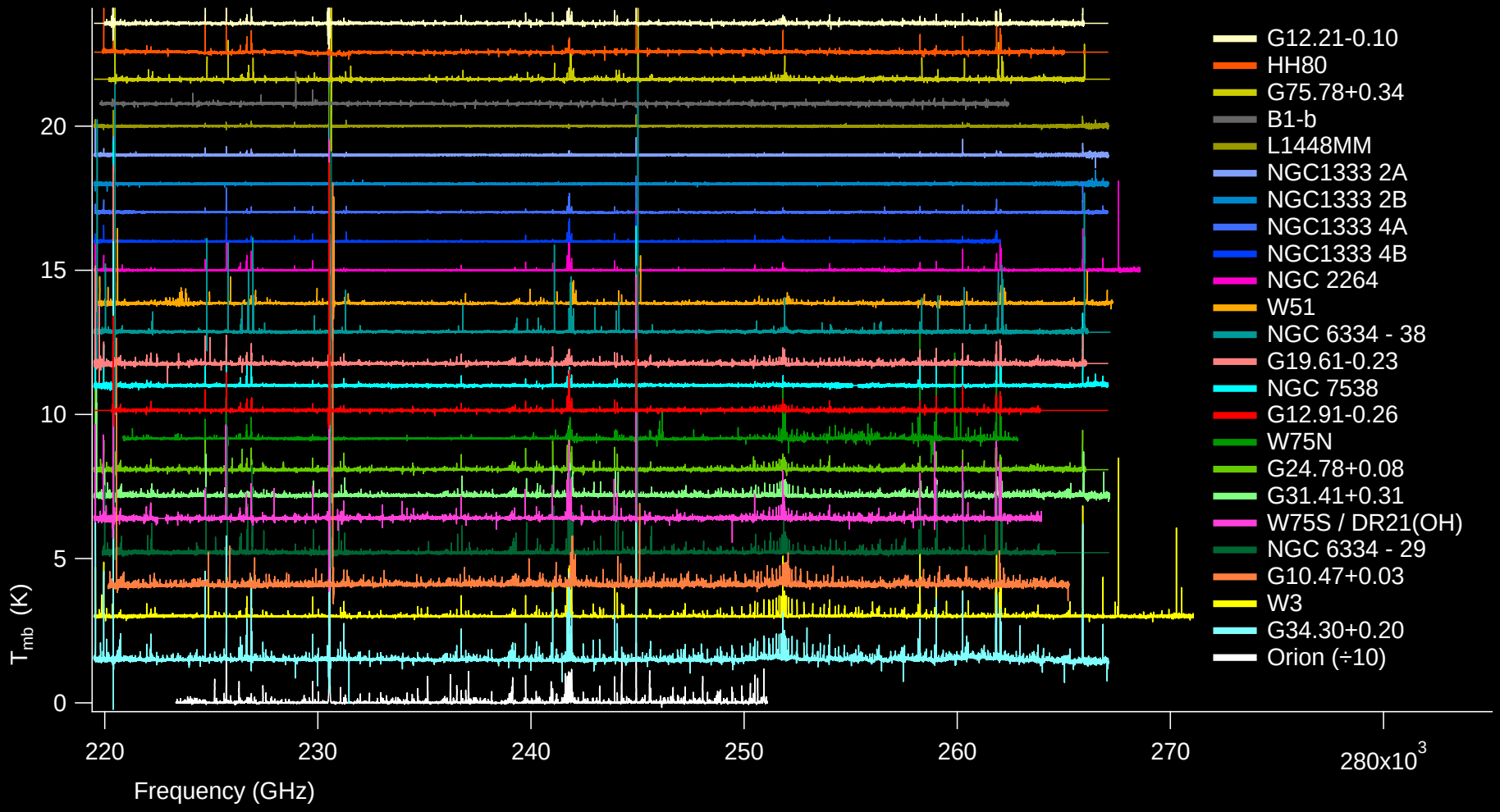
NGC1333 2A	NGC2264	G10.47+0.03	G34.30+0.20
NGC1333 2B	NGC7538	G12.21-0.10	G45.47+0.05
NGC1333 4A	B1-b	G12.91-0.26	G75.78+0.34
NGC1333 4B	L1448MM	G19.61-0.23	GCM +0.693-0.027
NGC6334-29	L1157	G24.33+0.11	W3
NGC6334-38	HH80	G24.78+0.08	W51
NGC6334-43	SgrB2NLMH	G29.96-0.02	W75N
NGC6334-IN	Orion	G31.41+0.31	DR21(OH)

New Receiver, New Results

- FFTS Spectrometer
- Auto Tuning
- Increases Scan Efficiency Drastically
- Processing Data
  - Deconvolve Double Side Band Spectra
  - Clean Spectra
  - Set Baselines

