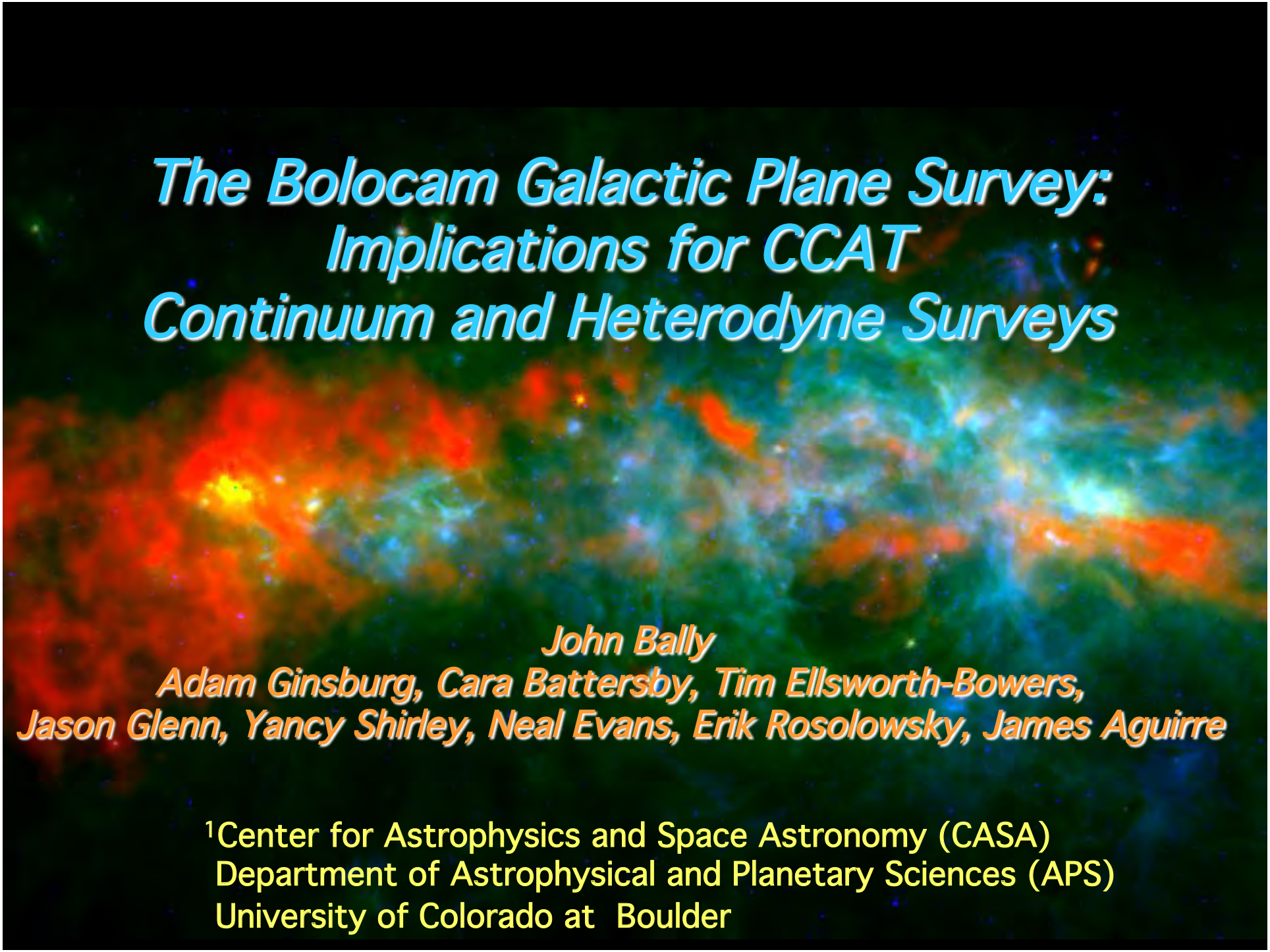

The Bolocam Galactic Plane Survey: Implications for CCAT Continuum and Heterodyne Surveys

John Bally

Adam Ginsburg, Cara Battersby, Tim Ellsworth-Bowers, Jason Glenn, Yancy Shirley, Neal Evans, Erik Rosolowsky, James Aguirre

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Department of Astrophysical and Planetary Sciences (APS)
University of Colorado at Boulder

Outline

- The Bolocam Galactic Plane Survey (BGPS):

  Lessons Learned

- Need for CCAT sub-mm continuum

  3" Beam @350 μm, Polarization, Variability

- Need for Wide-field heterodyne surveys

  Physical parameters of ISM components

- Science in the ALMA / LSST/ JWST era

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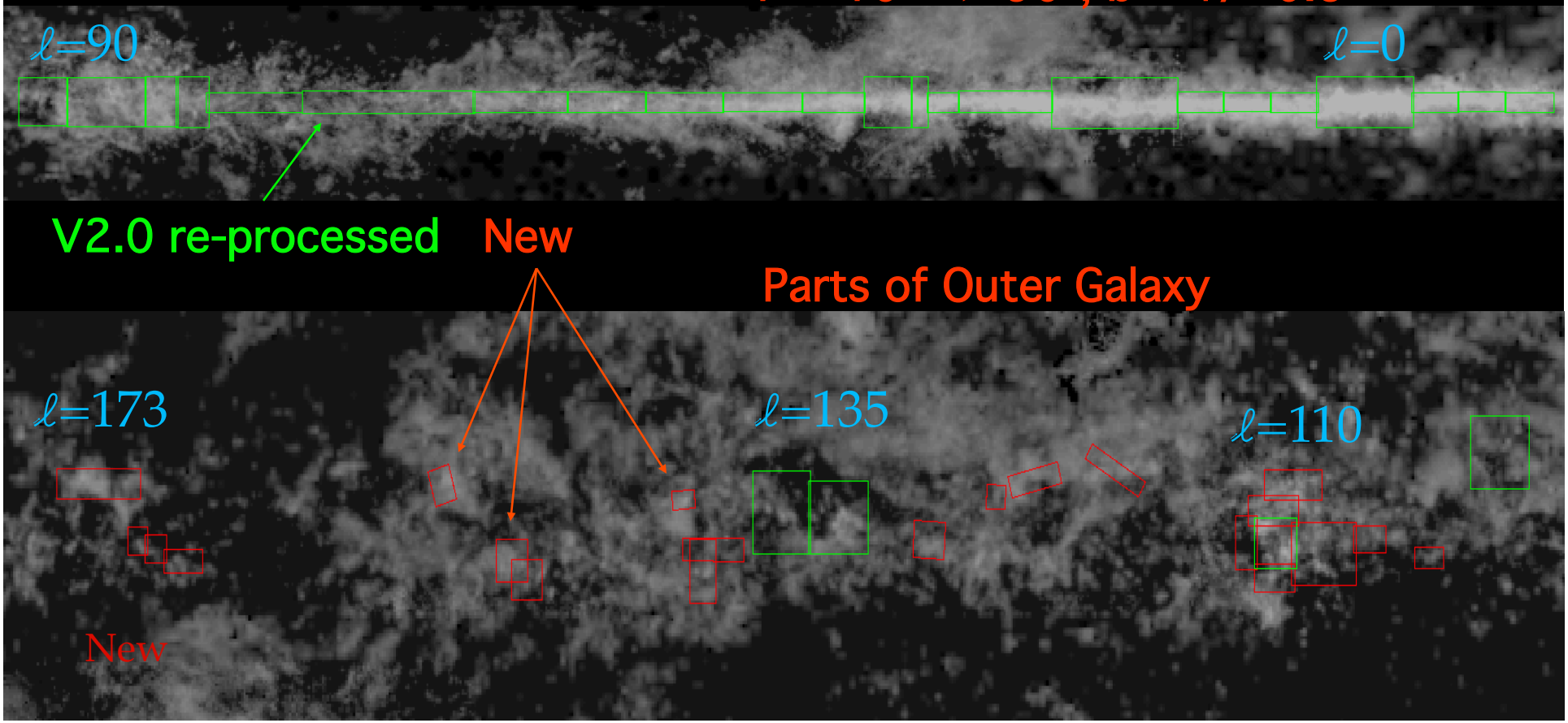
Bolocam Galactic Plane Survey (BGPS):

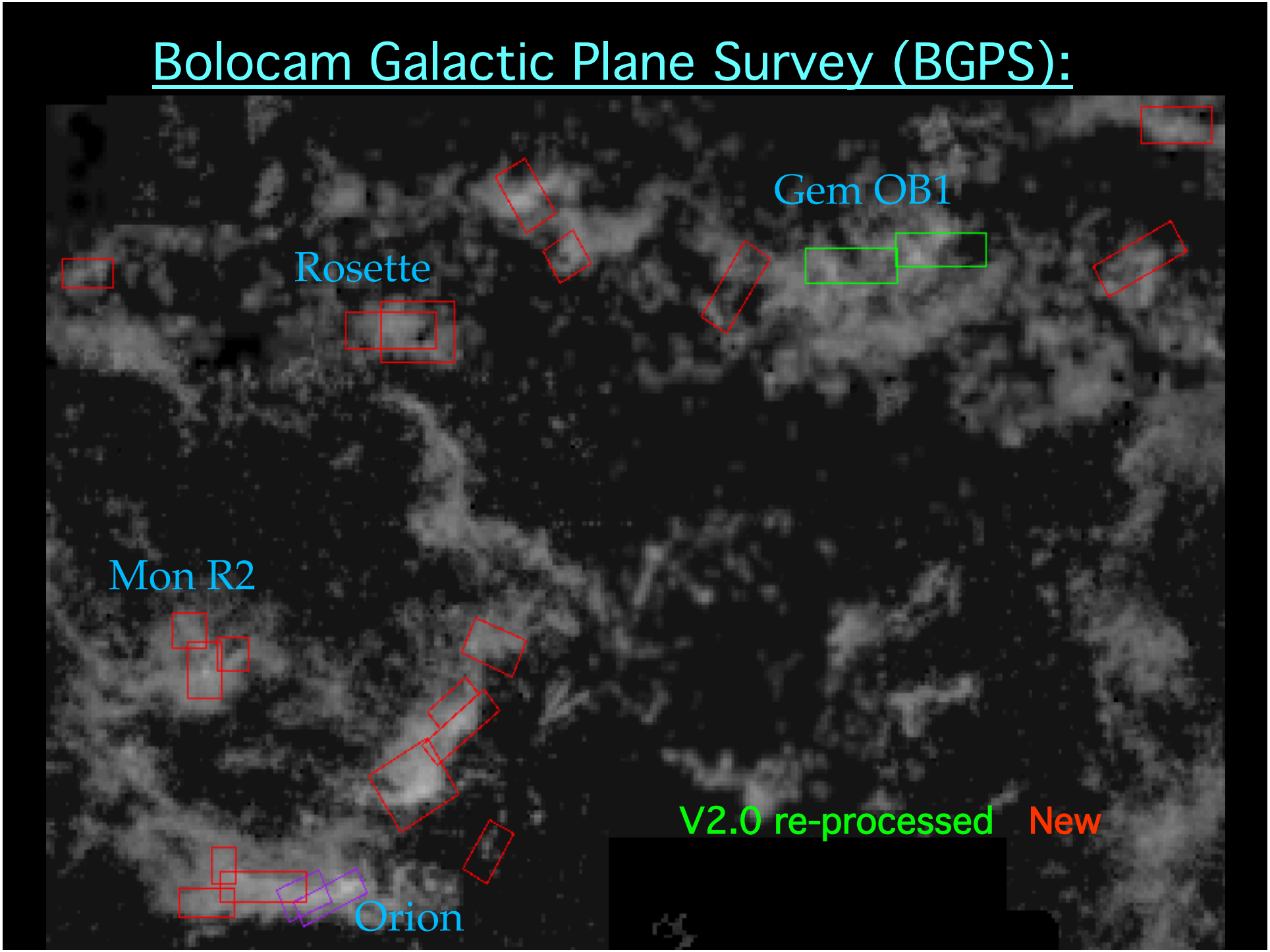
- λ = 1.1 mm, Caltech Sub-mm Observatory 10.4 m:

  θ = 33” Sensitivity ~ 50 to 100 mJy/beam

  200 square deg.



