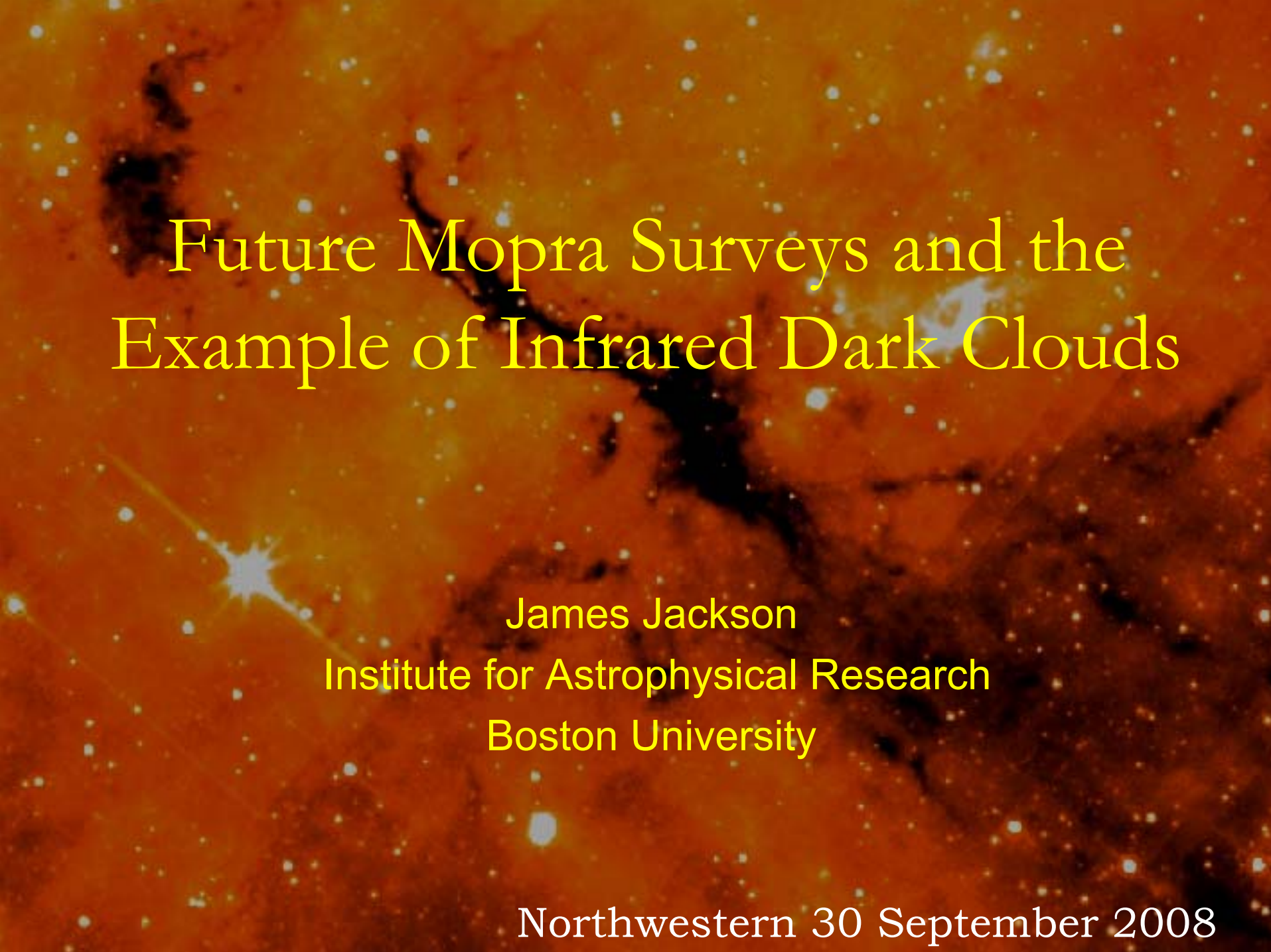

Future Mopra Surveys and the Example of Infrared Dark Clouds

James Jackson
Institute for Astrophysical Research
Boston University

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Collaborators

Jill Rathborne	CfA
Robert Simon	Cologne
Ed Chambers	Boston U.
Susanna Finn	Boston U.
Qizhou Zhang	CfA