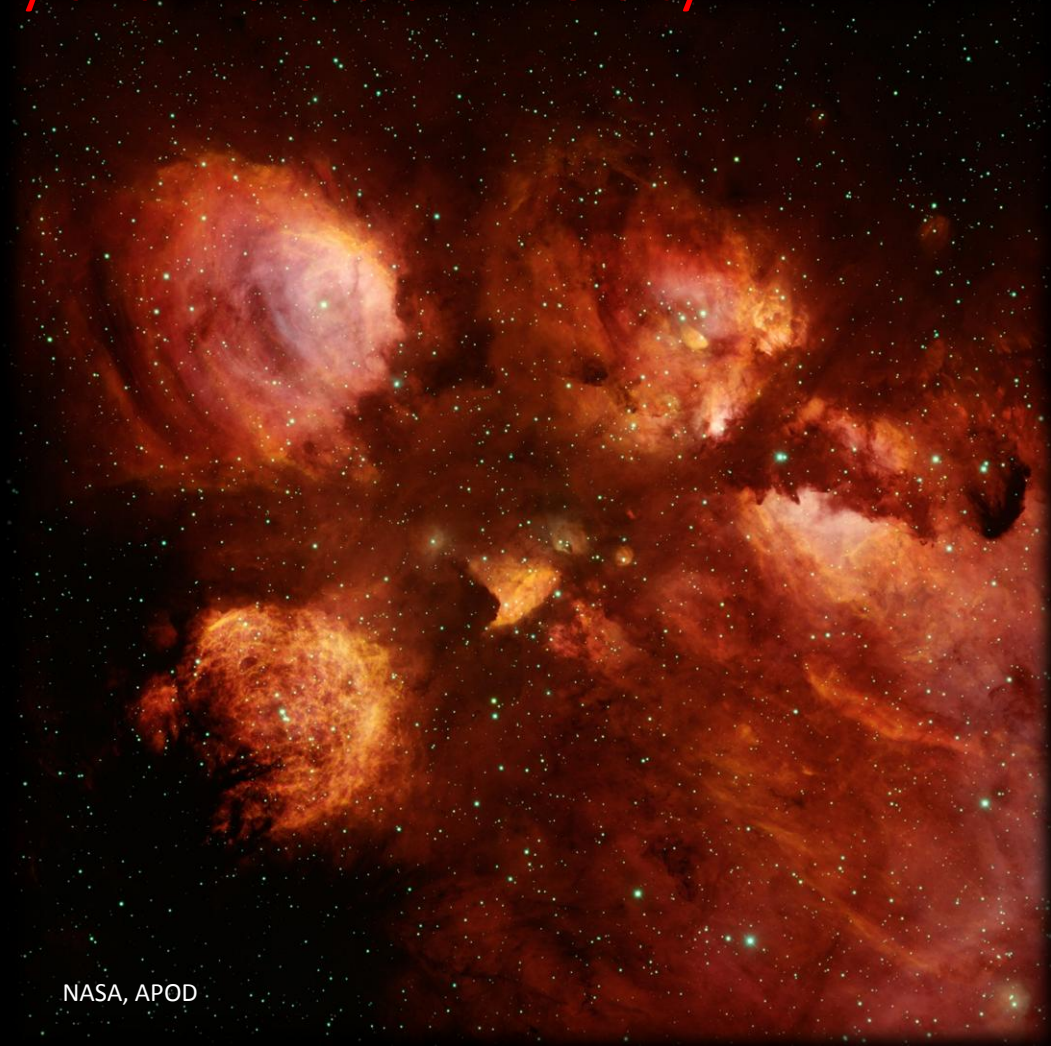
CSO Line Surveys

32 finished surveys: 16 analyzed, 8 being analyzed, 8 getting ready to be analyzed



Studying What Affects Chemical Diversity

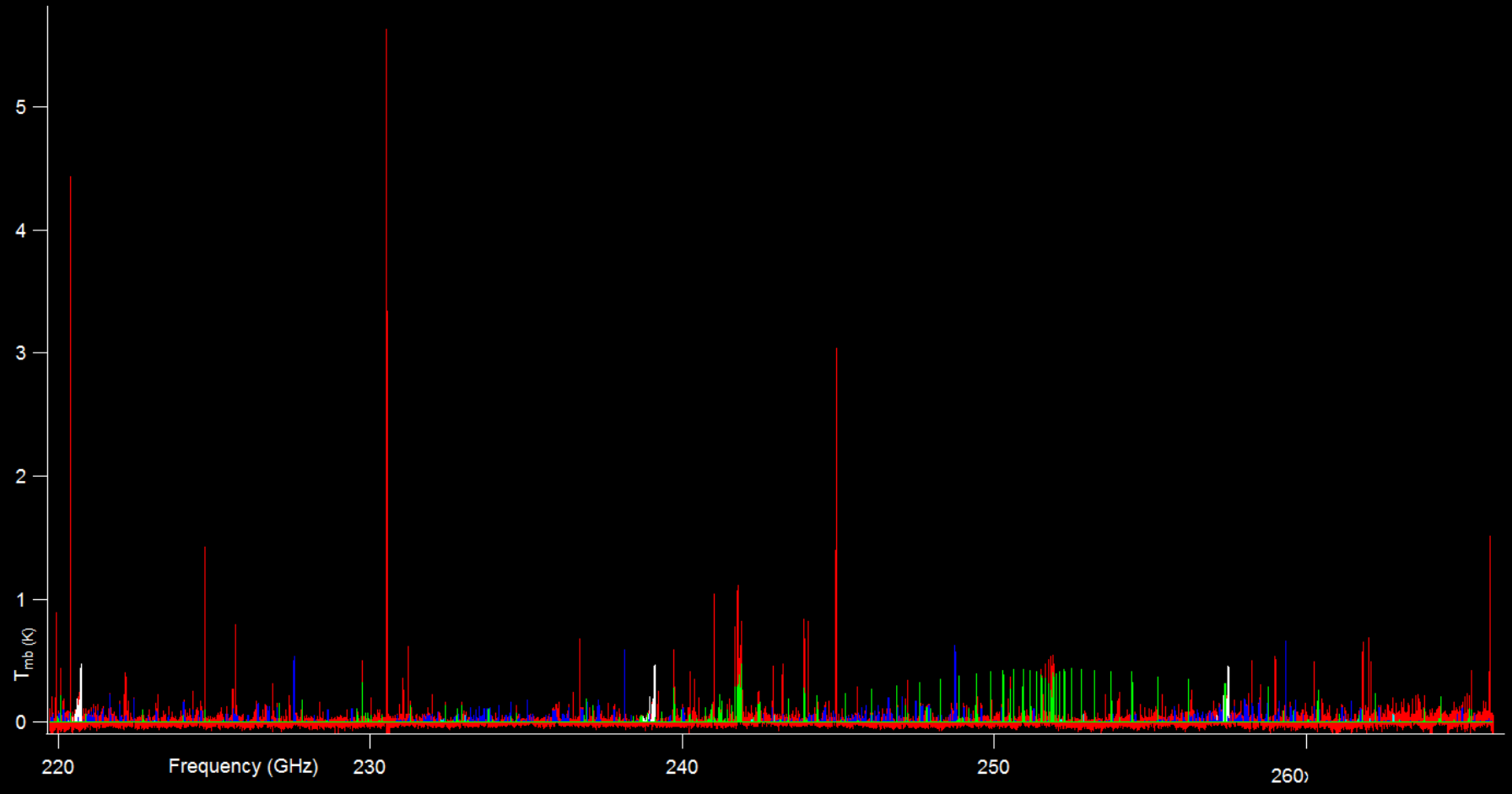
- What Influences Chemistry and Molecular Diversity
  - Physical Conditions
  - Parent Cloud
- Compare Sources
  - Evolved Differently
  - Trace Time Scales
- W75
  - W75N, DR21(OH)/W75S
- NGC 6334
  - 29, 38, 43, IN
- NGC 1333
  - 2A, 2B and 4A, 4B