Bolocam Galactic Plane Survey (BGPS):

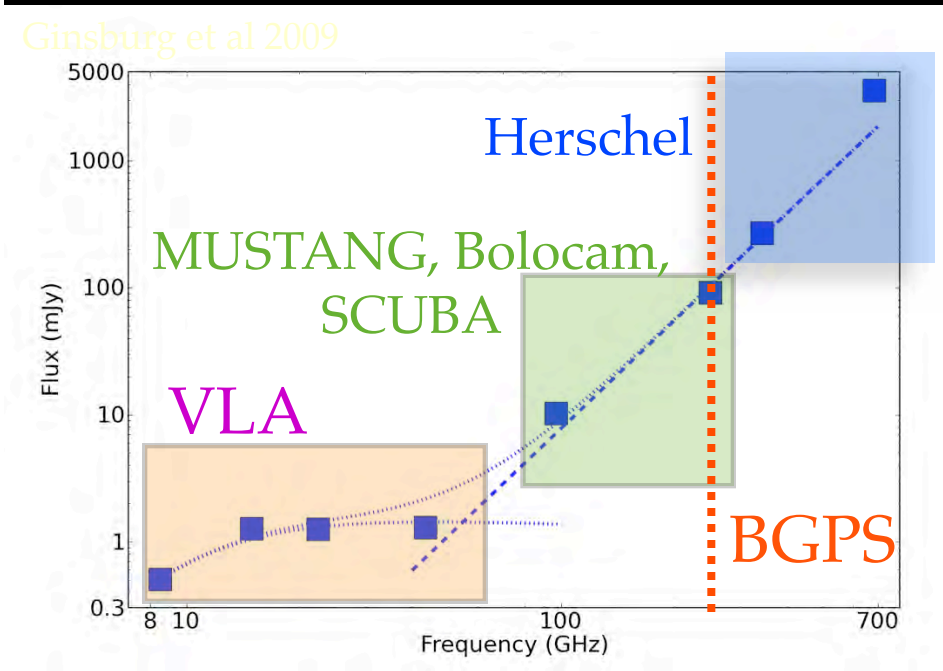


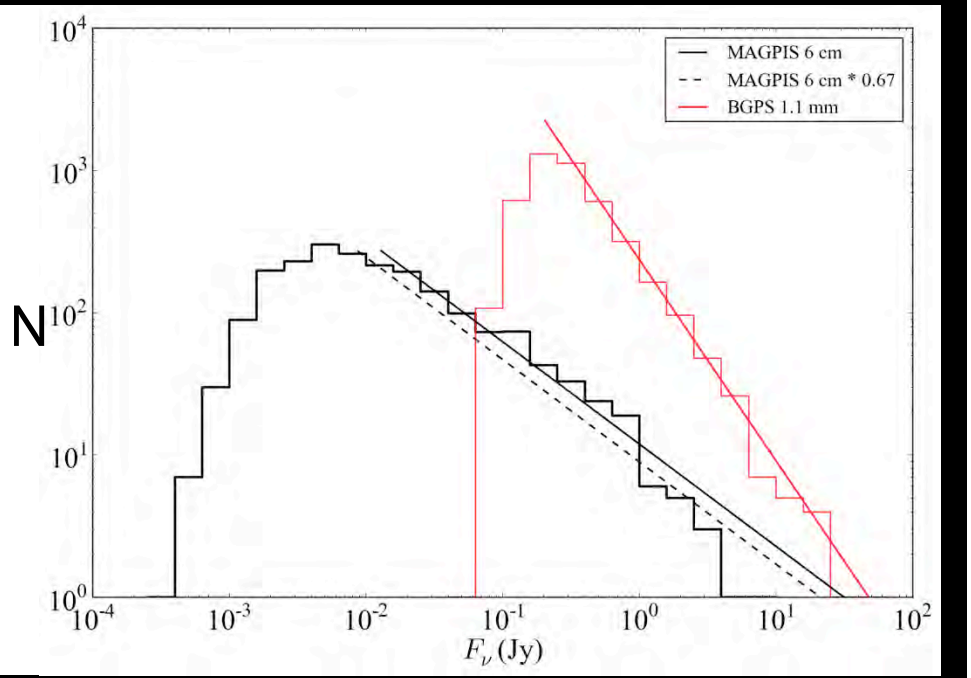
BGPS: Need for 1.1 mm

Distinguish dust from free-free

Find coldest dust

Measure β





See Ginsburg+2010; ...

BGPS Version 2:

(Adam Ginsburg)

- Better image quality
- Better calibration
- Quantified spatial transfer function
- Better coverage

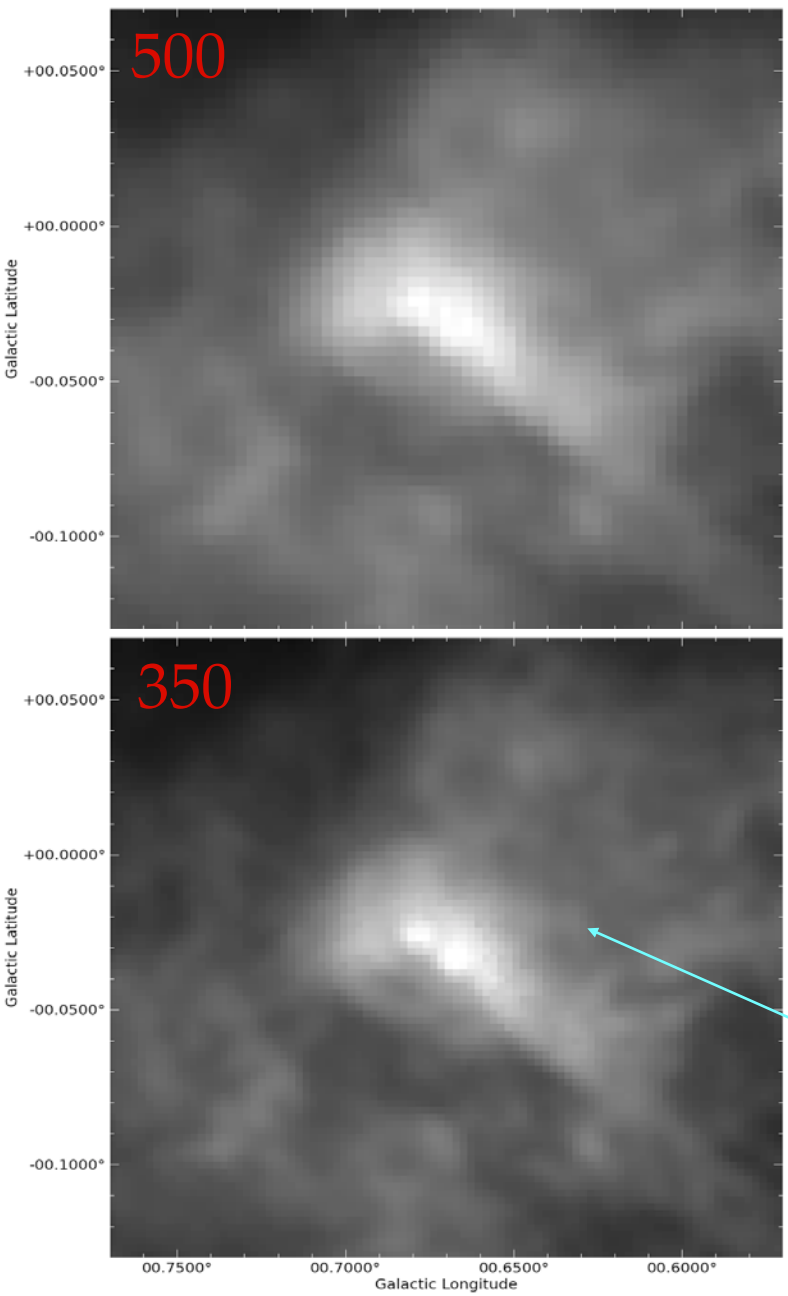
  (200 sq. deg. Vs 170 sq. deg.)

- Public access:

  http://irsa.ipac.caltech.edu/data/BOLOCAM_GPS/

  See Aguirre+ 2010; Rosolowsky+ 2010; Bally+2010; ...

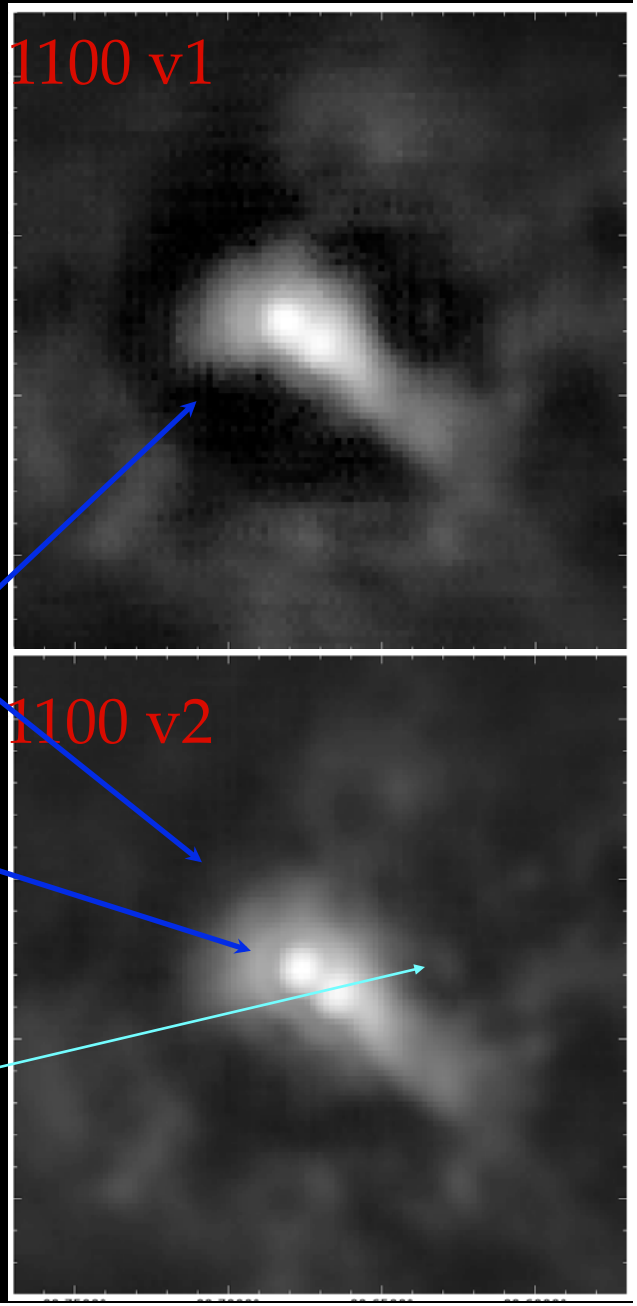
Hi-GAL Sgr B2 BGPS Version 2:



