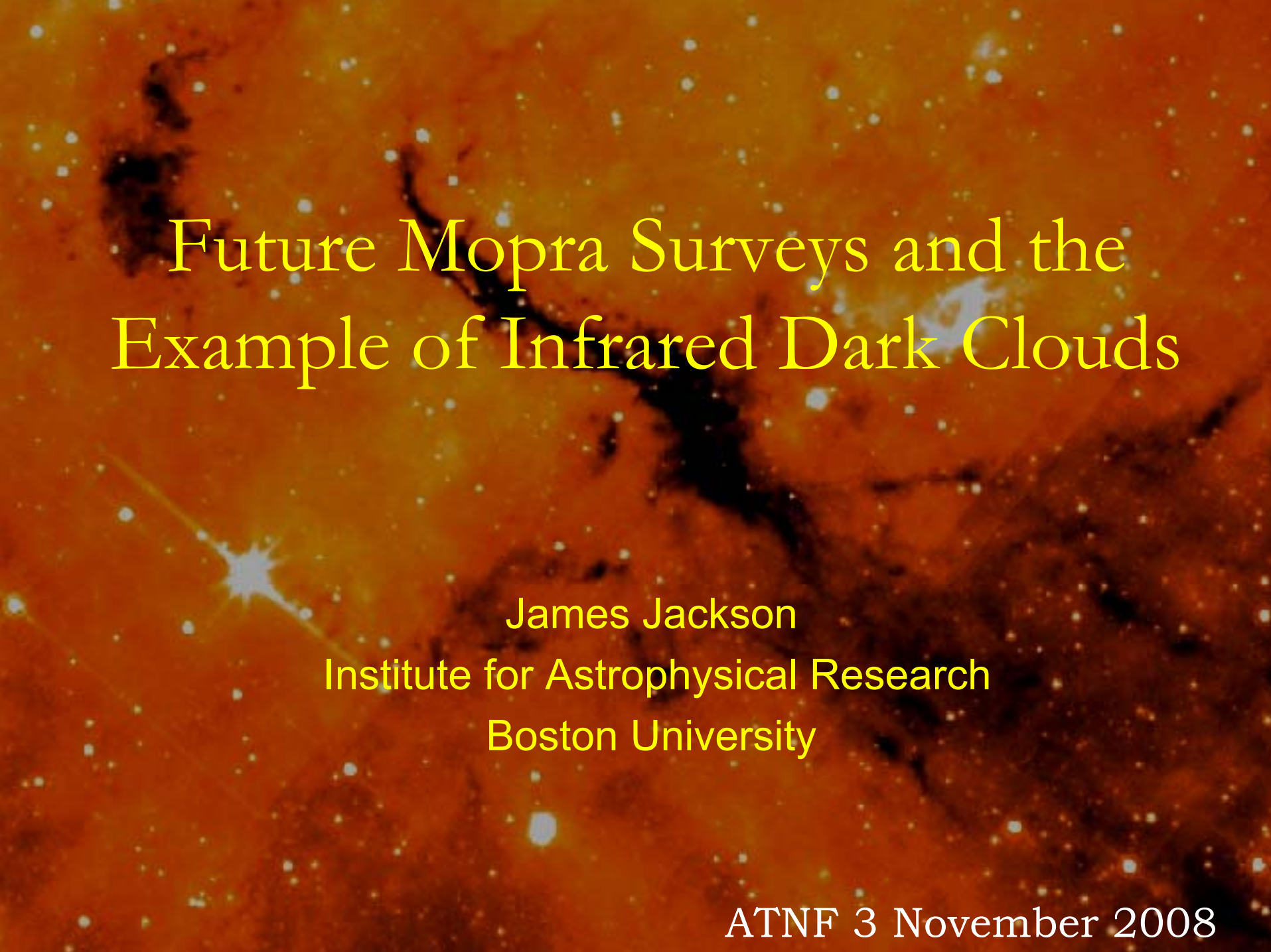

Future Mopra Surveys and the Example of Infrared Dark Clouds

James Jackson
Institute for Astrophysical Research
Boston University

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Collaborators

Jill Rathborne	CfA
Steve Longmore	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