NASA, APOD

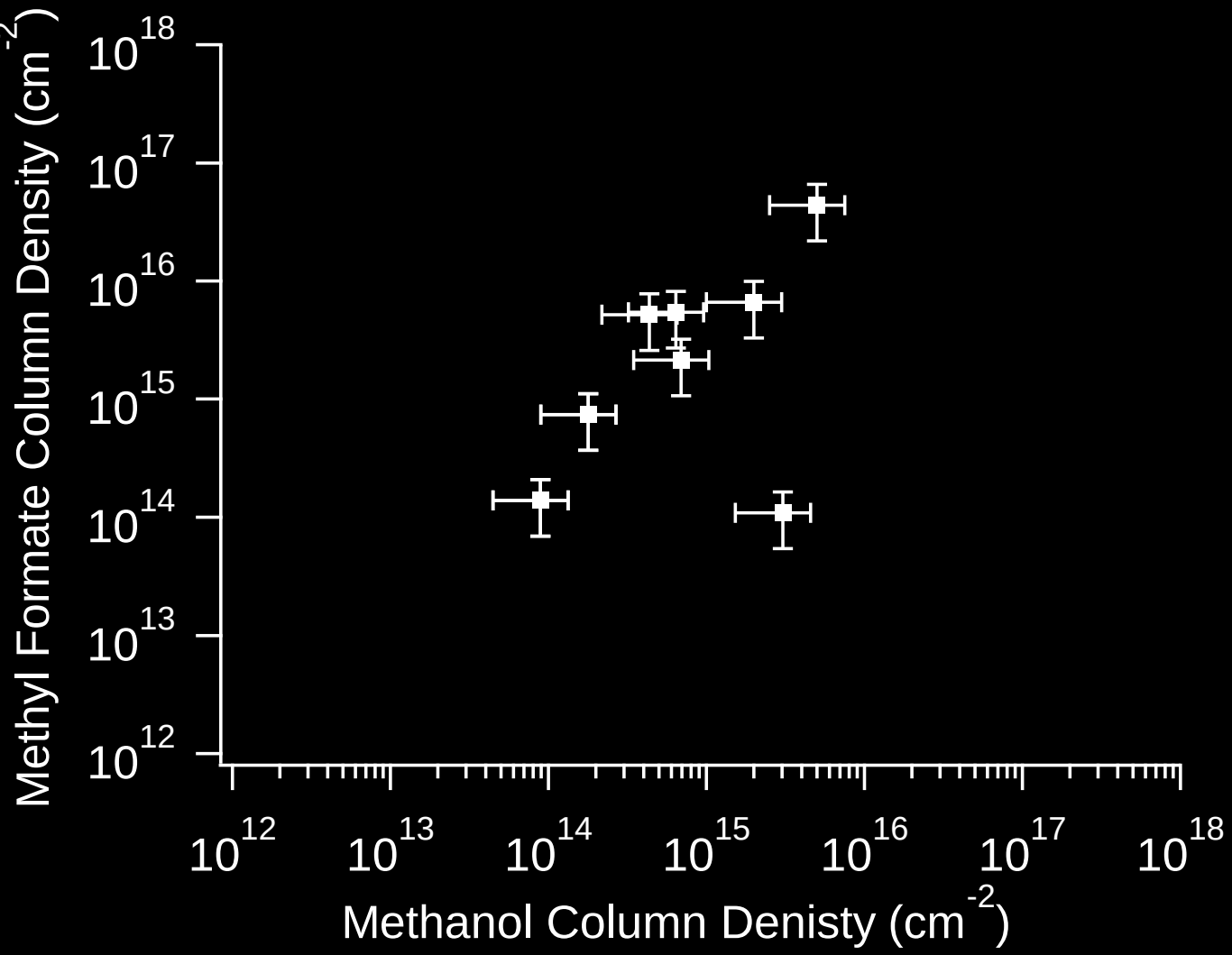
CSO Spectrum and Simulation

Simulation for G31.41+0.31 *created with GOBASIC in the MATLAB program suite*

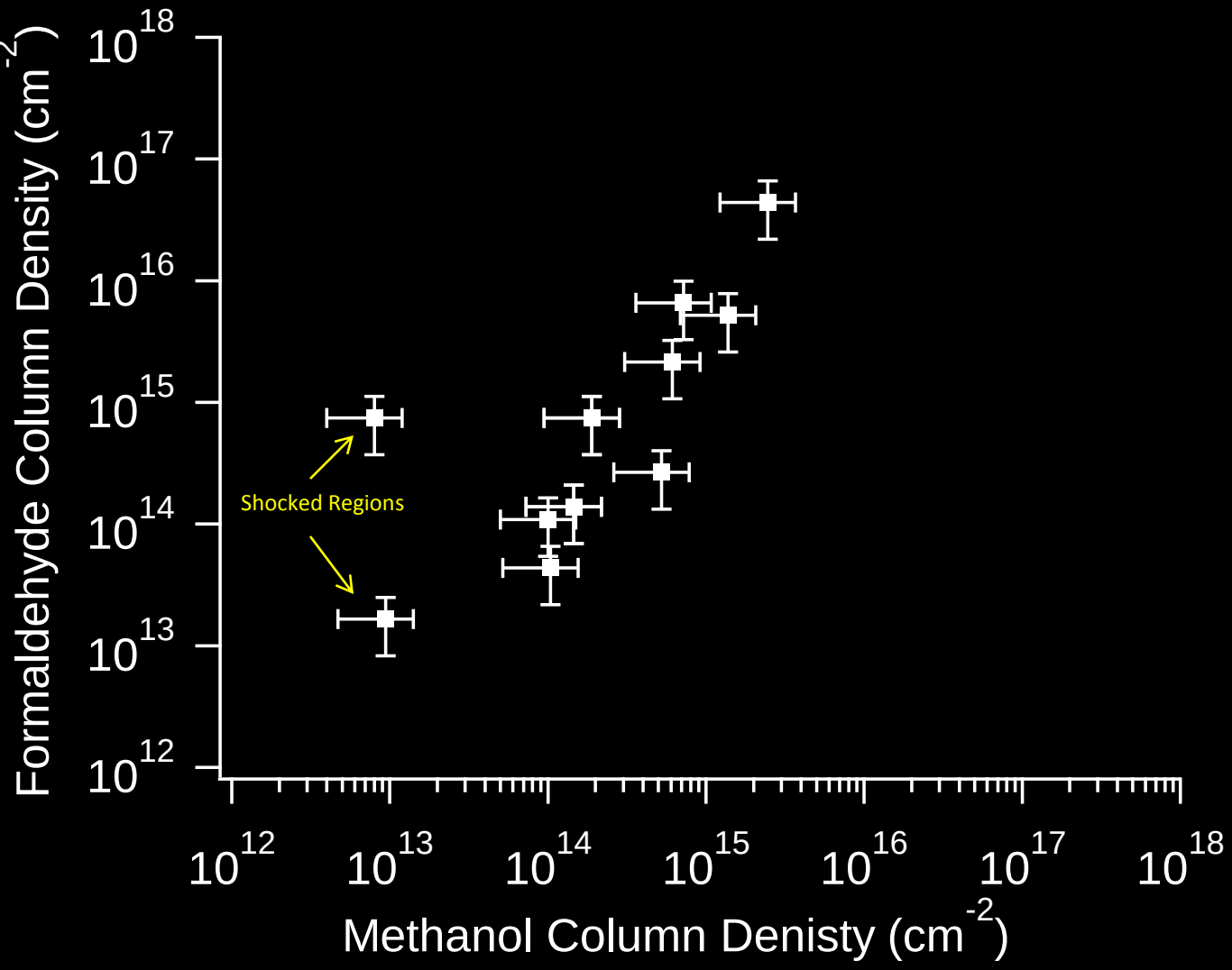


GOBASIC, Mary L. Radhuber Emory University

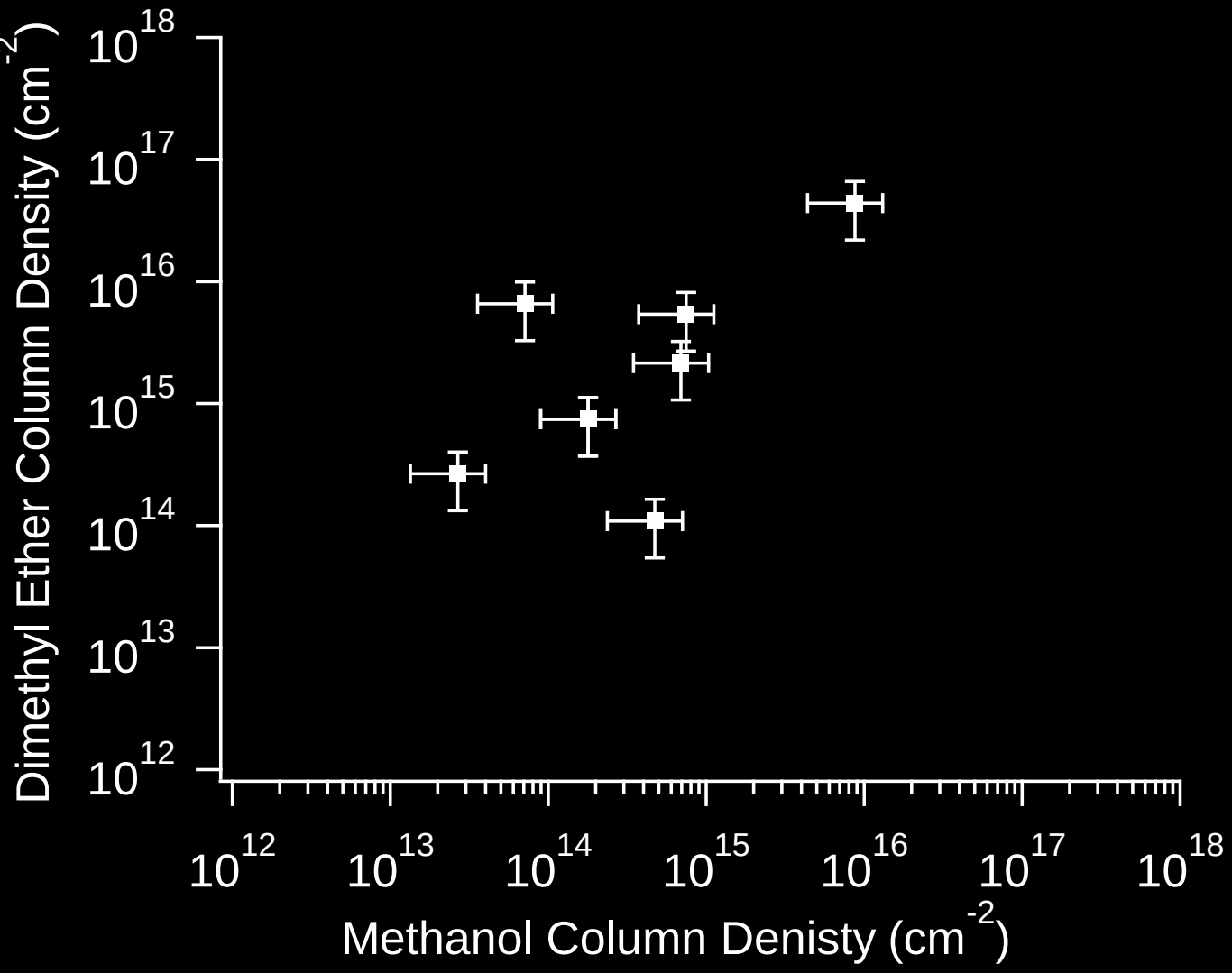
Methanol vs Methyl Formate



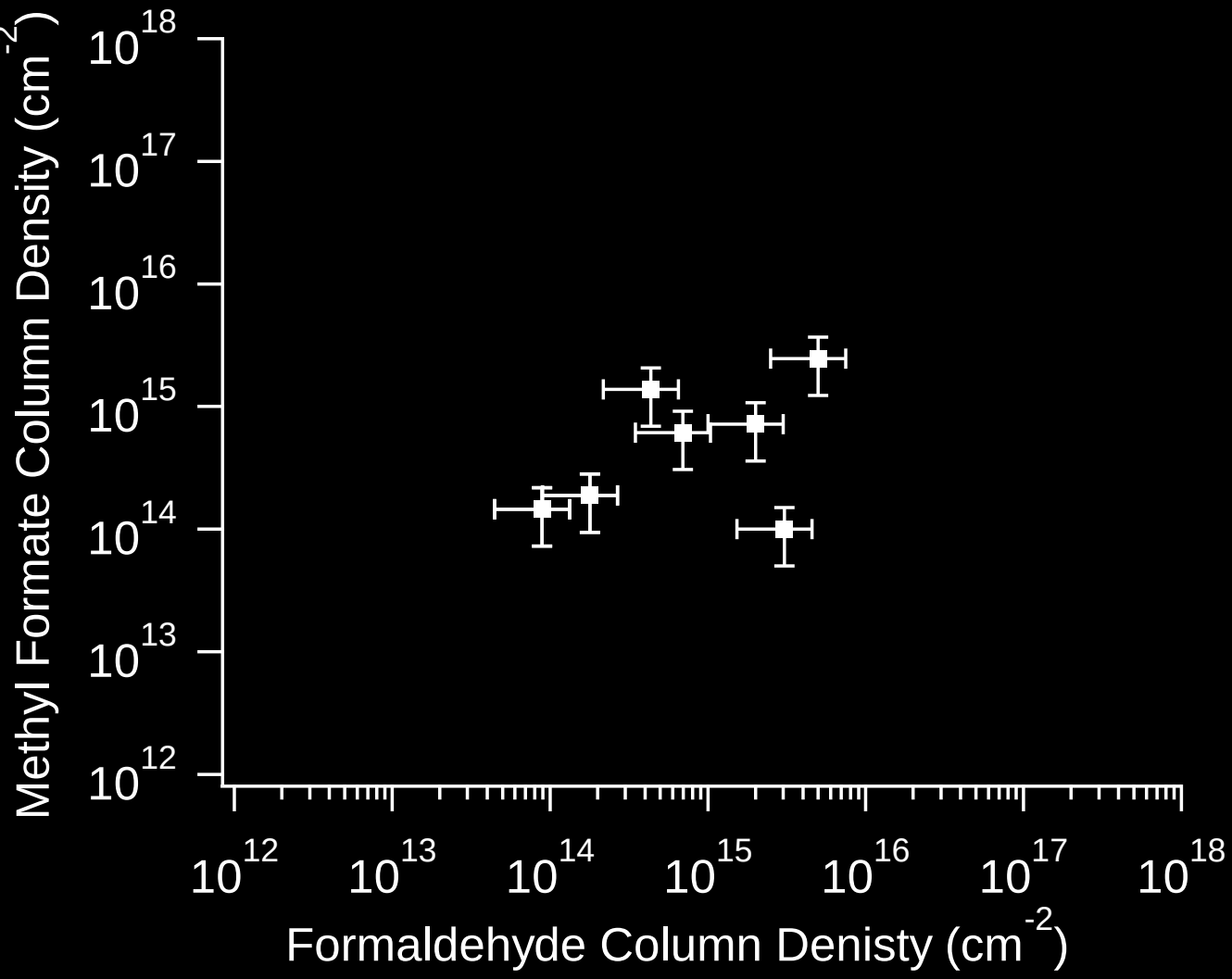
Methanol vs Formaldehyde