The State of the Art: The BU-FCRAO Galactic Ring Survey

- SEQUIOA 32-pixel array
- FCRAO 14m telescope
- ^{13}CO (1-0) 110.2 GHz → 46" beam
- On-the-Fly Mapping
- Survey covers $18^o < l < 55.7^o$

  $-1^o < b < 1^o$

  $\Omega = 75.4 \text{ deg}^2$

GALACTIC RING SURVEY

GRS

BOSTON UNIVERSITY-FCRAO

Started February 1998

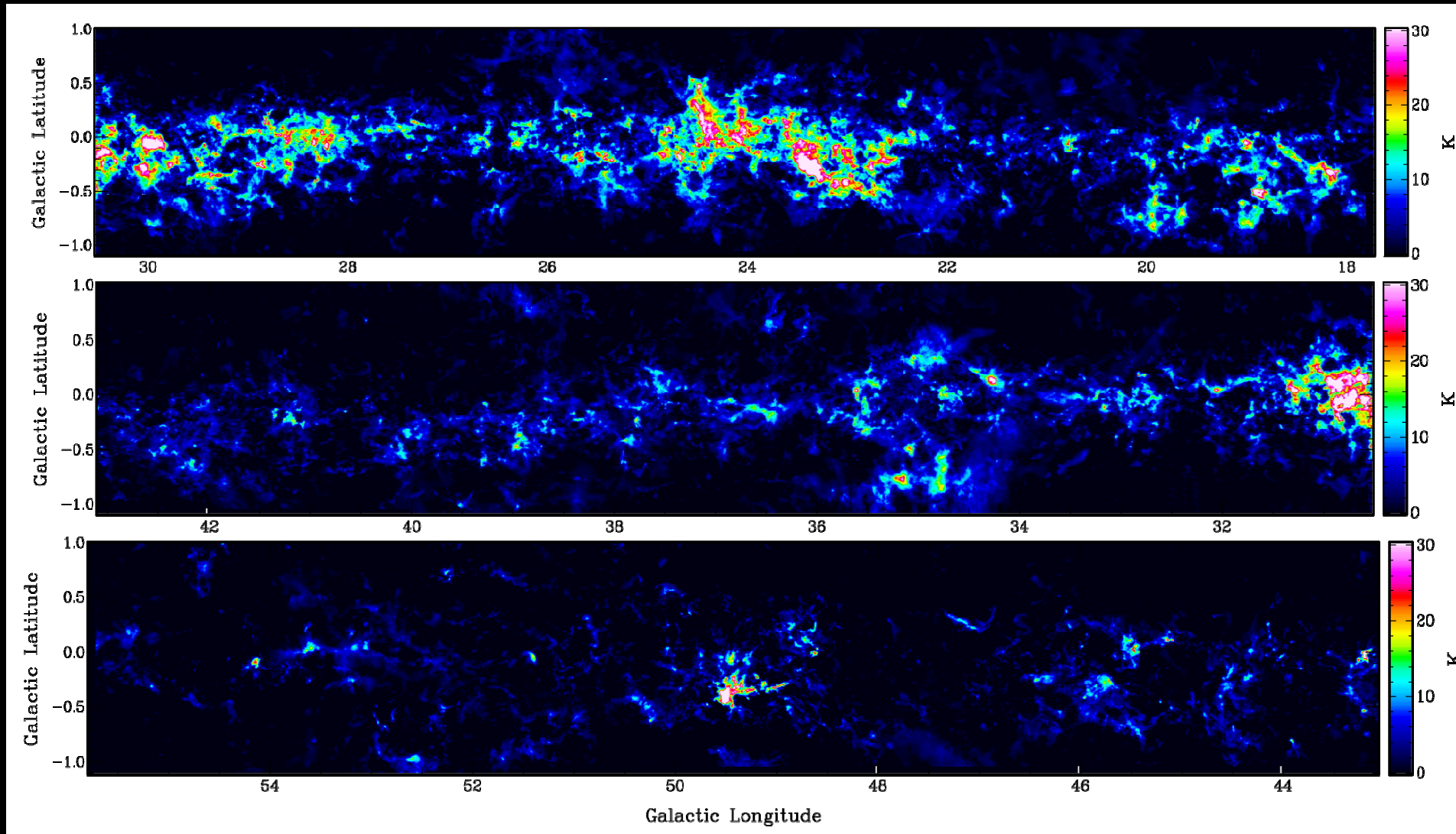