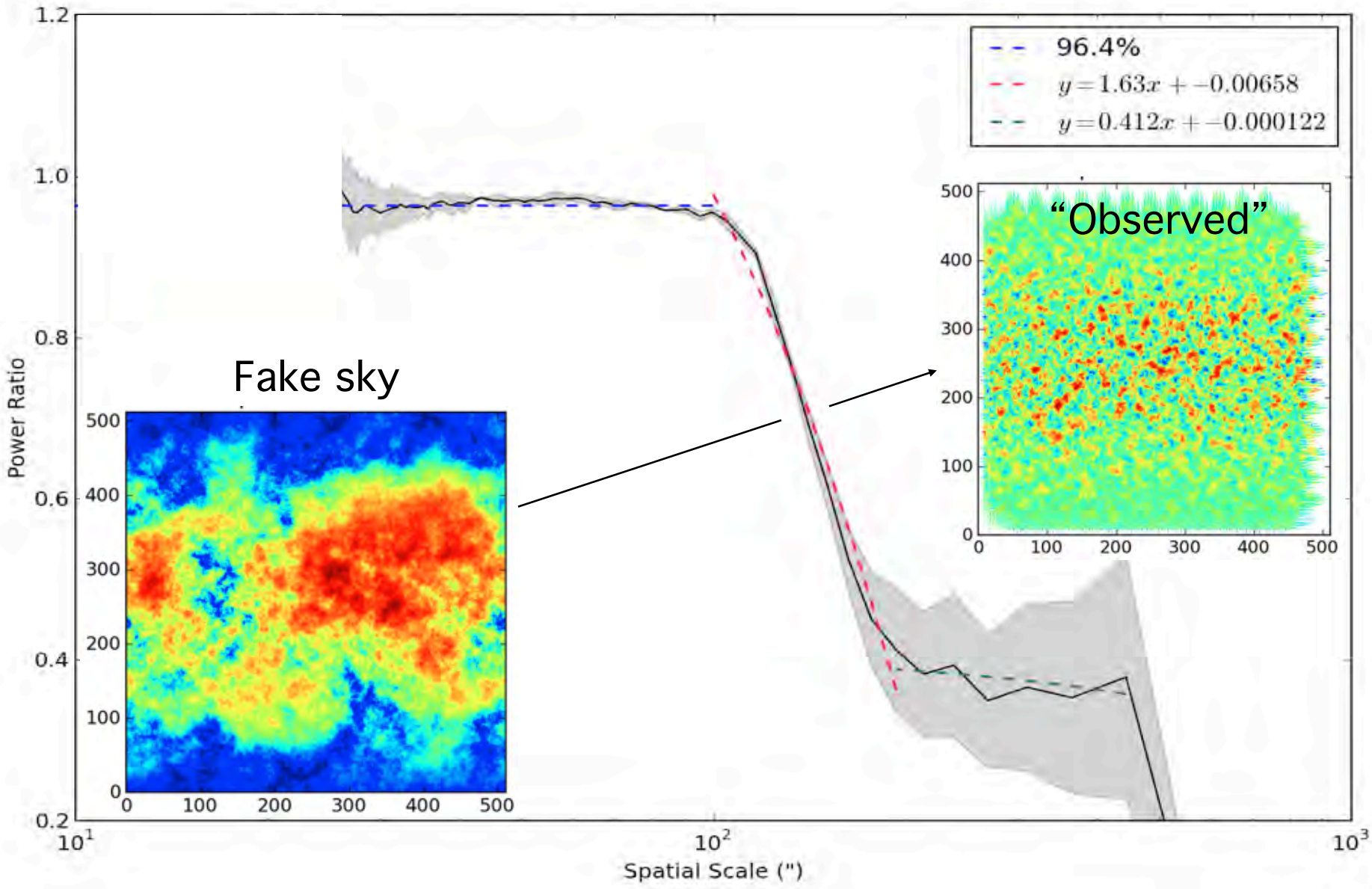
Negative Bowl

Airy ring

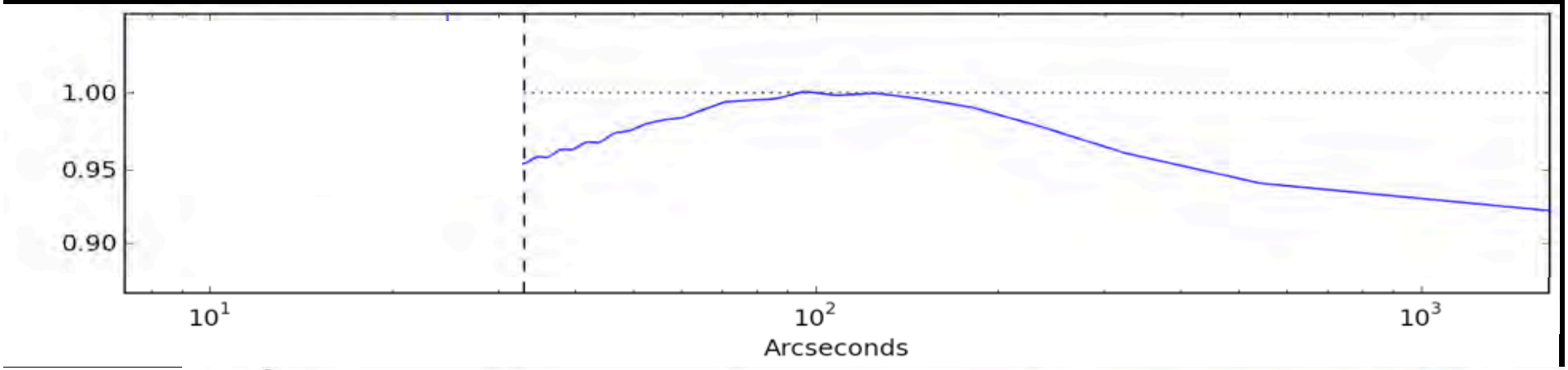
Faint sources

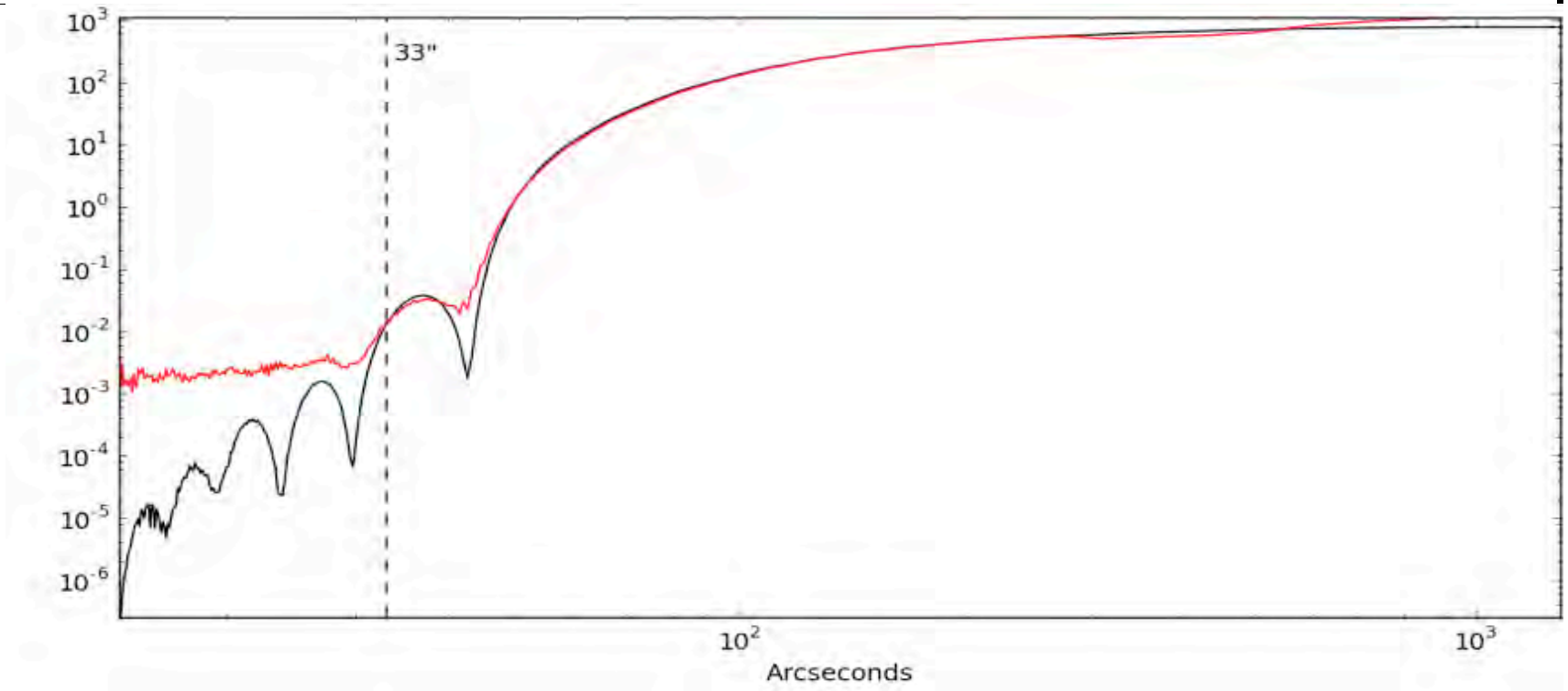


BGPS Version 2:
Spatial Transfer Function



BGPS Version 2:
Point Source Recovery





BGPS Distances:

(Timothy Ellsworth-Bowers)

- Heterodyne spectra => Kinematic distances #

  CS 2-1 (CSO); ~ 600

  NH_3 (GBT); ~ 500

  HCO^+ 3-2 & N_2H^+ (HHT - Mt. Graham) ~ 6,000

  H2CO (GBT + Arecibo) ~ 400

  FCRAO ^{13}CO ~ 2,000

Kinematic Distance Ambiguity Resolution ($R < R_o$)

- IRDCs + HI self-absorption + latitude + foreground *s

  Conjoint distance probability estimator

  - An automated IDL-based program ! -

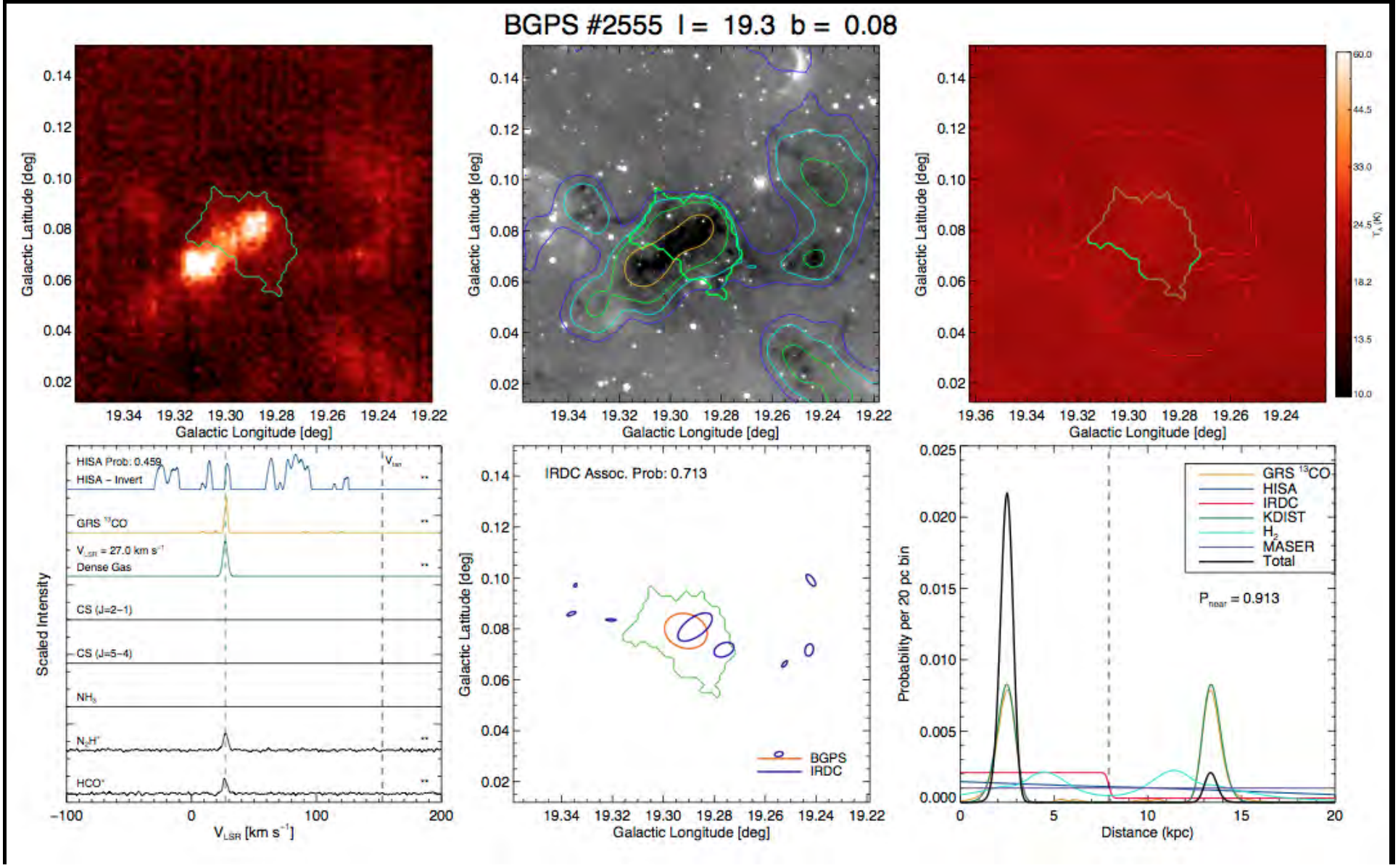
BGPS Distances:

(Timothy Ellsworth-Bowers)

- Kinematic distances may be derived from radial velocity measurements of associated dense gas tracers and a Galactic rotation curve.
- Objects within the Solar Circle suffer from the kinematic distance ambiguity (KDA).
- With a Bayesian formalism, we use information from external Galactic plane data sets to form prior probabilities on the distance probability density function.
- The goal: An automated distance determination technique applicable to large data sets.

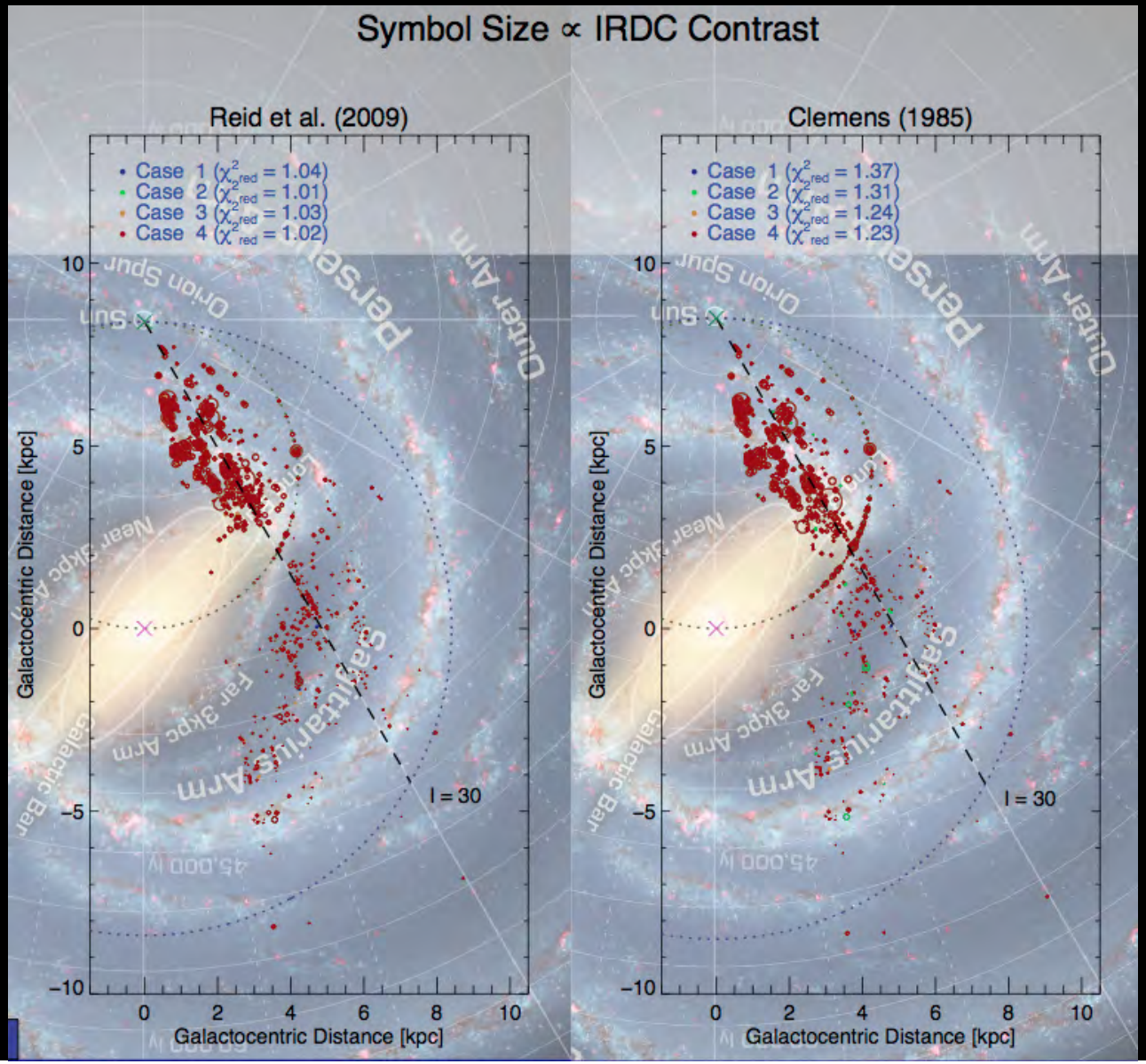
BGPS Distances:

(Timothy Ellsworth-Bowers)



BGPS Distances:

(Timothy Ellsworth-Bowers)



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  3” Beam @350 mm, Polarization, Variability

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  Physical parameters of ISM components

- Science in the ALMA / LSST/ JWST era

Need for CCAT Sub-mm Continuum

- Total power at 3” resolution @350 μm
  - Match Spitzer, improve on Herschel
  - ALMA 0-spacing
  - dust properties
- Polarization
  - Grain alignment => B-field
- Variability
  - Dynamic interaction in ultra-dense clusters
  - Stellar mergers in super-star-clusters
  - IR light echoes from flares
    - (FU Ori, Massive YSOs, LBVs, SNe, QSO, etc.)