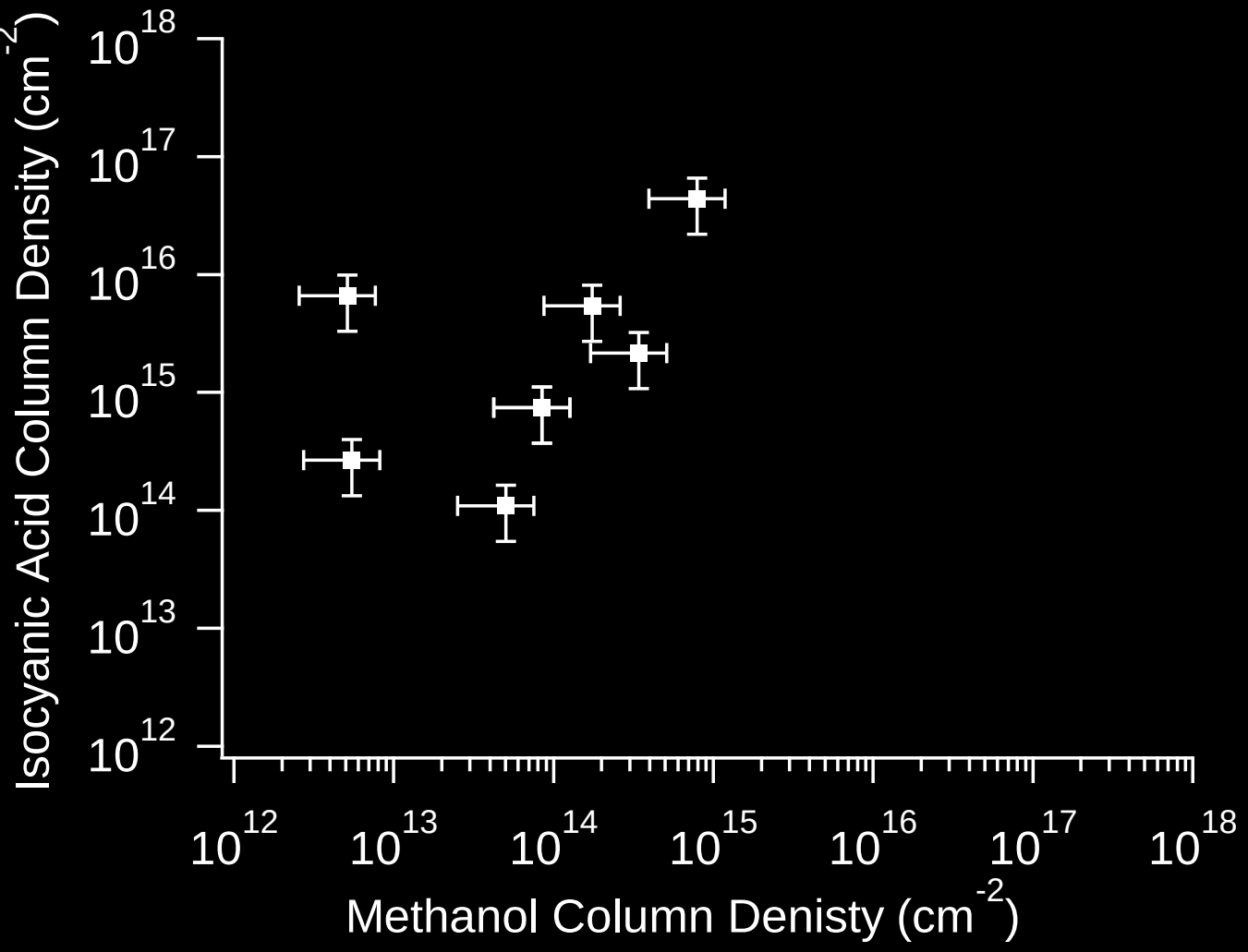
Methanol vs Dimethyl Ether



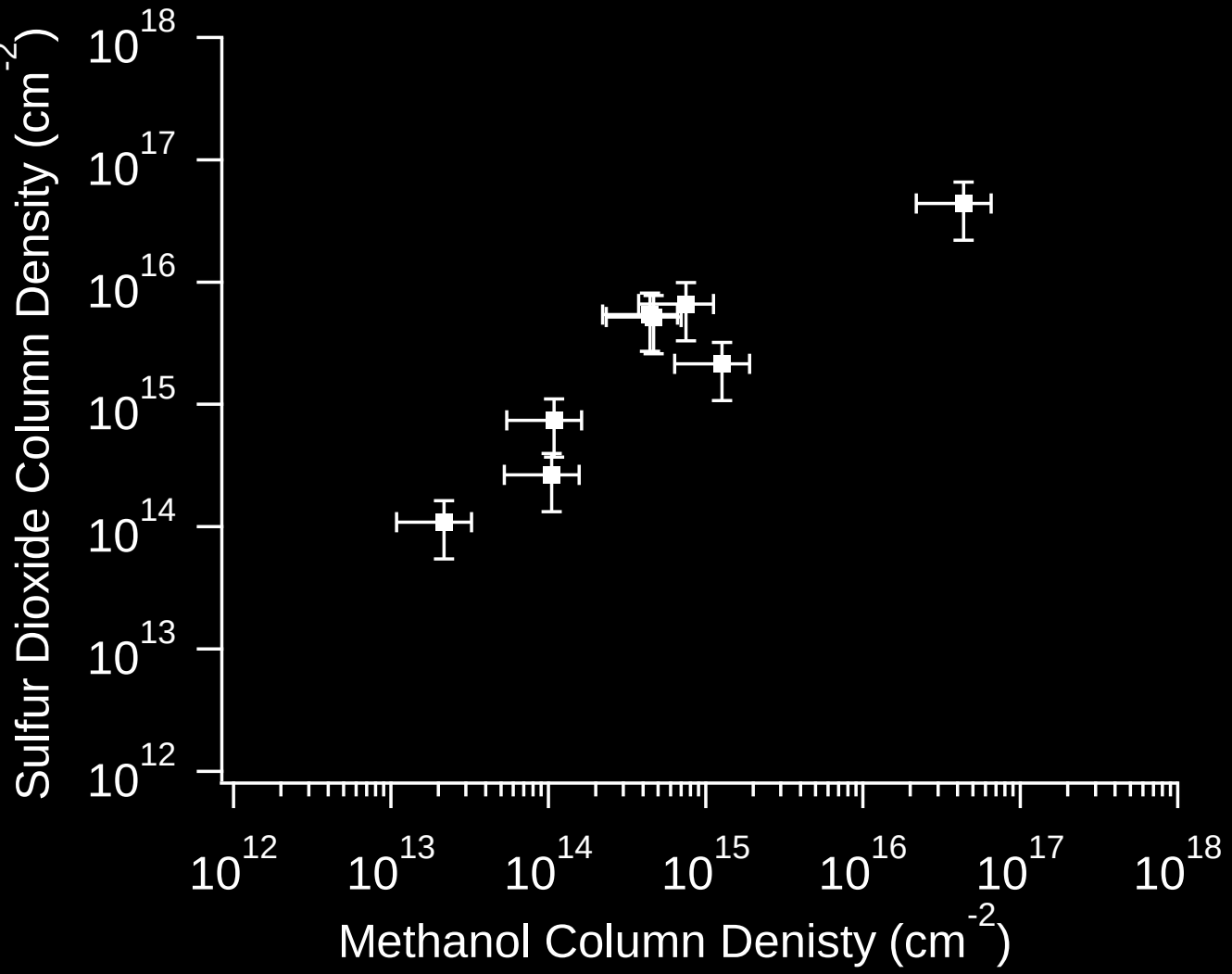
Formaldehyde vs Methyl Formate



Methanol vs Isocyanic Acid



Methanol vs Sulfur Dioxide



Glycolaldehyde

G31.41+0.31

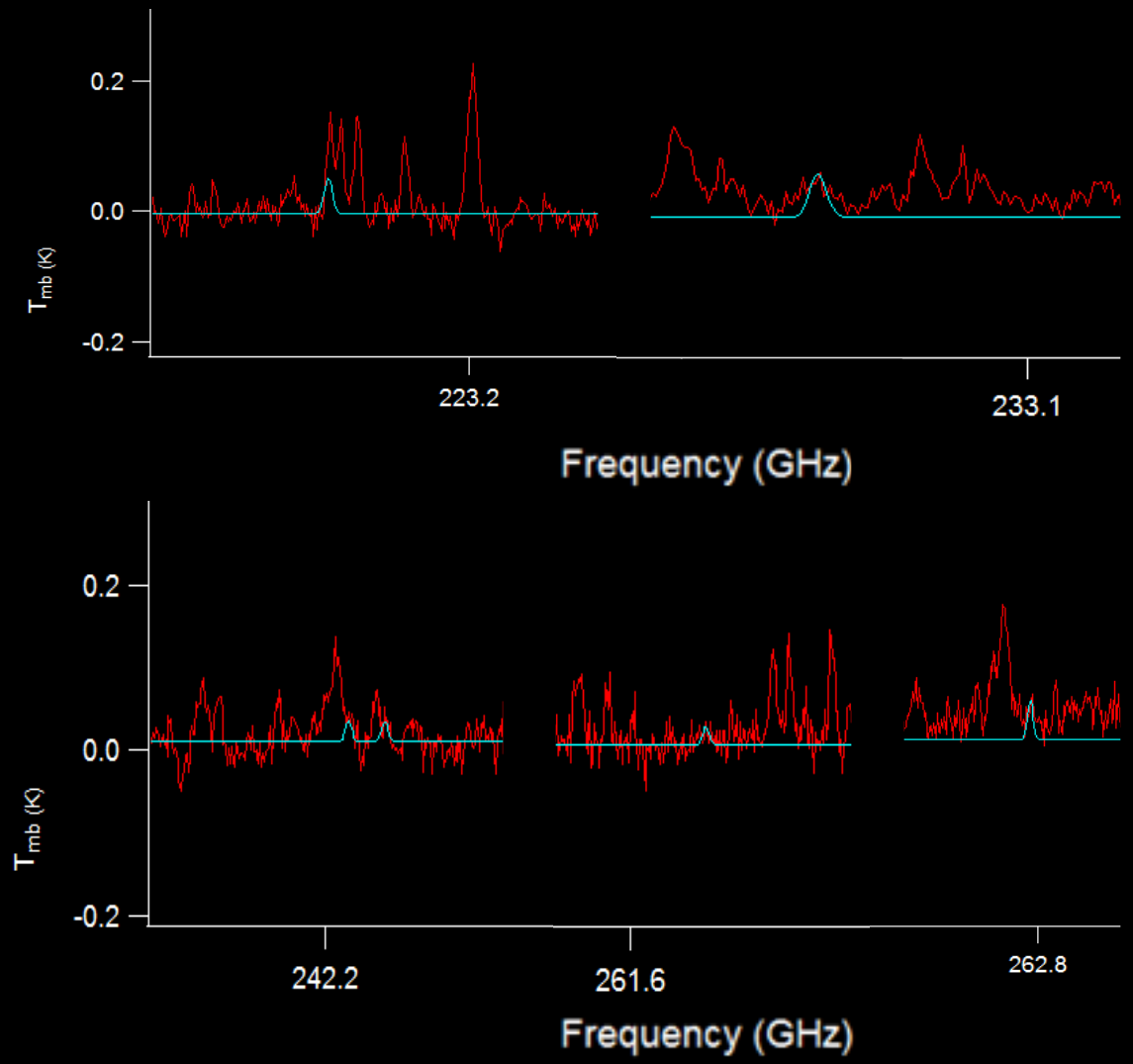
Beltrán (et al. 2008) reports

T = 300K [Fixed Temperatre]
N_t = 3e15

We report

T = 115K