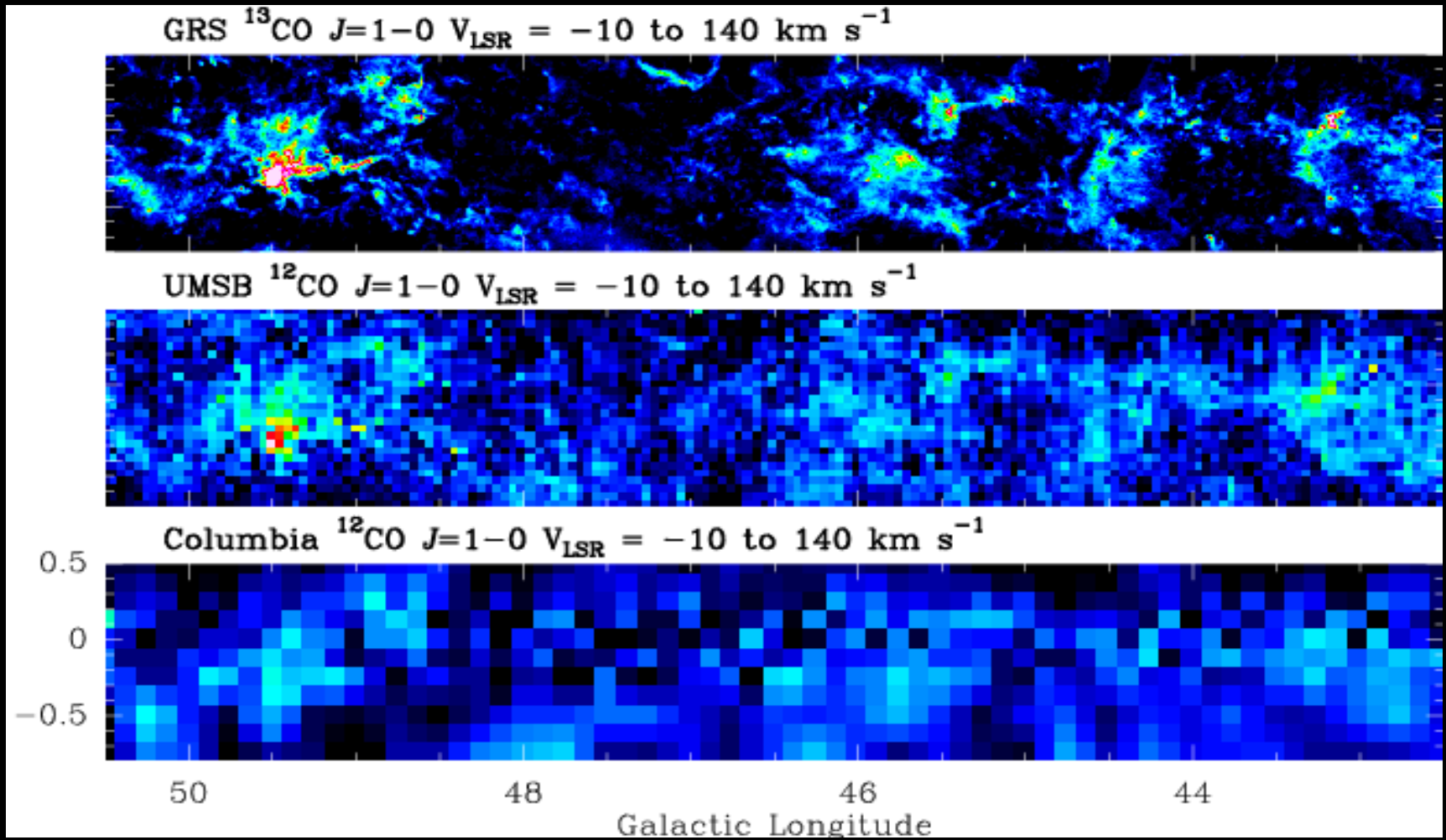
Completed March 2005

Jackson et al. 2006

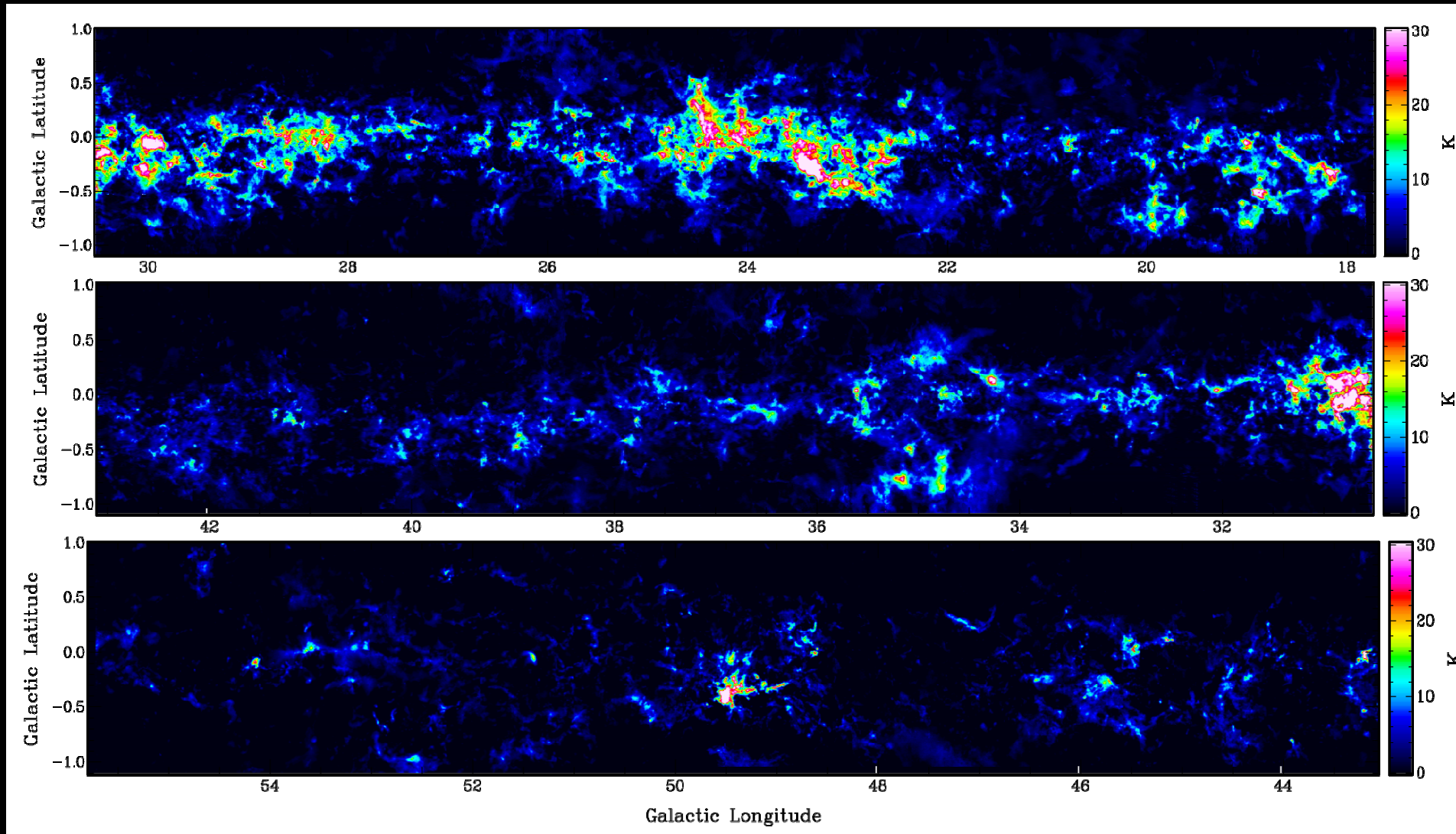
Comparison with Previous CO Surveys

Survey	GRS	UMSB	Columbia	Nanten
Dates	1998 - 2005	1982-1986	1986-2000	1999-?
Line	^{13}CO (1-0)	^{12}CO (1-0)	^{12}CO (1-0)	^{12}CO (1-0)
Sensitivity (K)	0.3	0.1	0.15	0.2