CCAT Sub-mm Continuum Surveys

- Multi-color Galactic Plane Surveys

  Deep: to few mJy (to ex-GAL confusion)

  Small-scale sub-structure =>

  fragmentation /clustering

  Spectral index => dust β

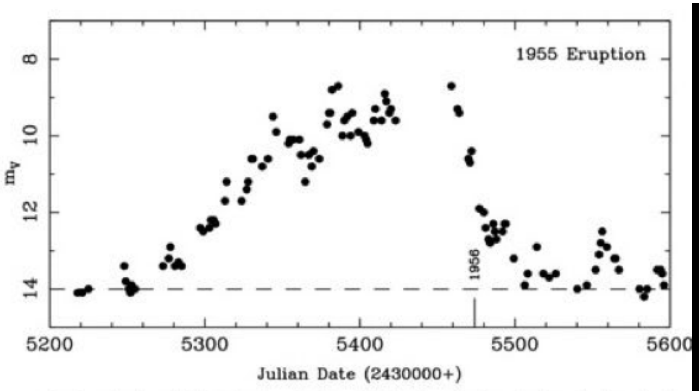
  Polarization

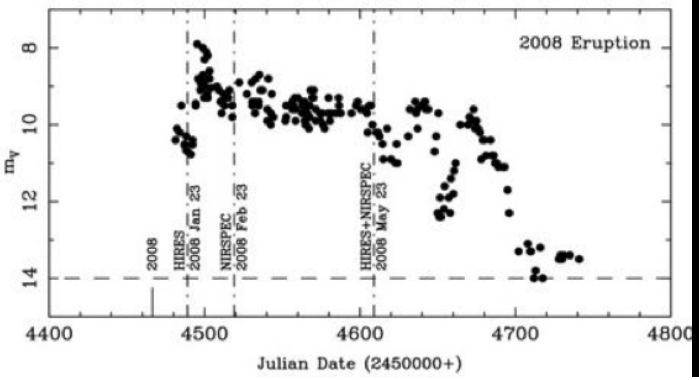
  Grain alignment => B-field

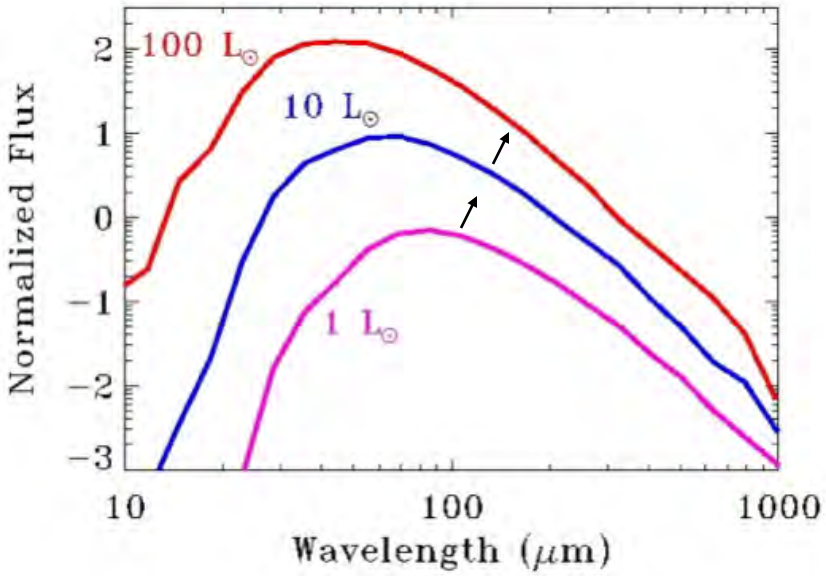
Sub-mm continuum variability

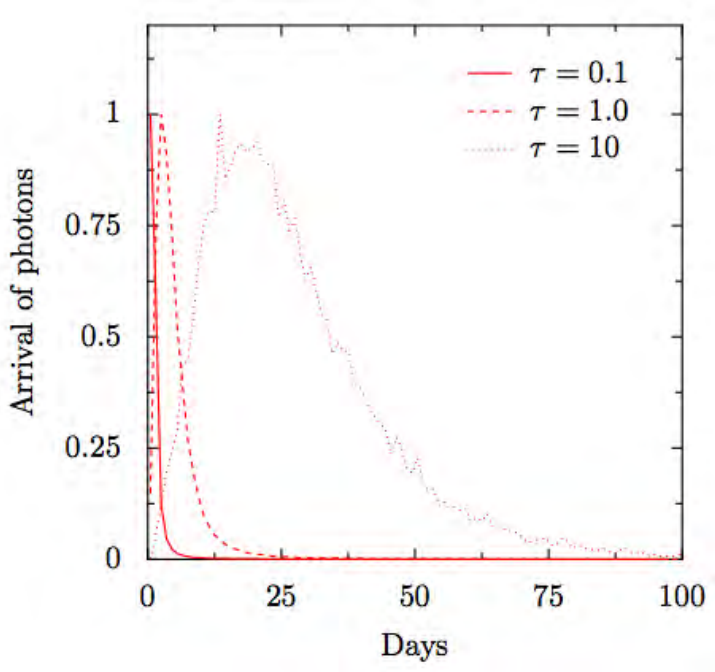
EX Lupi flares: 1955 & 2008
(Aspin 2010)

FIR / sub-mm time-delay
(Herczeg 2011)



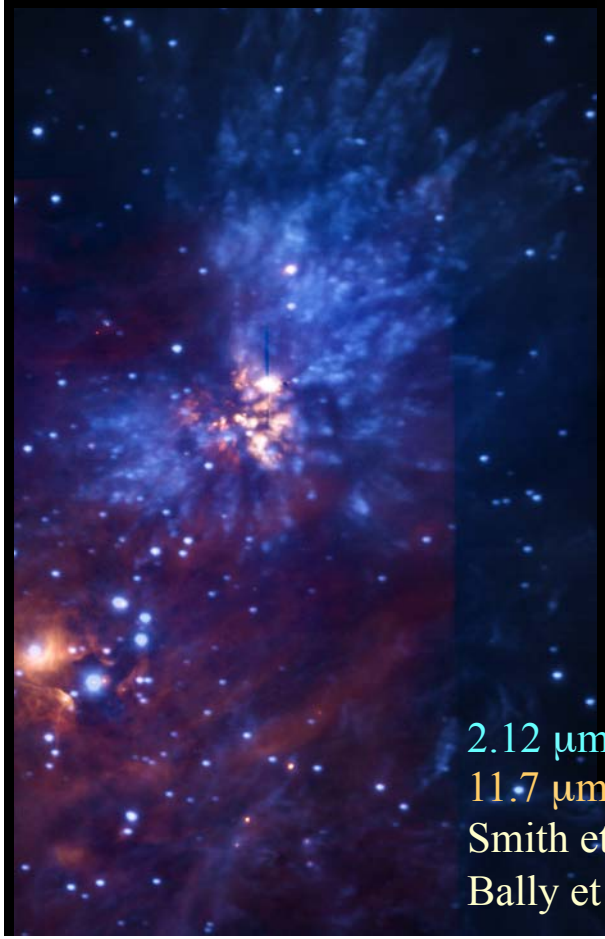




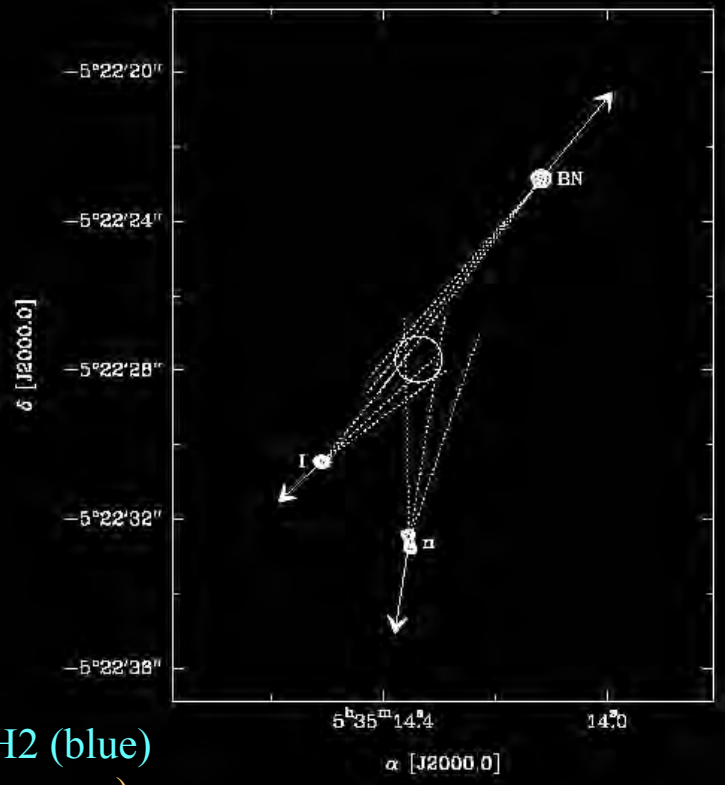


The OMC1 Explosion (Bally 2011)

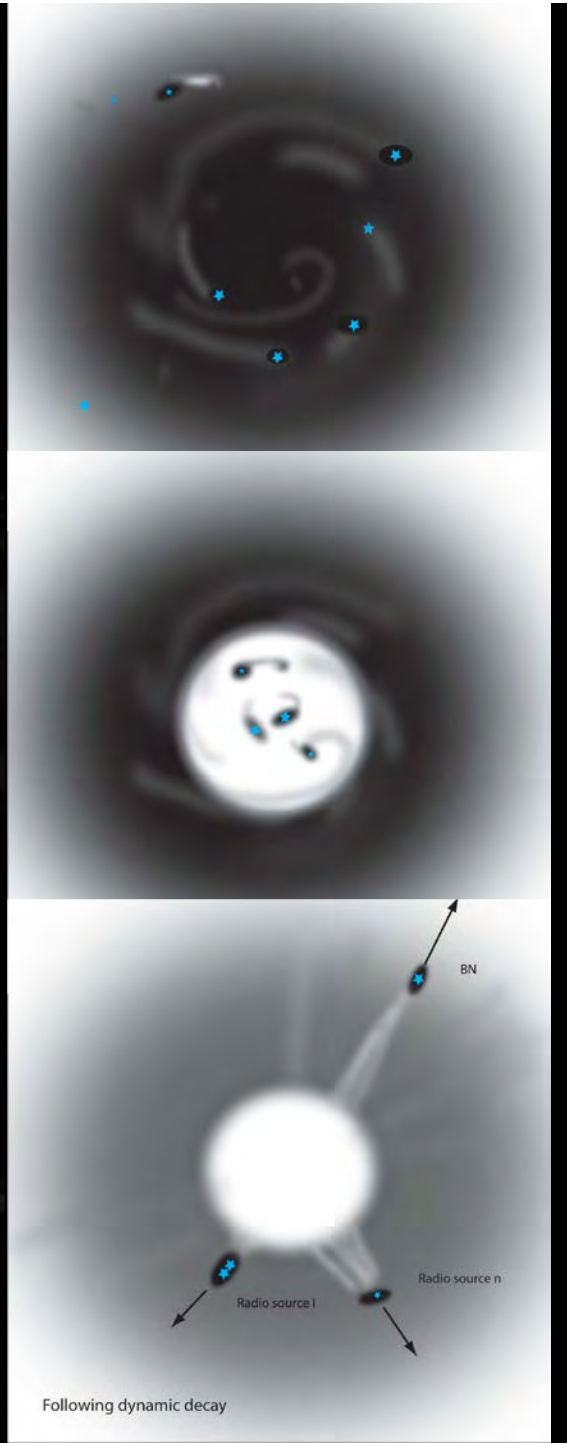
- Dynamical decay of non-hierarchical system:
  $E_* \sim 3 \times 10^{47}$ ergs
- Ejection of high velocity stars (BN, I, n)
  => $\langle V \rangle \sim V_* \sim 20$ km/s



2.12 μm H2 (blue)
11.7 μm (orange)
Smith et al. (2005)
Bally et al. (2011)

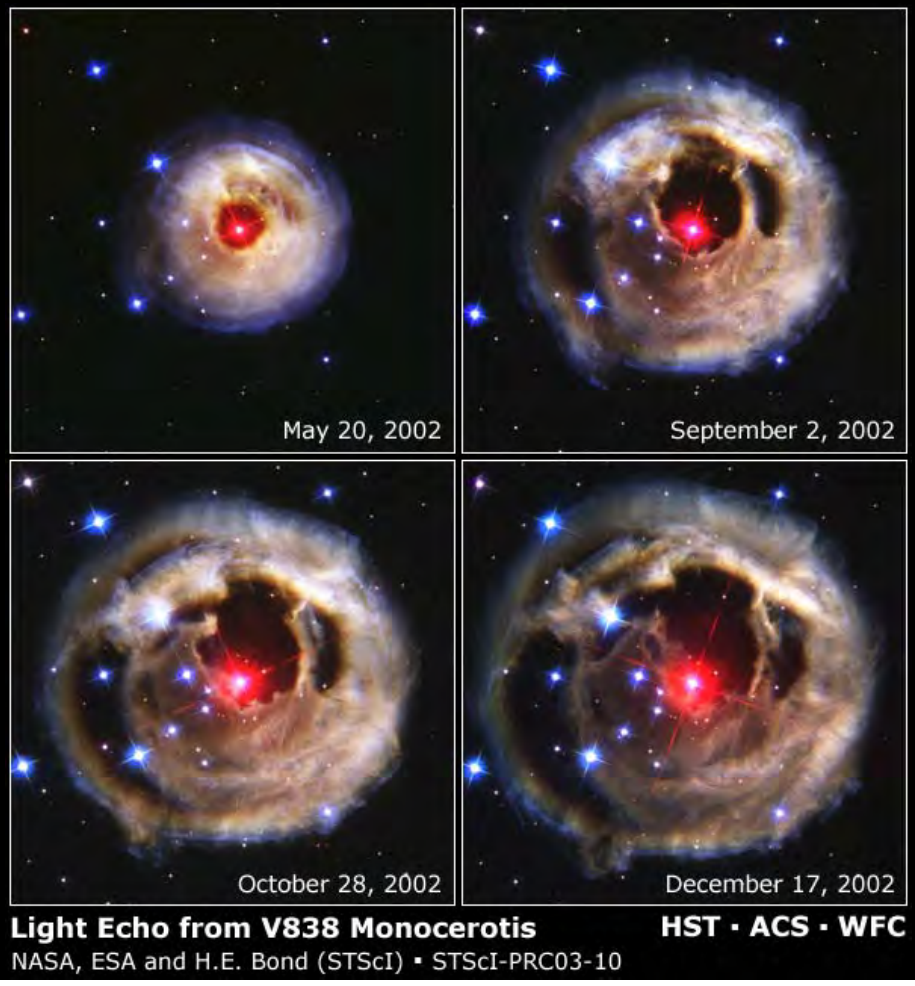


Gomez et al. (2008)



CCAT Variability:

Massive star merger (V839 Mon)