N_t = 3e13 ± 7e5

With 14 transitions

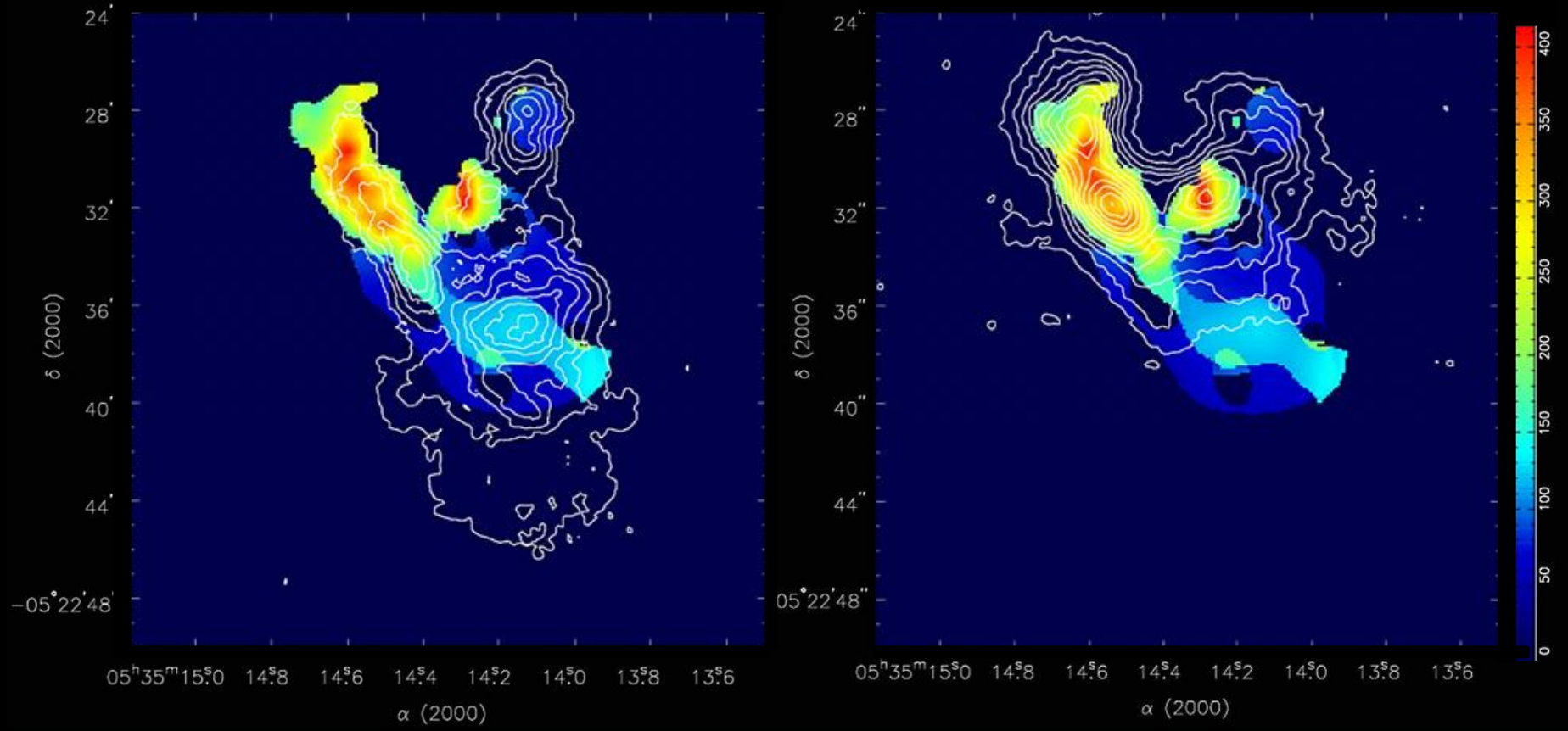


Follow-Up Imaging

- Orion-KL Temperature maps with molecular emission contours

Methyl Formate

Ethyl Cyanide



Contours mark molecule column density, color map marks cloud temperature

Widicus Weaver and Friedel, ApJ, 2012.

Conclusions and Future Work