Completed March 2005

Jackson et al. 2006

Comparison of GRS with previous surveys

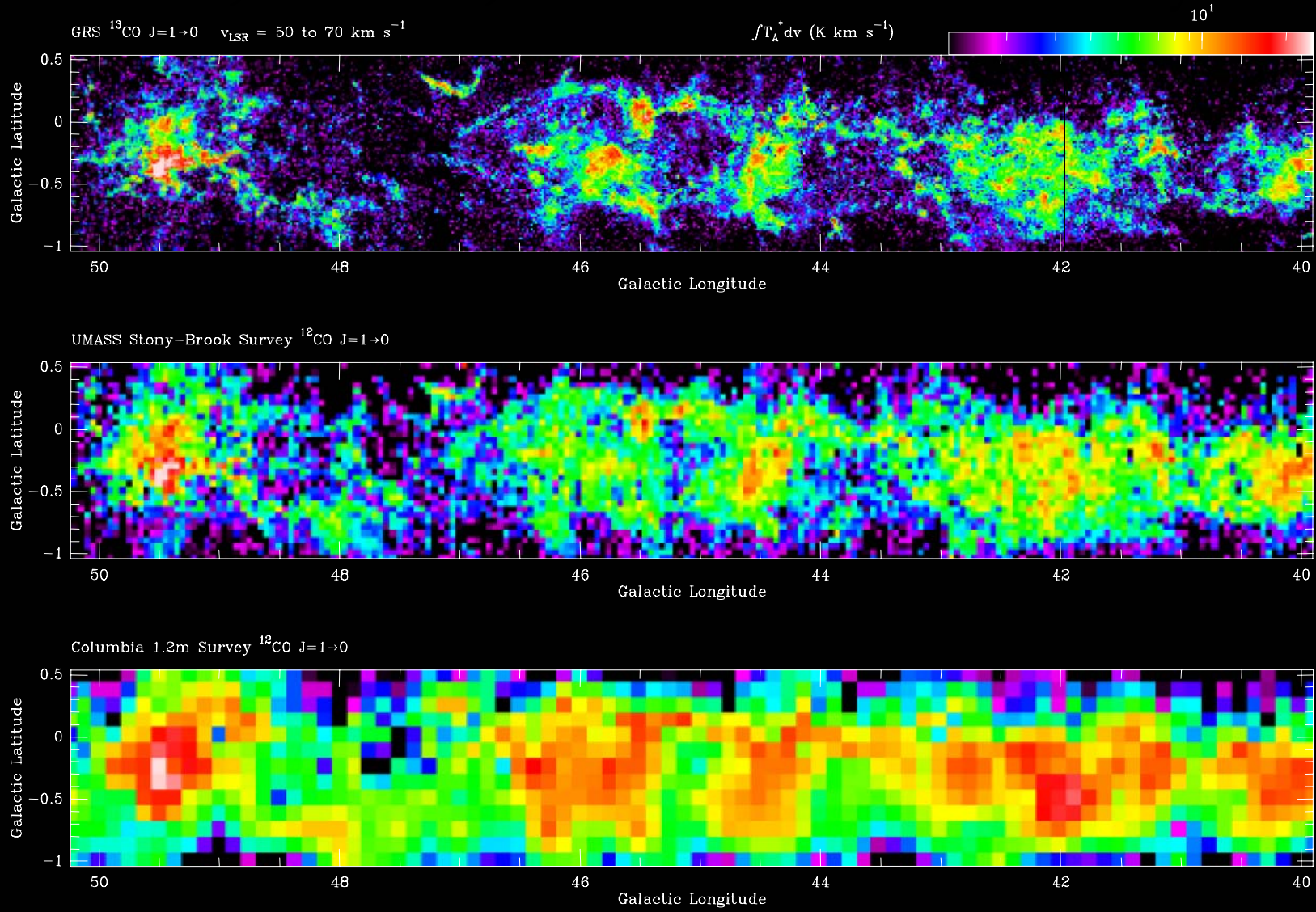
	UMSB	Columbia	Bell Labs	GRS
Angular resolution	46”	480”	100”	48”
Grid	180”	450”	180”	22”
Sensitivity	0.4 K	0.1-0.4 K	0.12 K	0.26 K
Spectral resolution	1.0 km/s	1.3 km/s	0.68 km/s	0.21 km/s
Isotope	^{12}CO	^{12}CO	^{13}CO	^{13}CO