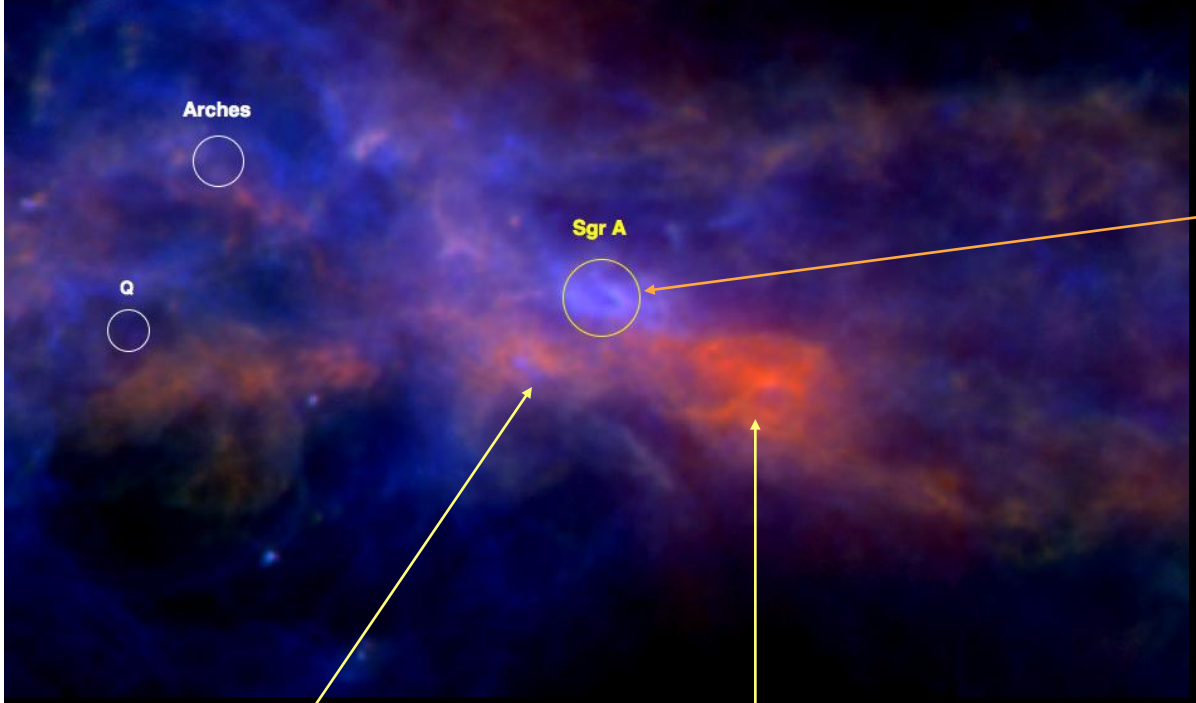
- Embedded merger & Inteactions
  => 10^4 - >10^9 L_o flares
  (Bally & Zinnecker 2005)
- Embedded SN

CCAT:

- Monitor nearby star-burst galaxies
  NGC 253, He 2-10, ...
- Monitor Galactic embedded Young Massive Clusters
  Sgr B2, W51, W33A ...

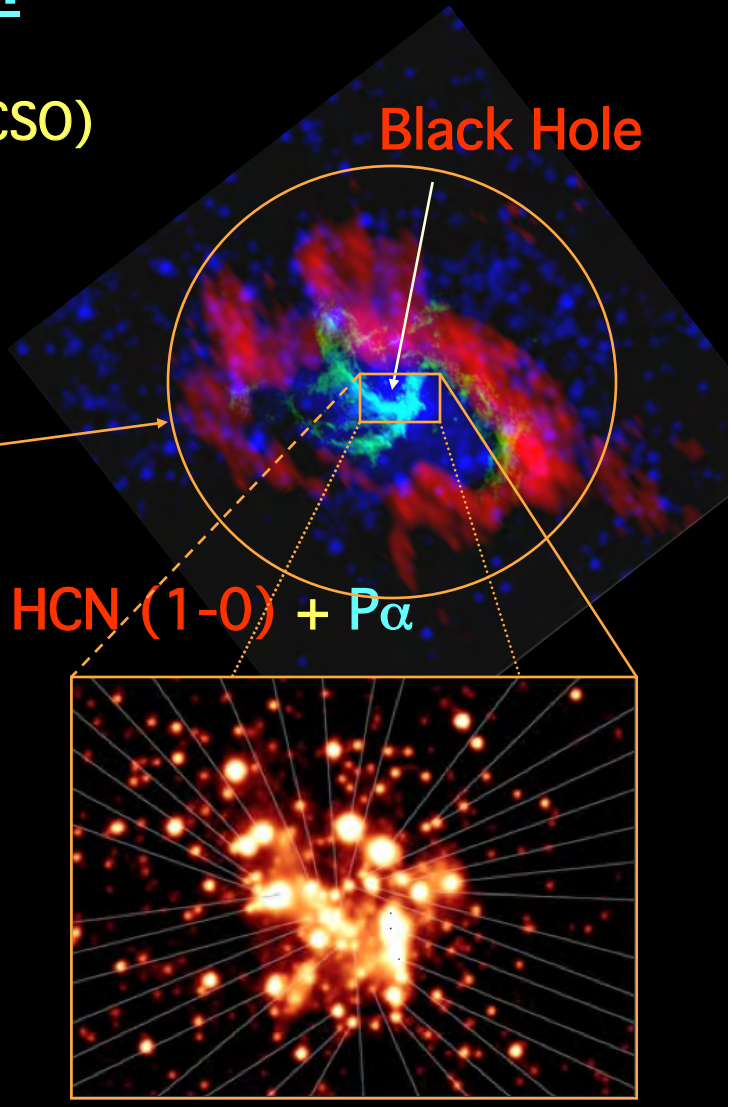
Sgr A & Circum Nuclear Ring (CNR):

70 um, 160 um (Herschel), 350 um (SHARC/CSO)



50 km/s cloud

20 km/s cloud



Sgr A cluster
L-band: (Viehmann 06)

CCAT: Sub-mm Flares from black hole, stellar dynamic interactions

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CCAT heterodyne camera surveys

- Heterodyne surveys of Galactic Plane:

  CO, CS, HCO^+, N_2H^+, H_2CO, ...

  Distances

  Cloud structure

  Formation, evolution, destruction

  Galactic structure

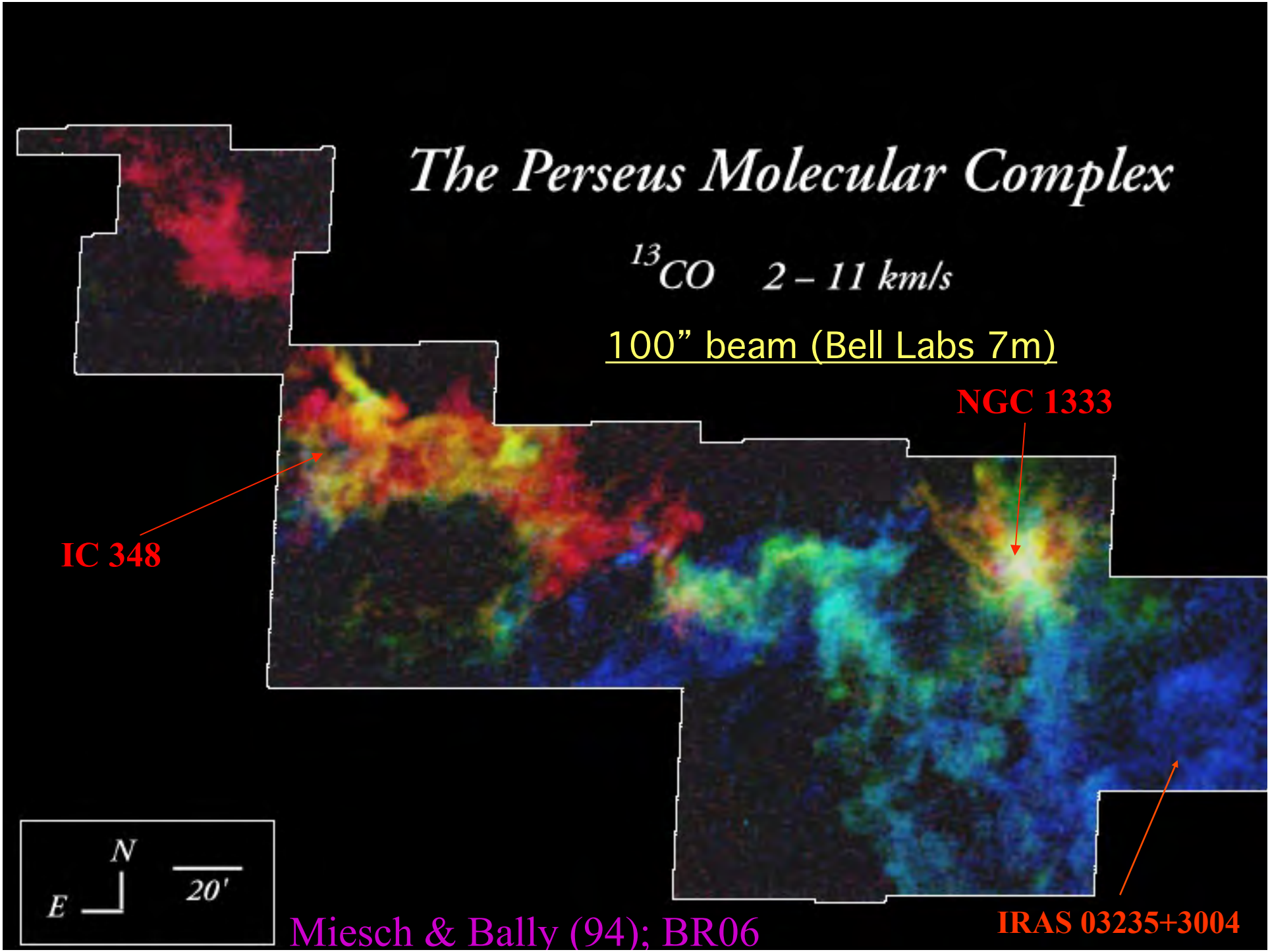
  CMZ, far-outer Galaxy (warp => high *b*!)

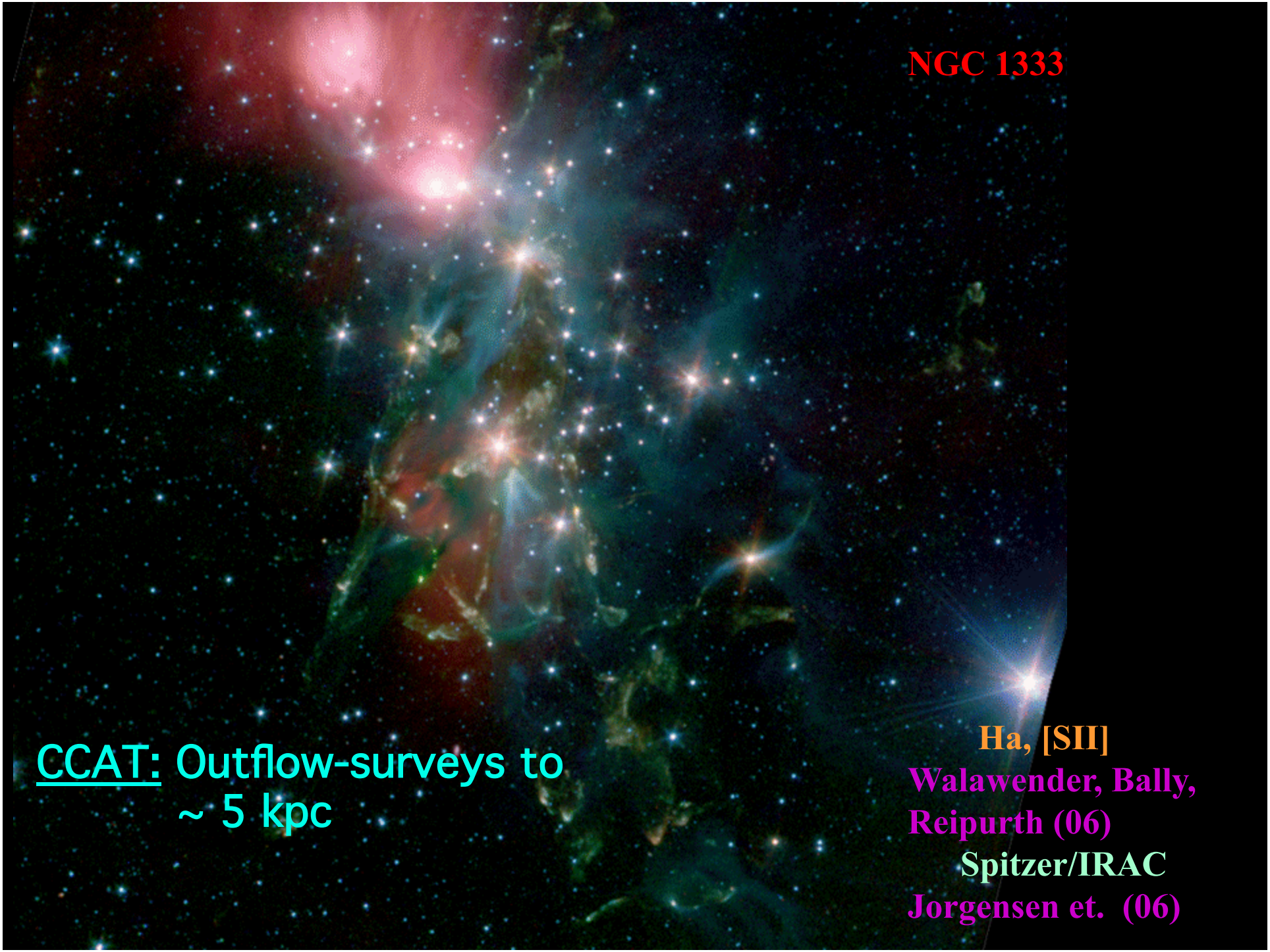
  H 26-α recombination line-surveys

  Outflows

  Chemical age-dating

  PDR, XDR, and cosmic-ray interactions


The Perseus Molecular Complex
^{13}CO 2 – 11 km/s
100" beam (Bell Labs 7m)
NGC 1333
IC 348
N
E
20'
Miesch & Bally (94); BR06
IRAS 03235+3004