- Star forming regions contain many complex organic species, differing in complexity from region to region
- Analysis fits were performed using the GOBASIC program suite and assumptions of Local Thermodynamic Equilibrium
- We observe correlations between molecules with similar chemistries and some unexpected correlations
- Analyze the remaining sources for all detected complex ISM species
- Refine further searches for previously undetected surveys for which we have laboratory spectral data
- Follow-up imaging studies using CARMA and ALMA are necessary to resolve source structure and size

Acknowledgements

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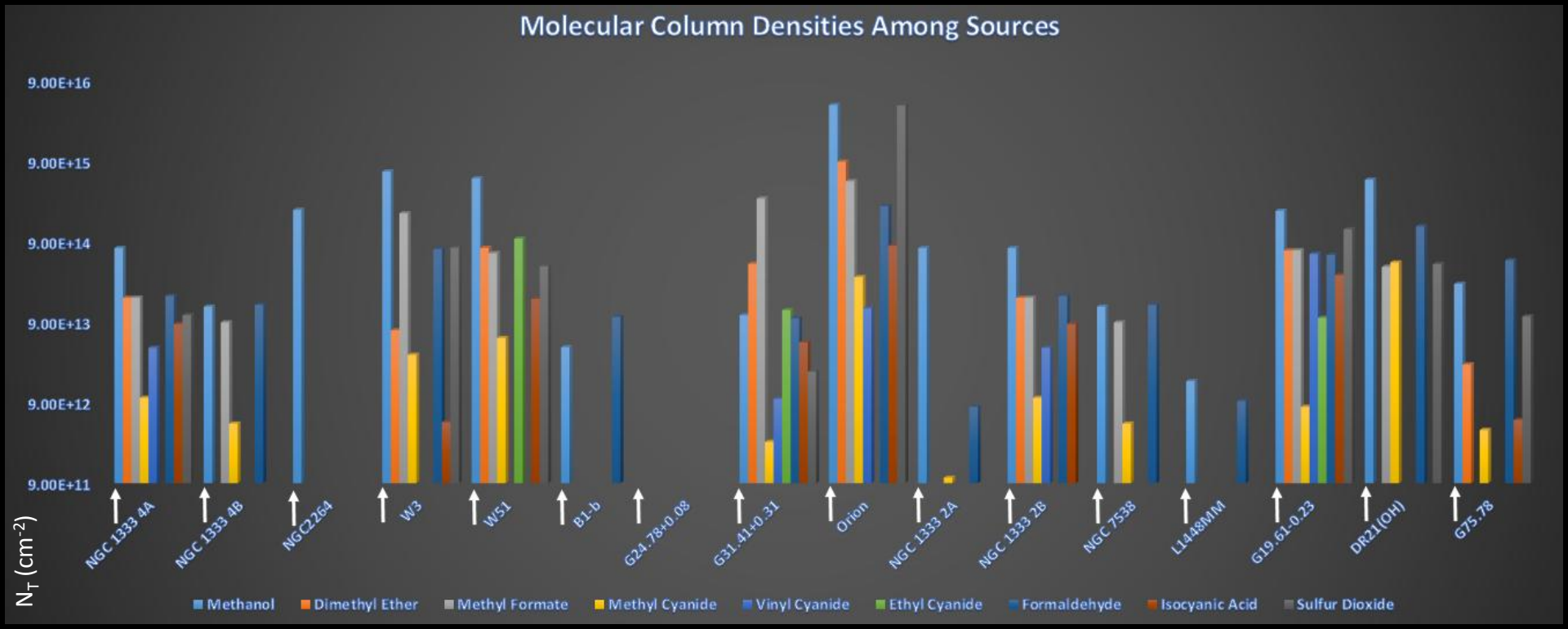
HIFI/HEXOS: Ted Bergin, Nathan Crockett, Claudia Comito, Peter Schilke, Martin Emprechtinger, Steve Lord