GRS ^{13}CO Integrated Intensity Image



www.bu.edu/galacticring

Jackson et al. 2006


GRS ^{13}CO J=1→0 v_{LSR} = 50 to 70 km s^{-1}
$\int T_A^* dv$ (K km s^{-1})
10^1
Galactic Latitude
Galactic Longitude
0.5
0
−0.5
−1
50
48
46
44
42
40
UMASS Stony−Brook Survey ^{12}CO J=1→0
Columbia 1.2m Survey ^{12}CO J=1→0

What is the best Mopra survey?

- Drivers:
  - Science questions
  - Technical capabilities
  - Resources (AUD, time, and people)
  - Important improvements over previous surveys

Science Drivers

- **CO, ^{13}CO, C^{18}O**
  - Column density tracers (also T and τ)
  - Structure of molecular clouds
  - Galactic structure
- **~90 GHz lines (HCN, N_2H^+, HNC, CS)**
  - Dense gas tracers
  - Star forming cores
  - Chemistry and physical conditions in dense gas

Mopra's advantages

- Large bandwidths
- Simultaneous multi-line observations

- System performance is better at lower frequencies (90 GHz vs 115 GHz)
  - Non-optimal mm site
  - Better atmospheric transmission
  - Better telescope efficiency

A Mopra CO Survey

- Assume same sensitivity in ^{13}CO with GRS (T_B~0.3 K at 0.2 km/s resolution)
- To reach this sensitivity requires 5 standard 5'x5' maps
- To cover same solid angle (75 sq deg) Mopra would require 11,000 maps, or ~67,000 hours, or ~6,000 12 hour nights.
- If Mopra is dedicated to such a survey (6 months per year, no bad weather), the survey would require ~30 years.

Parameters of a Mopra CO Survey

- For significant improvement over previous surveys, need to compromise
  - Angular resolution (where Mopra holds a distinct advantage)
  - Spectral resolution
  - Solid angle coverage
  - Sensitivity
- Could live with good S/N at ^{12}CO but would then compromise with poor S/N at ^{13}CO and $C^{18}O$

A Mopra ~90 GHz Multi-line Survey

- The 90 GHz lines (e.g, CS, HCO+, N2H+, HCN, HNC) are fainter than CO
- Cannot perform a large solid angle, blind survey
- Such a survey must be targeted to cover high-column, high-density regions
- Such regions can be identified with existing surveys (e.g., GLIMPSE, MIPSGAL, Columbia CO survey)

Infrared Dark Clouds

GLIMPSE 8 μm image

- Clouds that exhibit significant mid-IR opacity
- Extreme properties
  - Cold (<15 K)
  - Dense (>10^4 cm^{-3})
  - Enormous column densities (>10^{23}–10^{25} cm^{-2})
- Most are extremely filamentary

Perault et al. 1996; Egan et al. 1998; Carey et al. 1998, 2000; Hennebelle et al. 2001; Simon et al. 2006; Rathborne et al. 2006

IRDCs are the birthplaces of high-mass stars

- IRDCs match size and mass of high-mass star-forming molecular clumps.
- IRDC cores match size and mass of high-mass pre-stellar and protostellar cores.
- IRDCs are located preferentially in spiral arms.
- Active IRDC unambiguously contain high-mass protostars.
- A few IRDC cores show evidence for young “proto-clusters.”