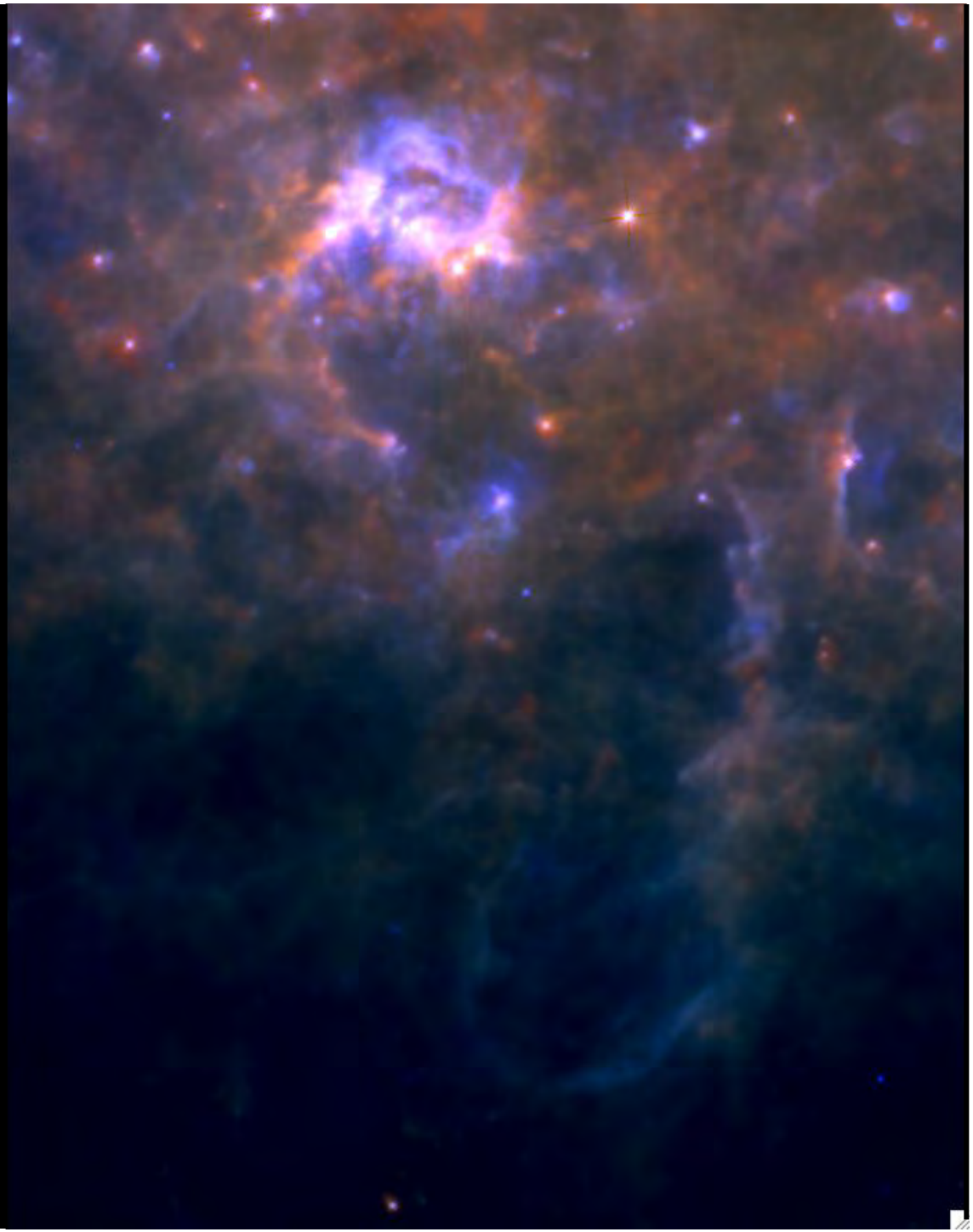

NGC 1333
CCAT: Outflow-surveys to
~ 5 kpc
Ha, [SII]
Walawender, Bally,
Reipurth (06)
Spitzer/IRAC
Jorgensen et. (06)

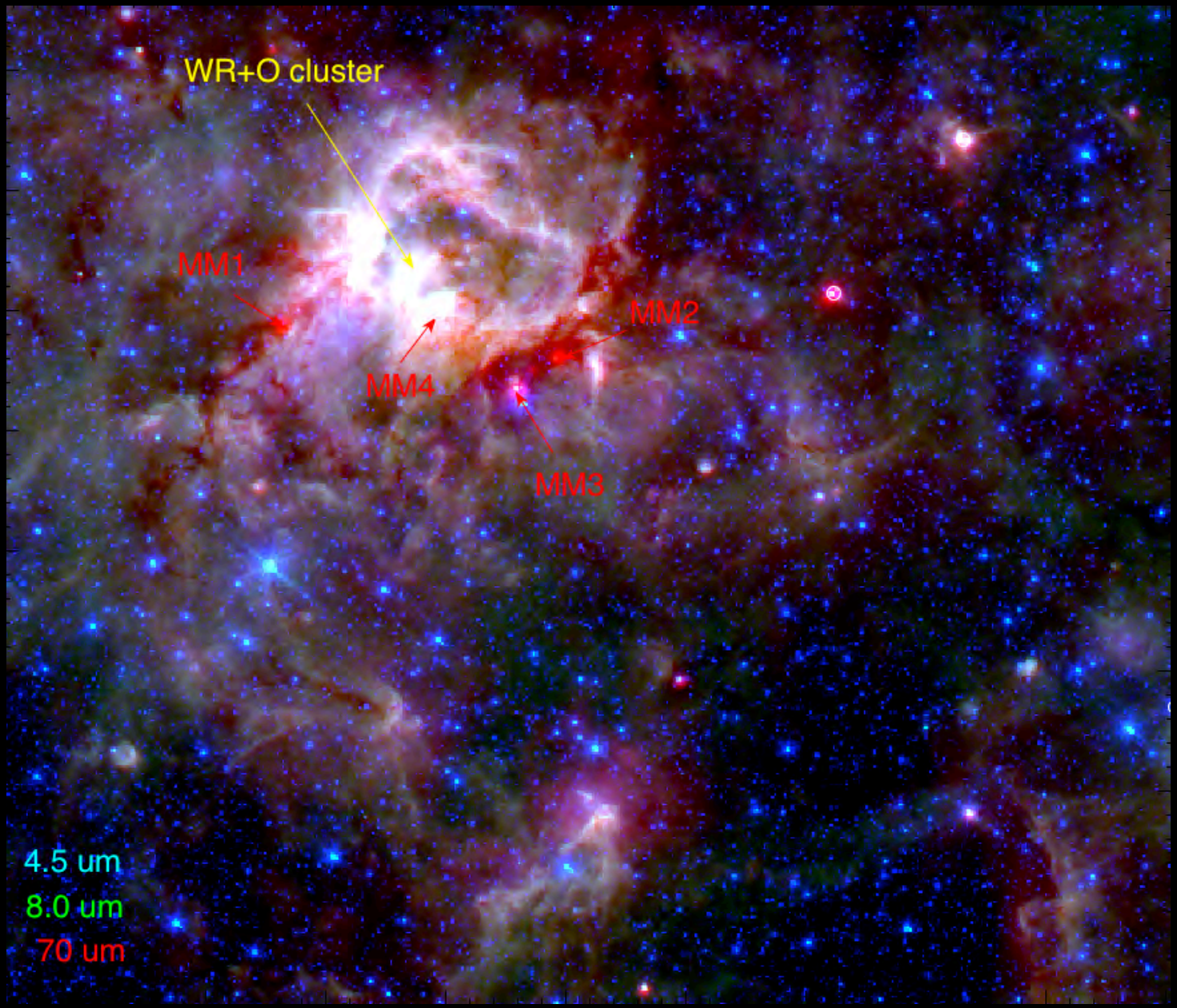
W43
Giant HII region
mini-starburst

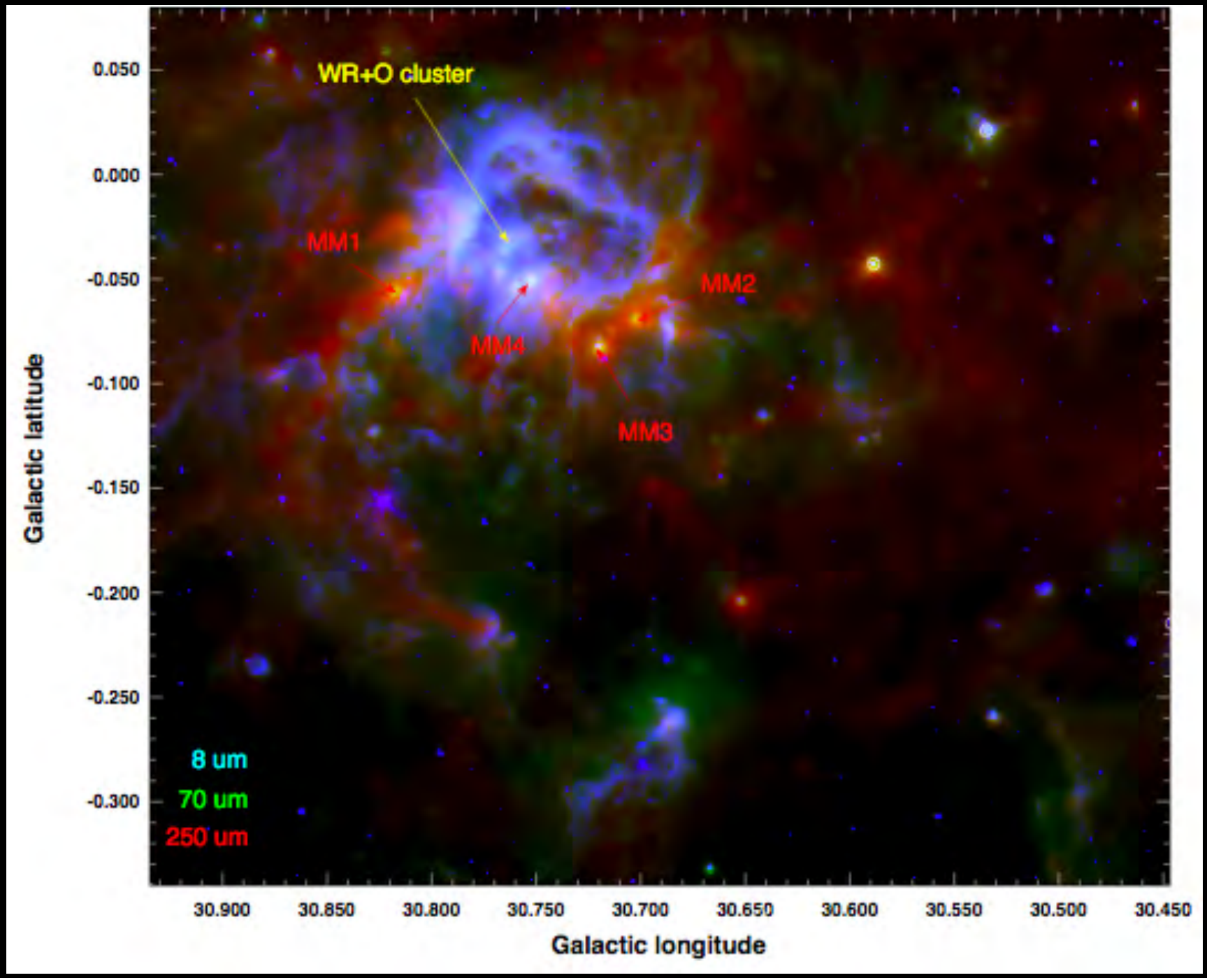
[l,b] = 30.77, -0.04
V_{lsr} ~ 86 to 106 km/s

D ~ 5.5 kpc
L > 3.5 x 10^6 L_o
M_{GMC} ~ 10^6 M_o

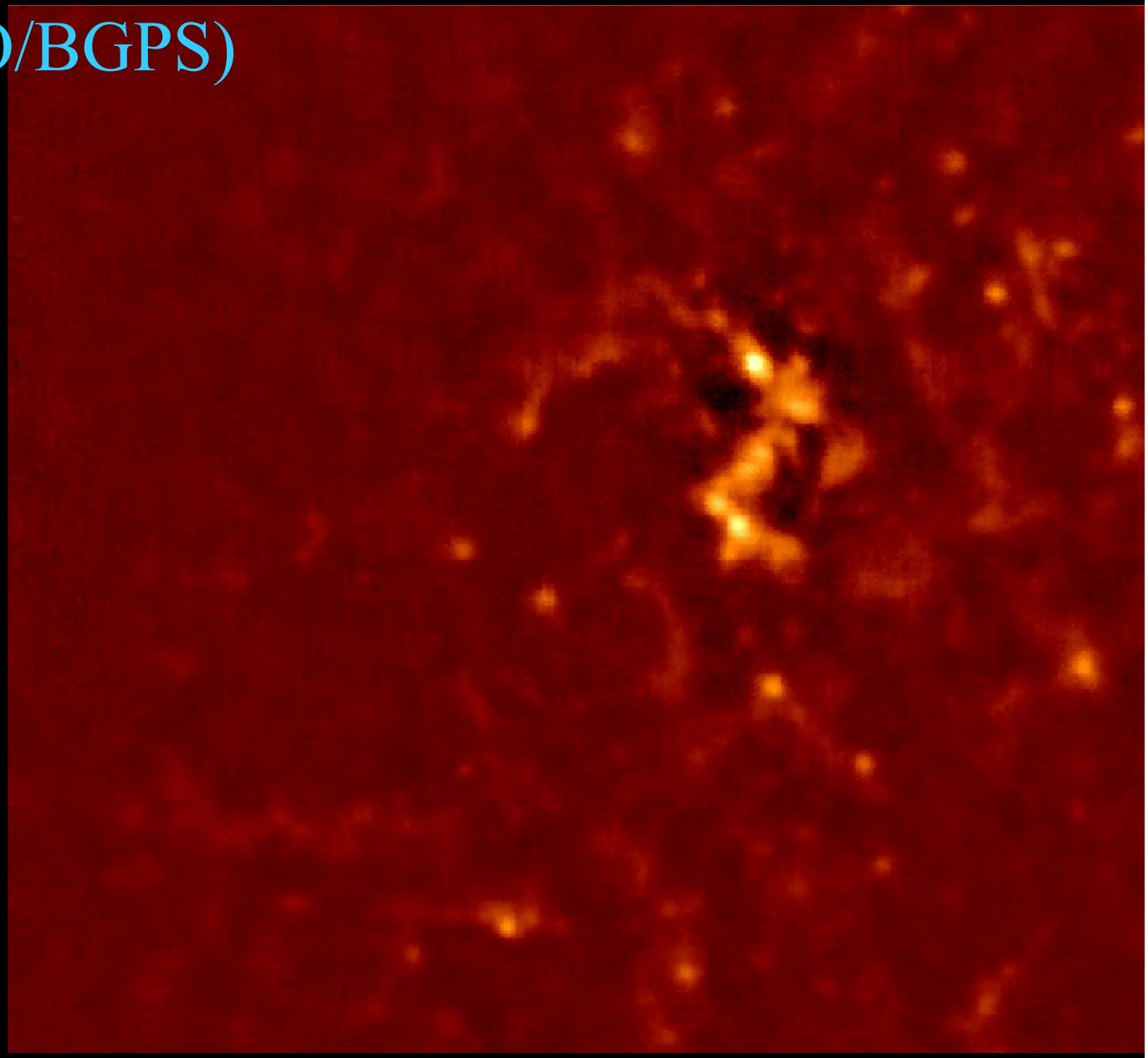
L_{LyC}~ 10^{51} ionizing γ s^{-1}
(50 x Orion Neb.
=> 50 O7 stars!)
O3 and WR stars
=> age >3 Myr