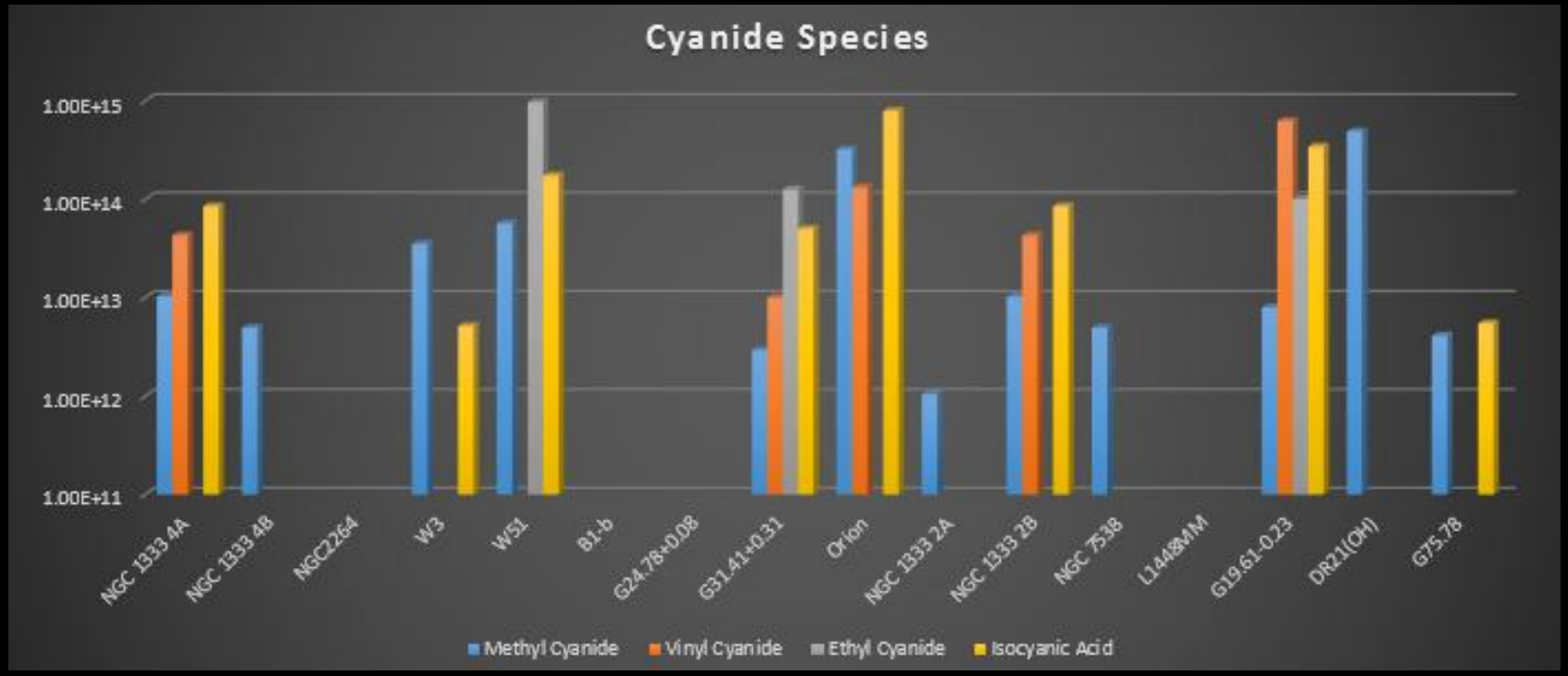
UIUC/CARMA: Doug Friedel

EMORY UNIVERSITY

Molecular Detections and Abundances



Cyanides

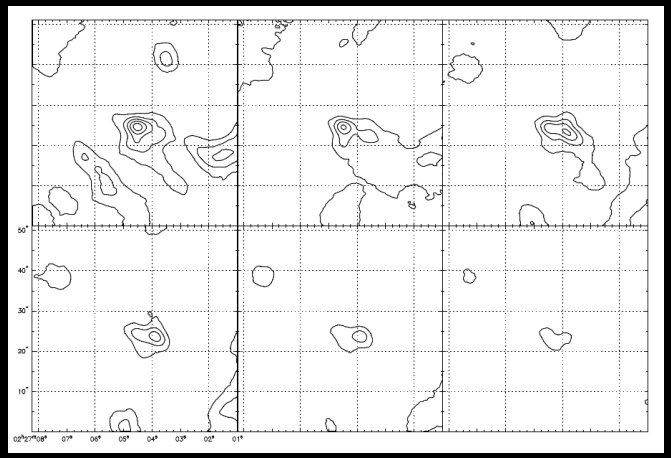

Cyanide Species
1.00E+15
1.00E+14
1.00E+13
1.00E+12
1.00E+11
NGC 1333 4A
NGC 1333 4B
NGC2264
W3
W51
B1-b
G24.78+0.08
G31.41+0.31
Orion
NGC 1333 2A
NGC 1333 2B
NGC 7538
L1448MM
G19.61-0.23
DR21(OH)
G75.78
Methyl Cyanide
Vinyl Cyanide
Ethyl Cyanide
Isocyanic Acid

Grain Surface Tiered Chemistry

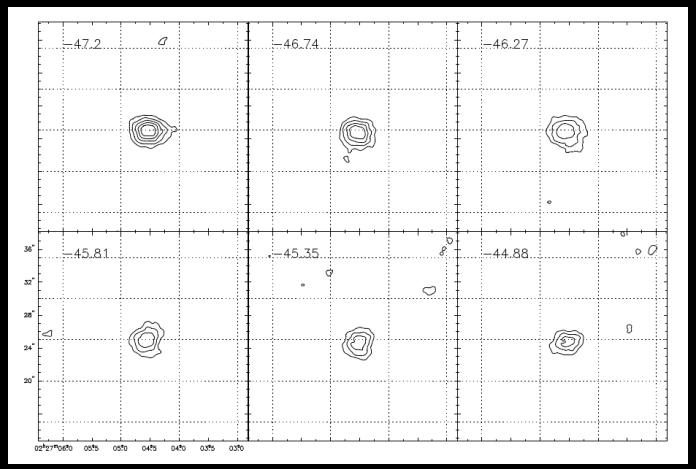
- MeOH vs EtOH
- Formic Acid and Formaldehyde
- Temperatures tell us about desorption temps -> grain surface binding energy

Follow-Up Imaging

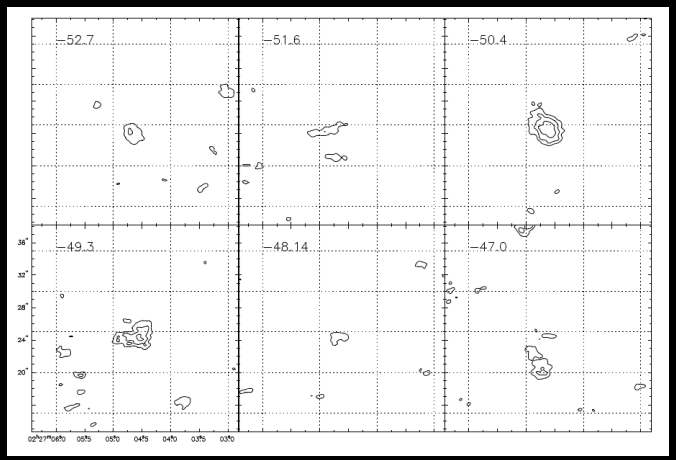
- Constraining Column Density with Source Size Beam Dilution: W3



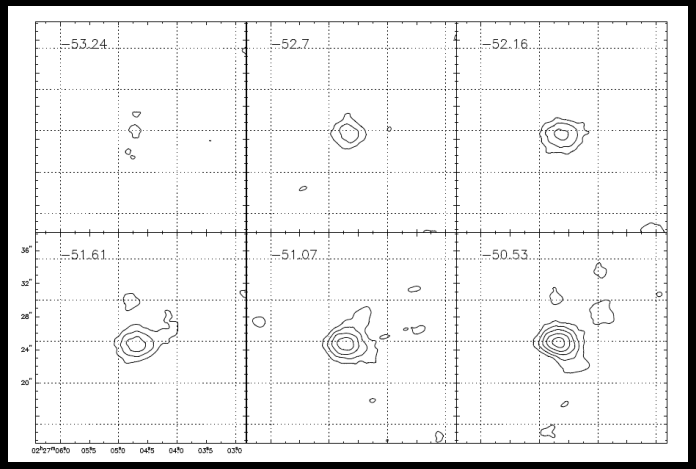
Sulfur Dioxide



Ethyl Cyanide



Acetone



Methyl Formate

Doug Friedel