Big Science Choice

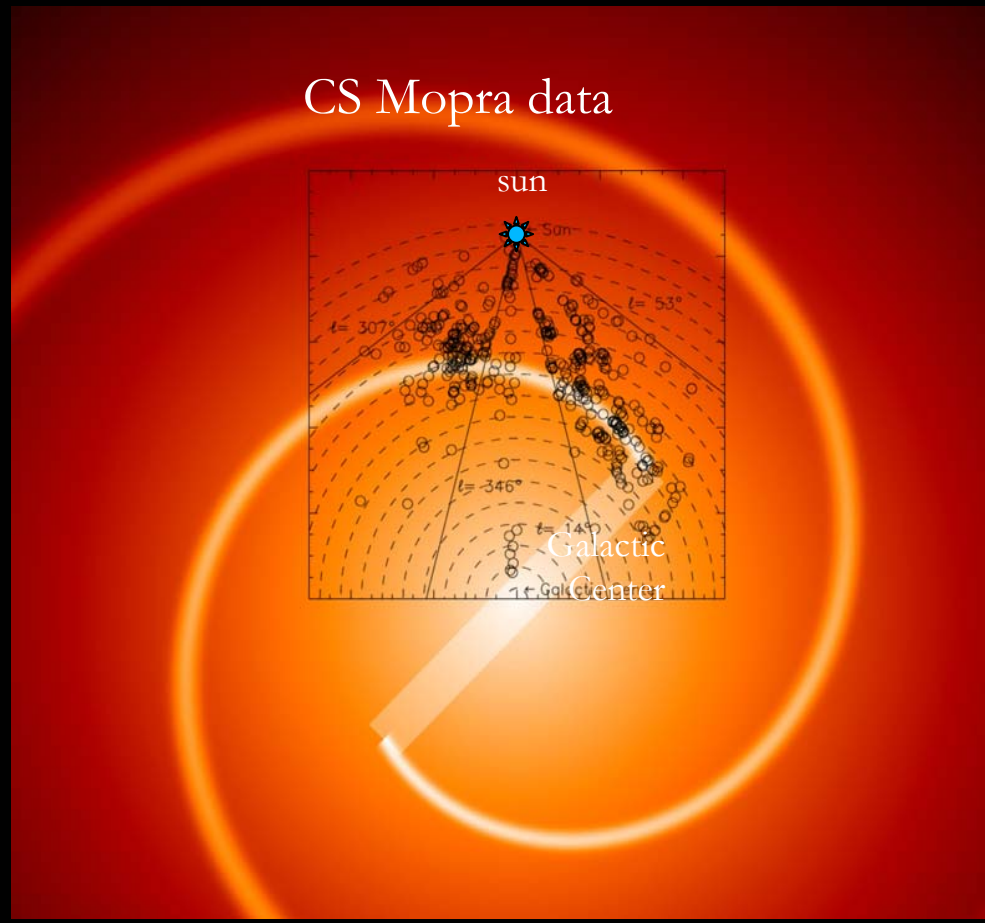
- CO: cloud structure and Galactic dynamics
  - Cloud structure will not be much improved over existing surveys (GRS)
  - Knowledge of dynamics would be improved
- 90 GHz lines: physical parameters and chemistry
  - Plays to Mopra's strengths
  - First large homogeneous database for such lines

The Galactic IRDC Distribution

If IRDCs are the birthplaces of high-mass stars, they should live in spiral arms.

The Mopra CS data indicates that this is indeed the case.

Pointed Mopra surveys can probe Galactic structure.