V. Resolution (km /s)	0.21	1.0	1.3	1.0
L extent (deg)	18 to 55	8 to 90	12 to 75	60 to 240
B extent (deg)	-1 to 1	-1 to 1	-4 to 4	-10 to 10
Vel. Extent (km s^{-1})	-10 to 140	-150 to 200	-60 to 160	-60 to 160
Resolution	46”	46”	480”	180”
Sampling	22”	180”	240”	120”
# of spectra	2,000,000	40,500	480,000	1,100,000

Comparison with previous CO surveys



GRS ^{13}CO Integrated Intensity Image



www.bu.edu/galacticring

Jackson et al. 2006

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

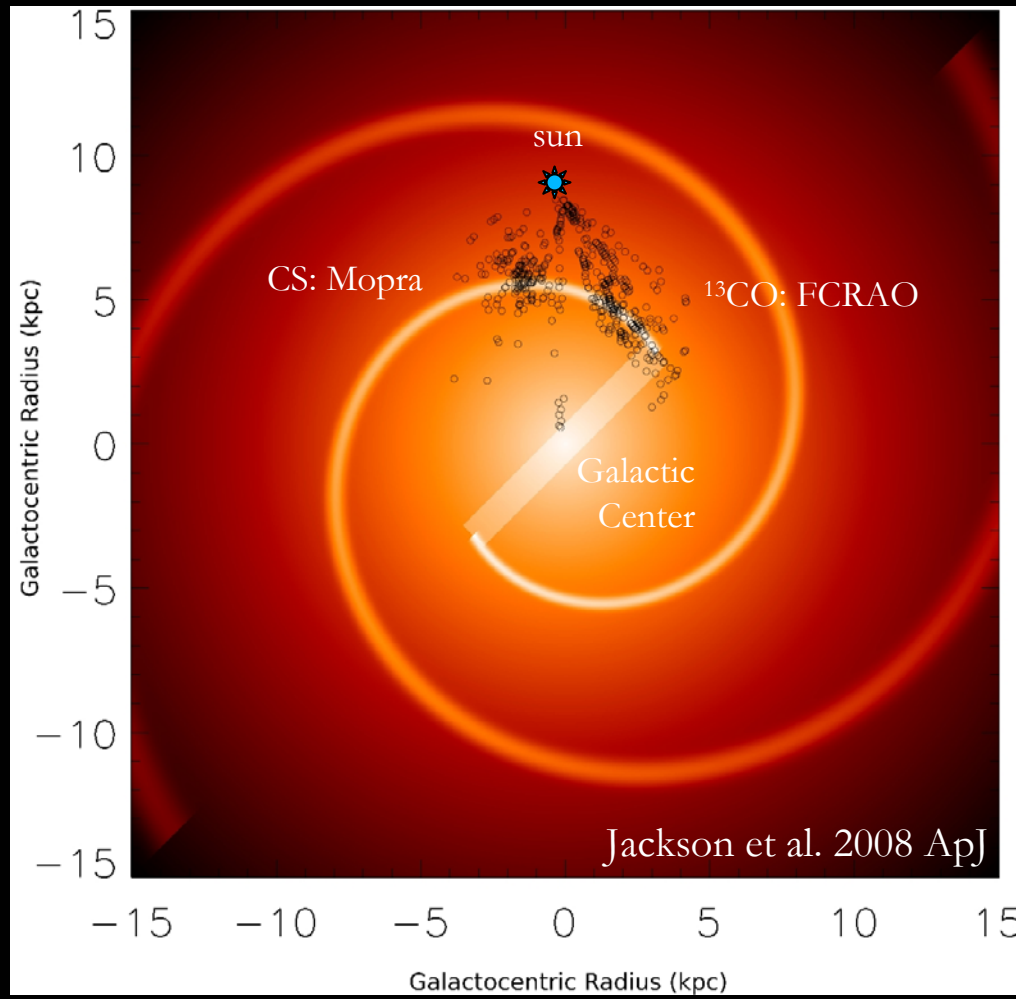
Perault et al. 1996; Egan et al. 1998; Carey et al. 1998, 2000; Hennebelle et al. 2001; Simon et al. 2006; Rathborne et al. 2006