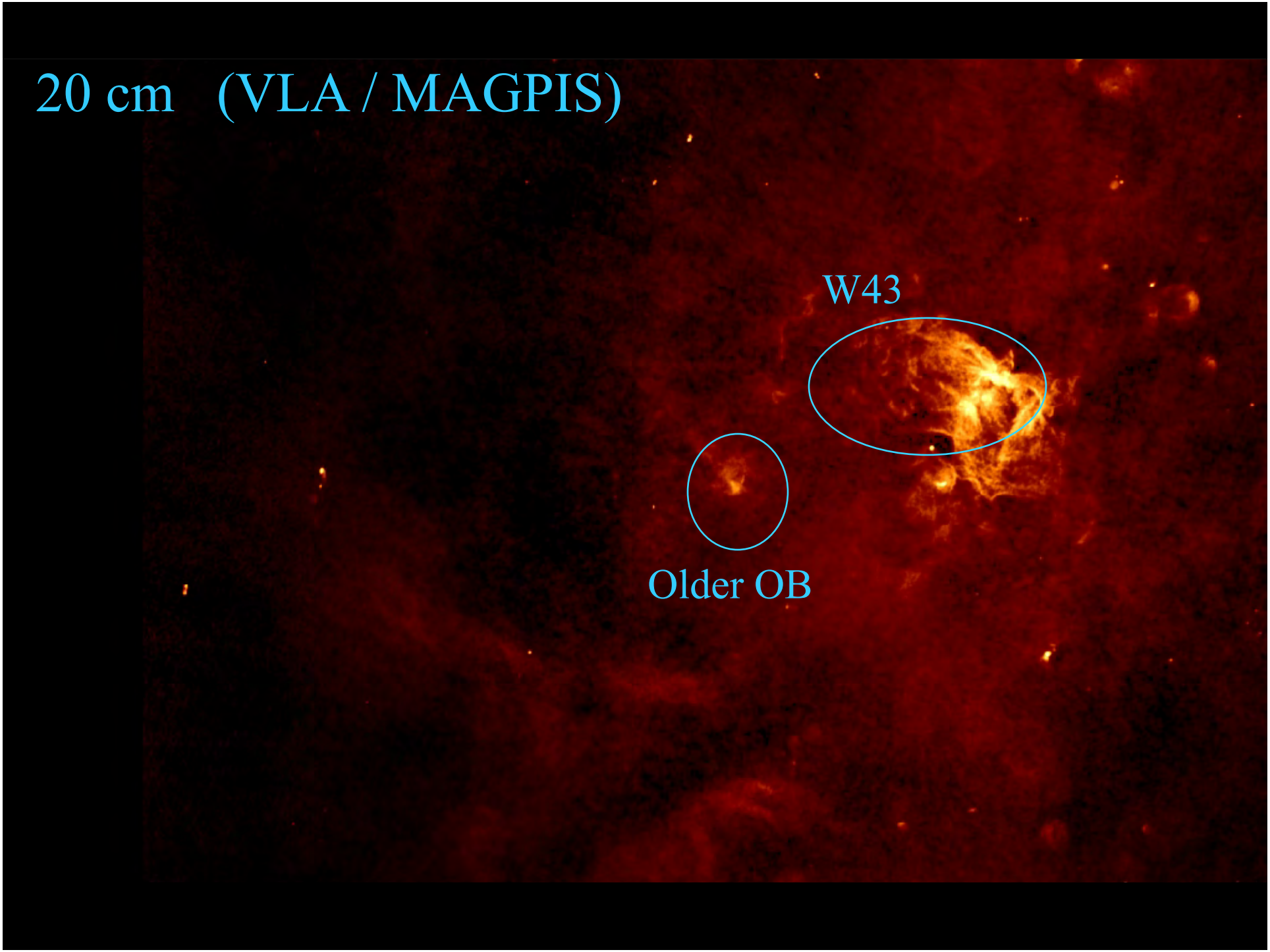



WR+O cluster
MM1
MM2
MM4
MM3
4.5 um
8.0 um
70 um

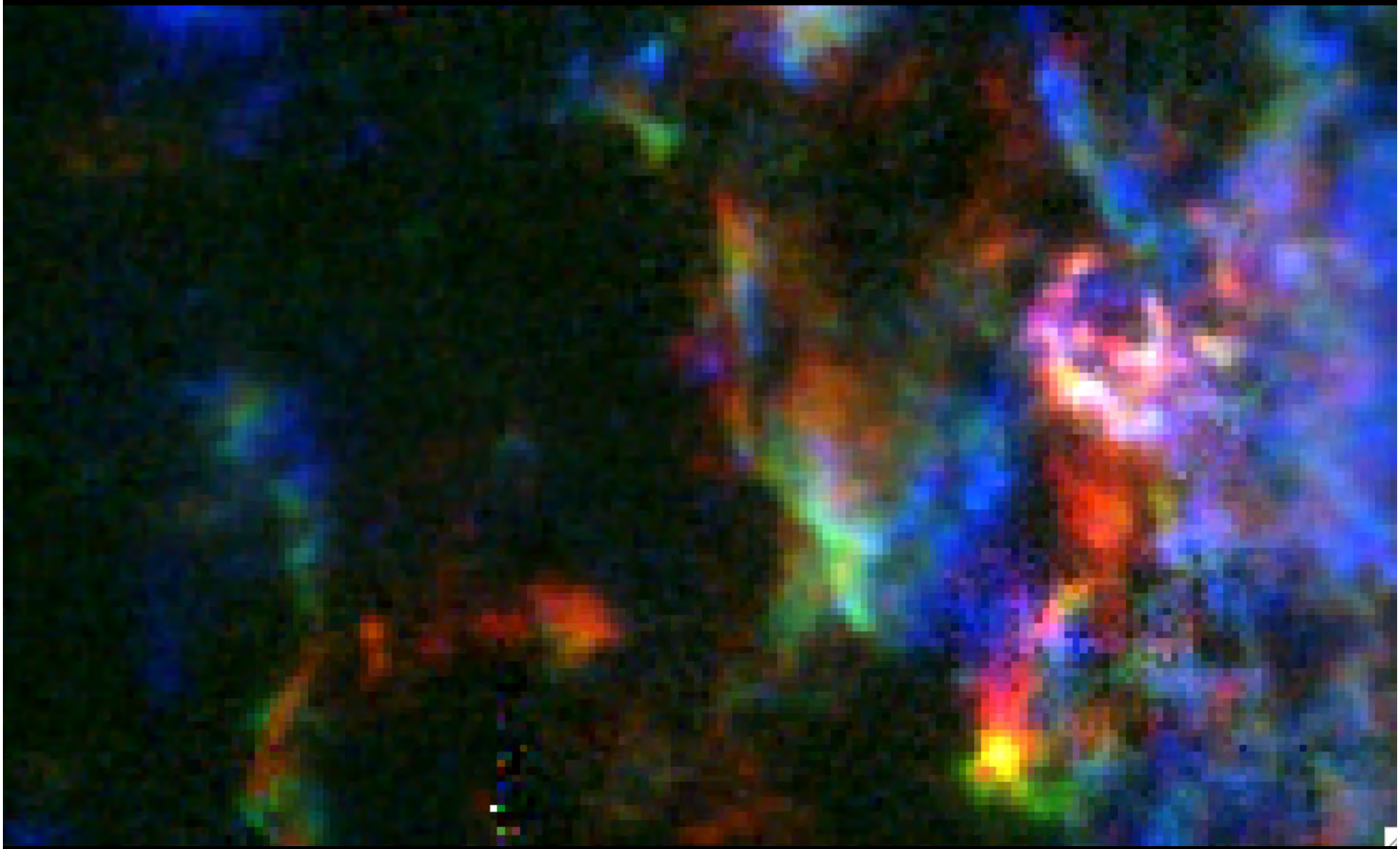

WR+O cluster
MM1
MM2
MM3
MM4
8 um
70 um
250 um
0.050
0.000
-0.050
-0.100
-0.150
-0.200
-0.250
-0.300
Galactic latitude
30.900
30.850
30.800
30.750
30.700
30.650
30.600
30.550
30.500
30.450
Galactic longitude

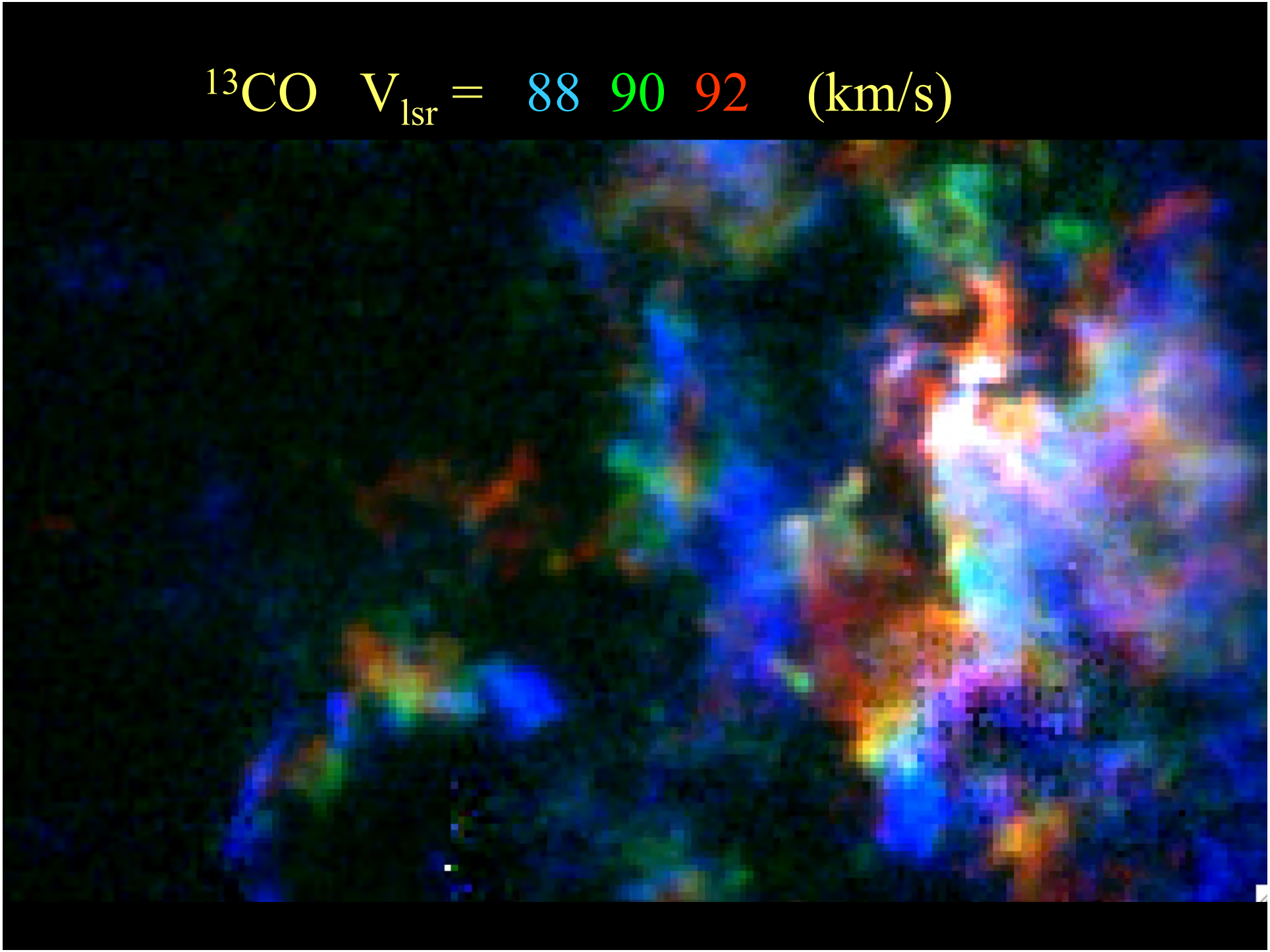
1.1 mm (CSO/BGPS)