Jackson et al. 2008 ApJ

Galactic model based on IR star counts (R. Benjamin)

Large Filamentary IRDCs

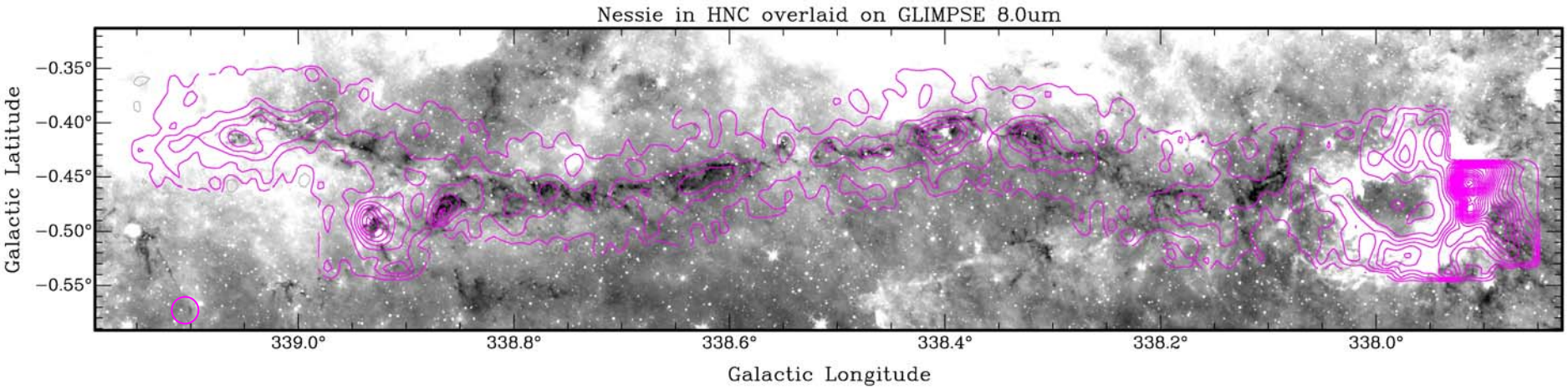
The "Nessie" Nebula

Size > ~100 pc x 0.5 pc

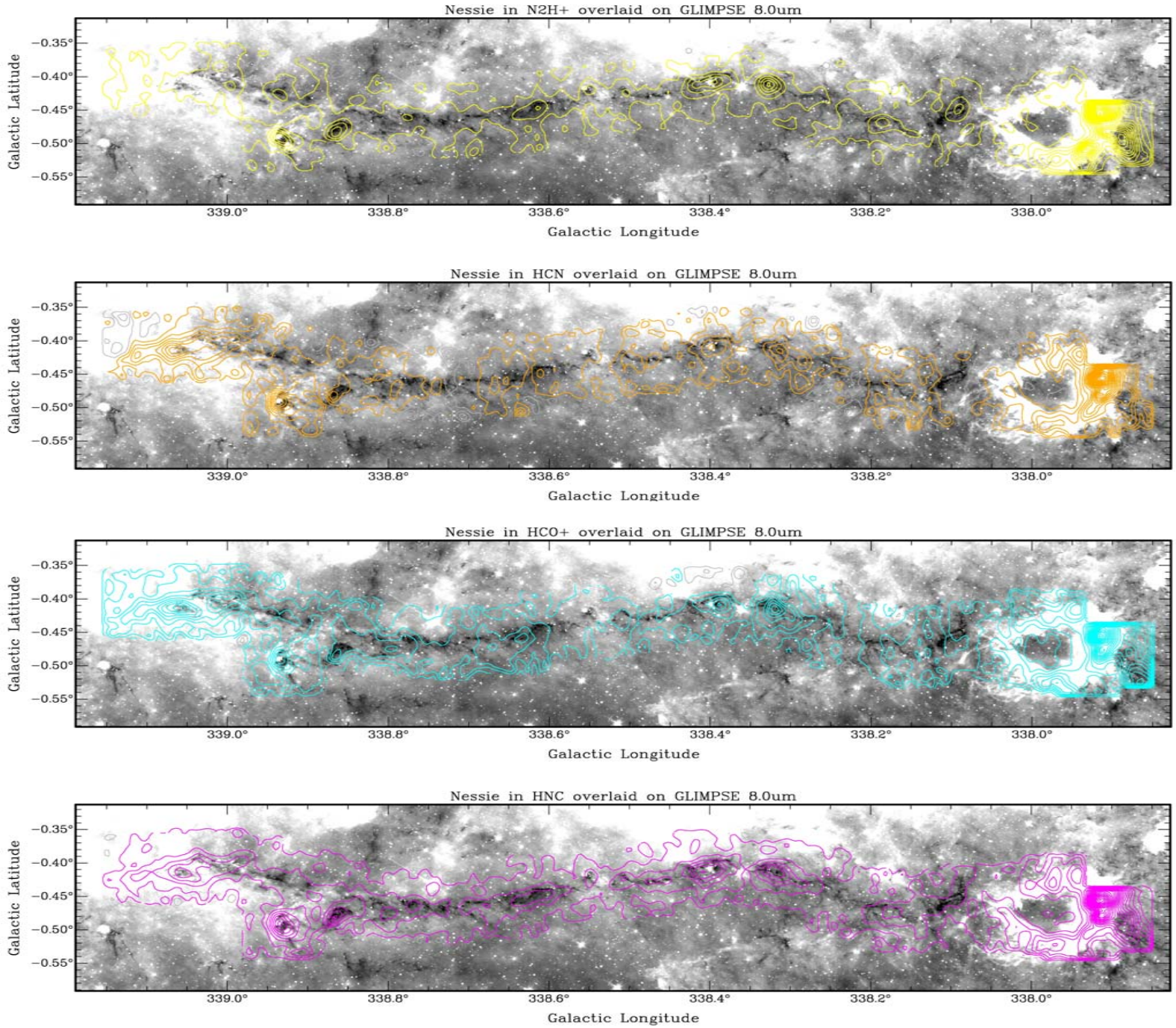
Blue - 3.6μm, Green - 8μm, Red - 24μm

Image credit: NASA/JPL-Caltech/Univ. of Wisconsin