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.”

The Galactic IRDC Distribution

- The IRDC distribution matches Galactic models dominated by two spiral arms.
- IRDCs appear to be associated with the "Scutum-Centaurus" arm.
- 90 GHz lines can probe Galactic spiral structure!



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

Large Filamentary IRDCs

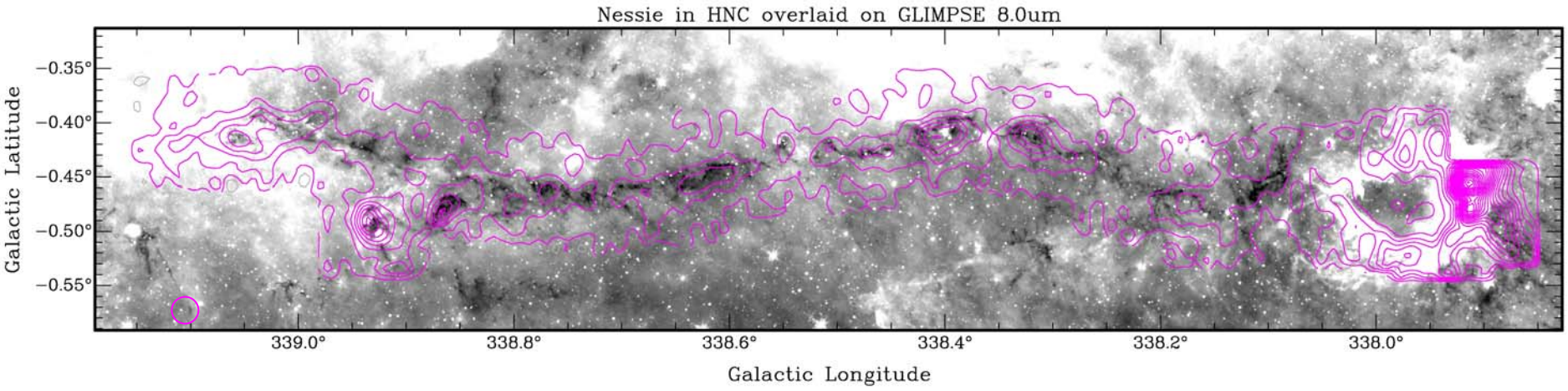
The "Nessie" Nebula

Size > ~100 pc x 0.5 pc

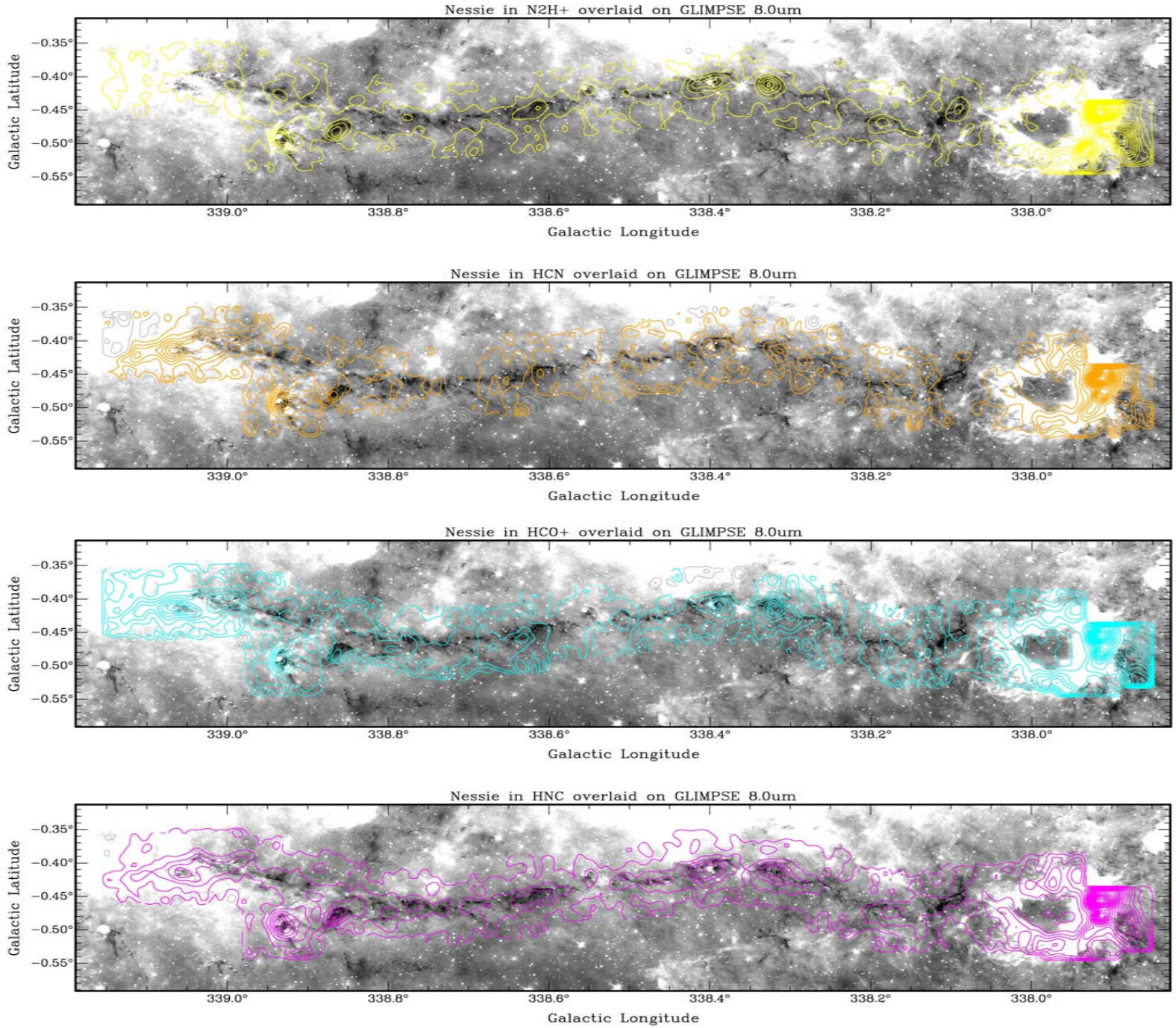
Blue - 3.6μm, Green - 8μm, Red - 24μm

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^+

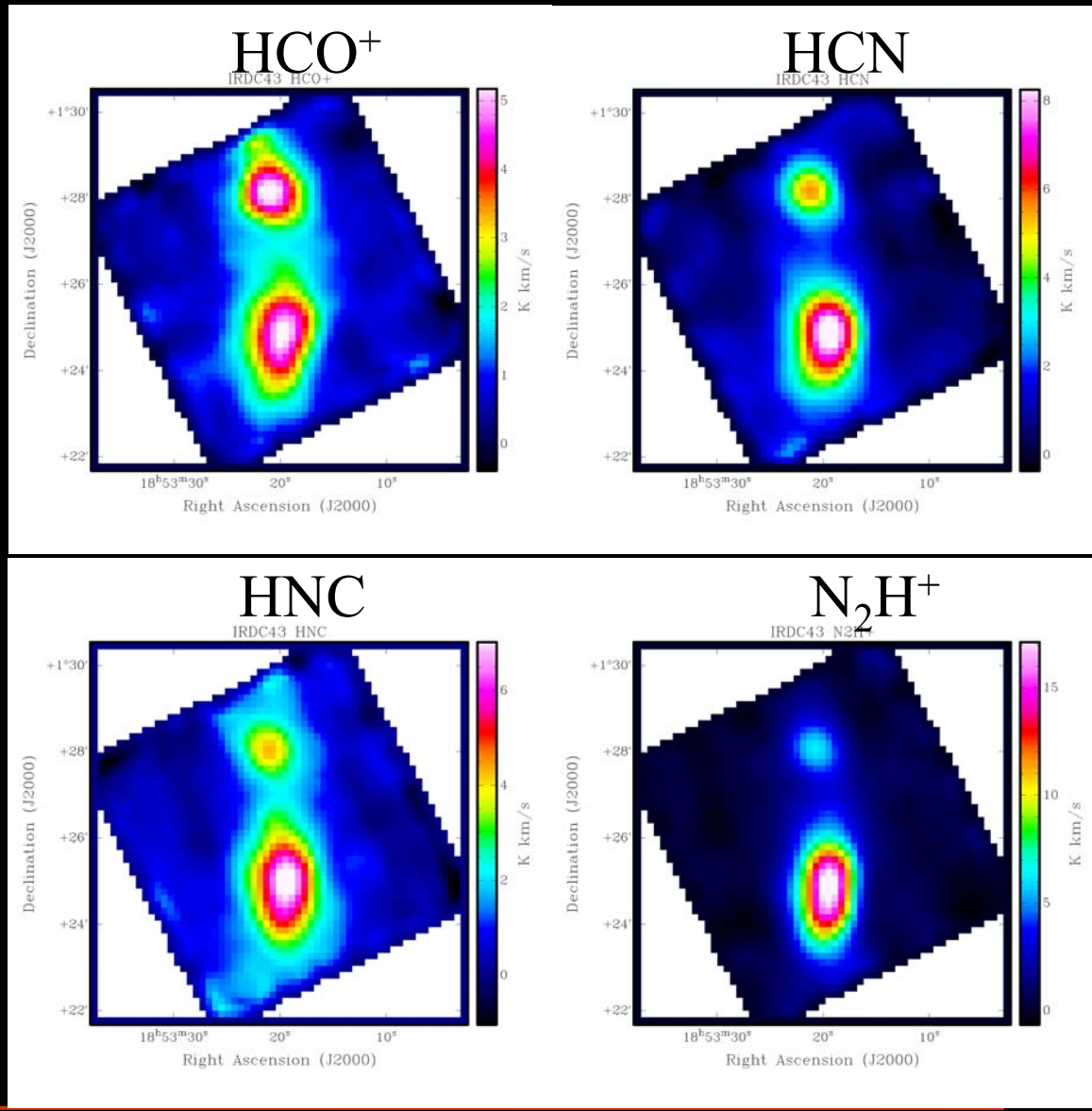
HNC

Chemical Environment

3 mm

Simultaneous mapping of 16 different molecular lines

Different molecular abundances for different star-forming cores



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
  - T and τ of individual cores would be improved
- 90 GHz lines: physical parameters and chemistry
  - Plays to Mopra's strengths
  - First large homogeneous database for many lines
  - First large scale MAPS of a dense gas tracers
  - Knowledge of IRDCs and star forming clump strucuture and chemistry would be vastly improved.