All of the material is at the same velocity, and by inference, the same distance



HNC 1-0, V = -38 to -42 km/s



N_2H^+

HCN

HCO^+

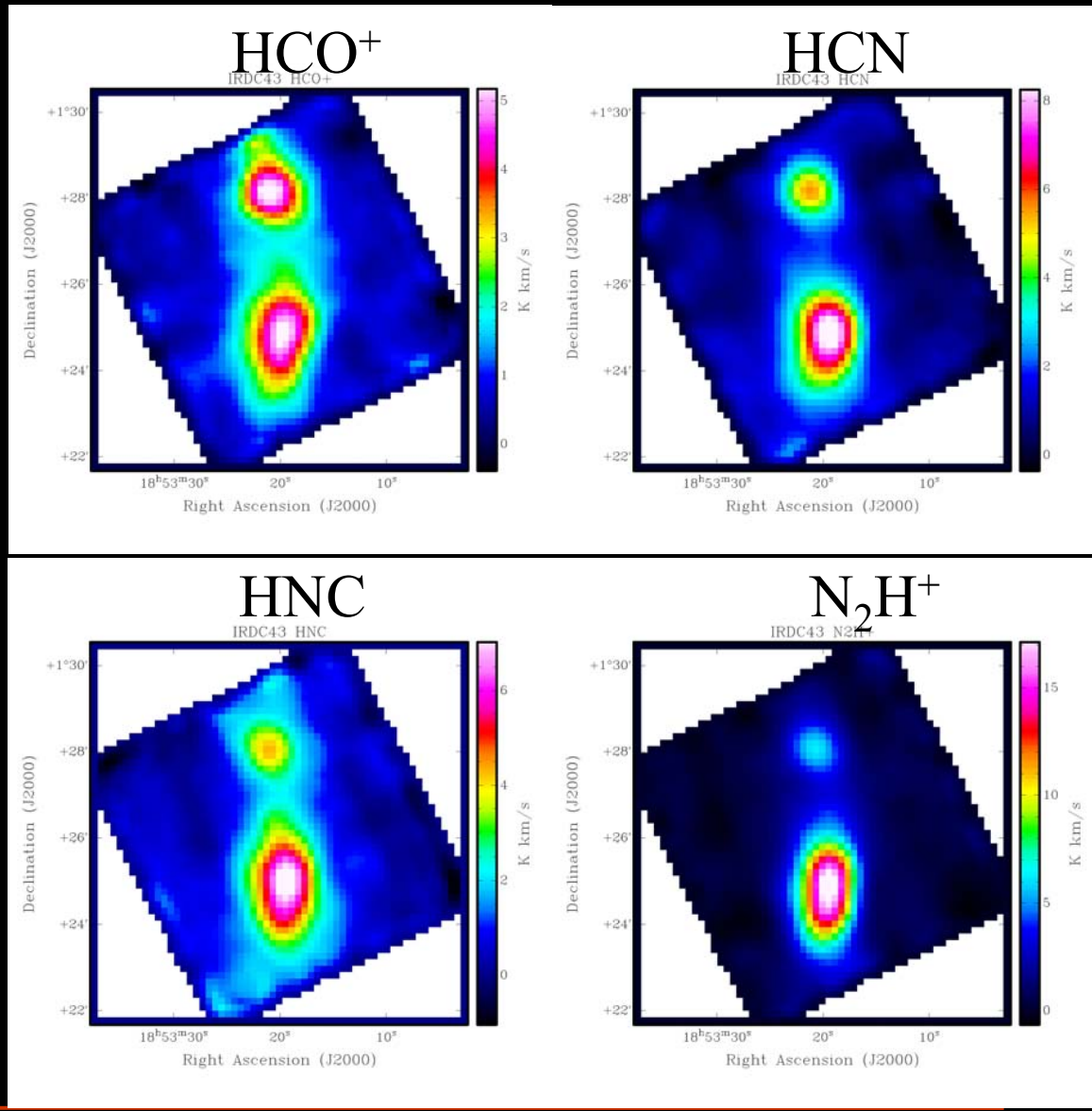
HNC

Chemical Environment

3 mm

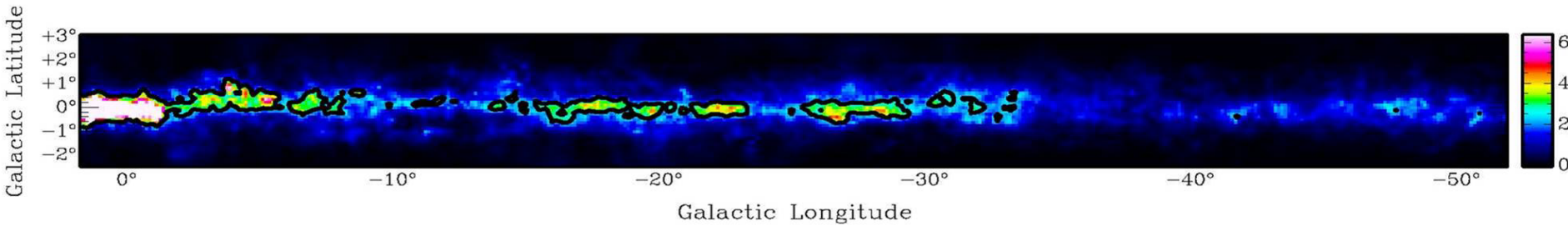
Simultaneous mapping of 16 different molecular lines

Different molecular abundances for different star-forming cores



Selecting areas of high column:

Peaks in the Columbia CO Survey



The enclosed area can be detected by N_2H^+ with S/N>3 with Mopra.

The solid black line marks the 2.5e22 column density limit.

The survey covers 13 sq deg and can be completed in 1.4 seasons (10 hours per night, 4 months per season).