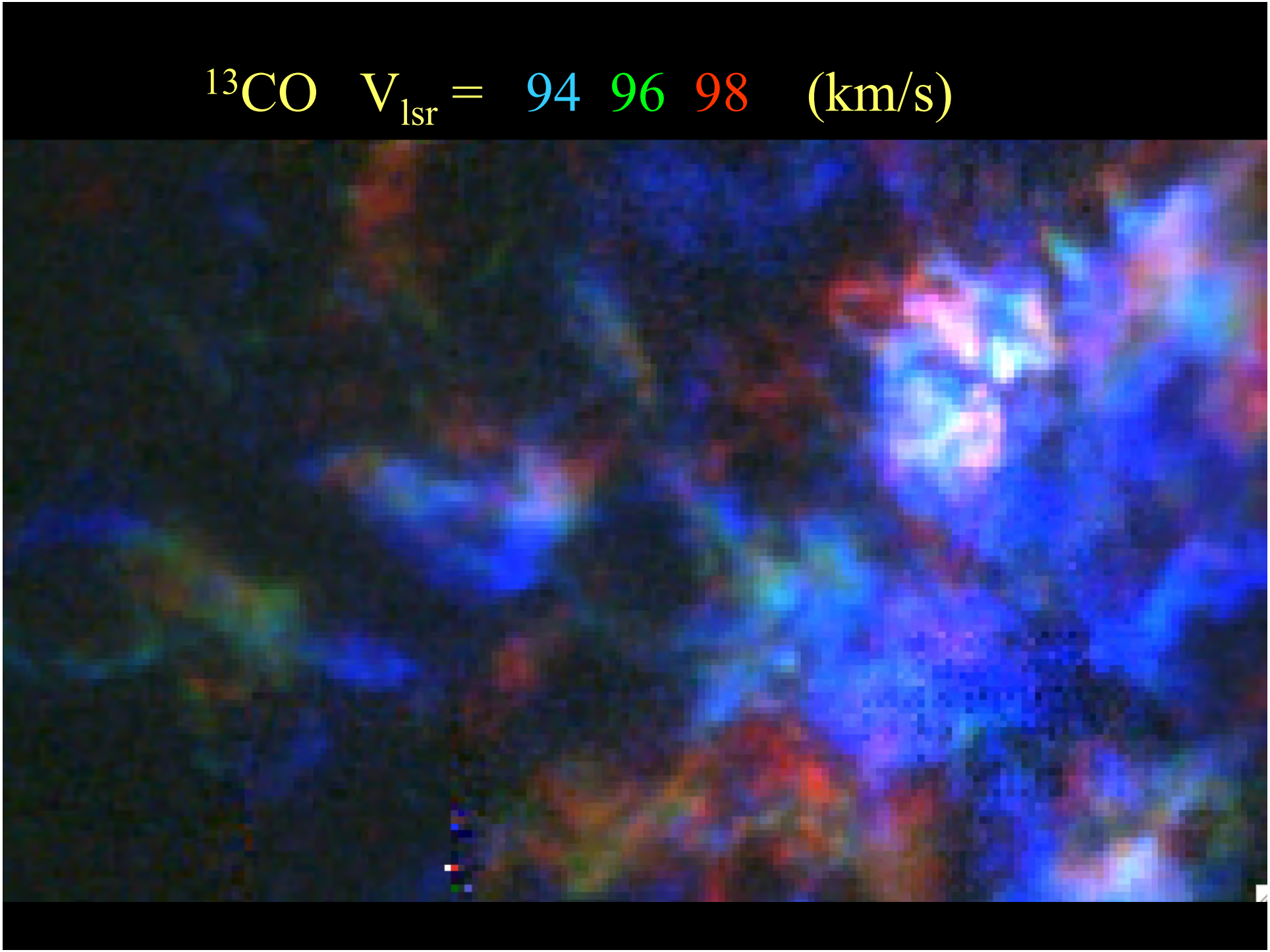


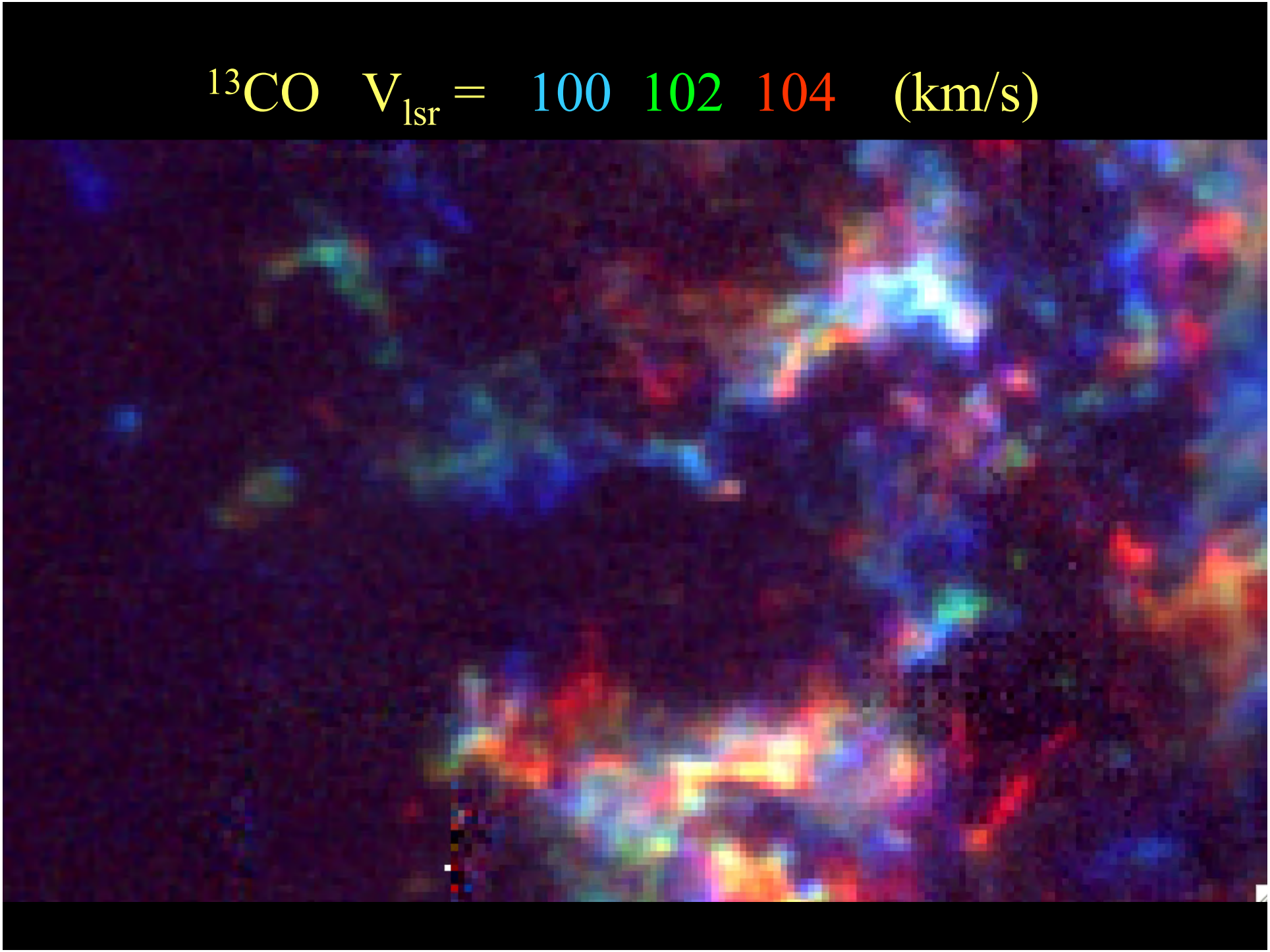

20 cm (VLA / MAGPIS)
W43
Older OB

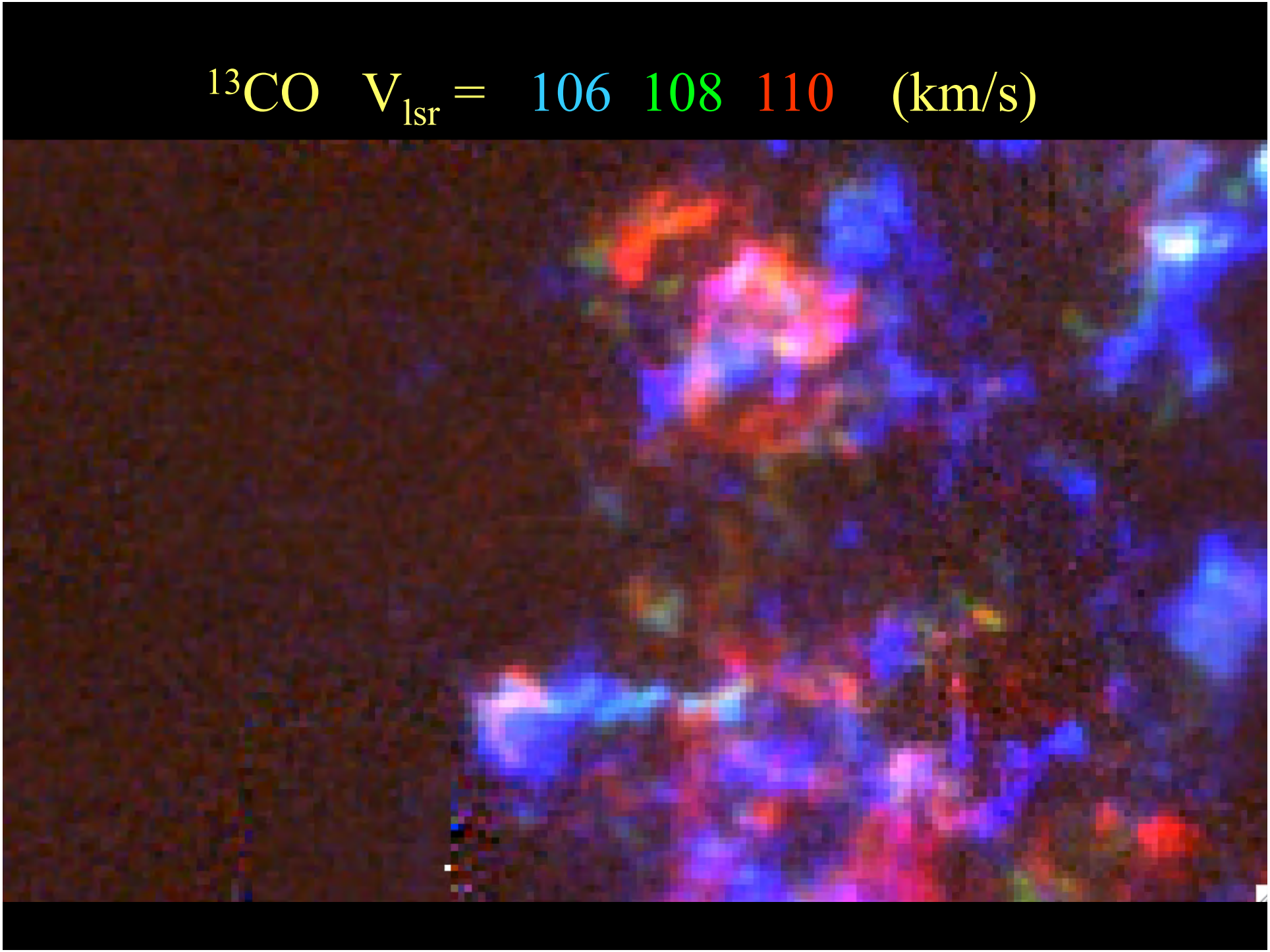
^{13}CO V_{lsr} = 84 86 88 (km/s)




^{13}CO V_{lsr} = 88 90 92 (km/s)


^{13}CO V_{lsr} = 94 96 98 (km/s)


^{13}CO V_{lsr} = 100 102 104 (km/s)


^{13}CO V_{lsr} = 106 108 110 (km/s)

Central Molecular Zone (CMZ)

- x10 - x100 denser, more turbulent than disk GMCs

  Traced by HCN, CS, etc.

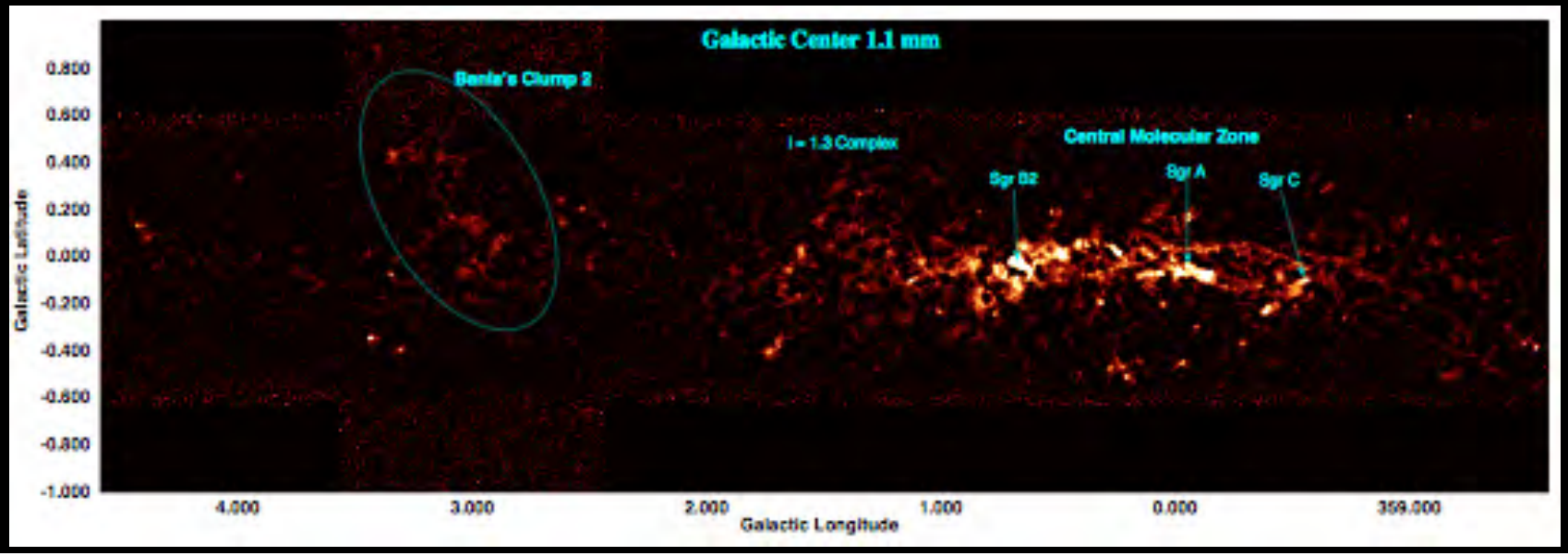
  $\Delta V > 10$ km/s

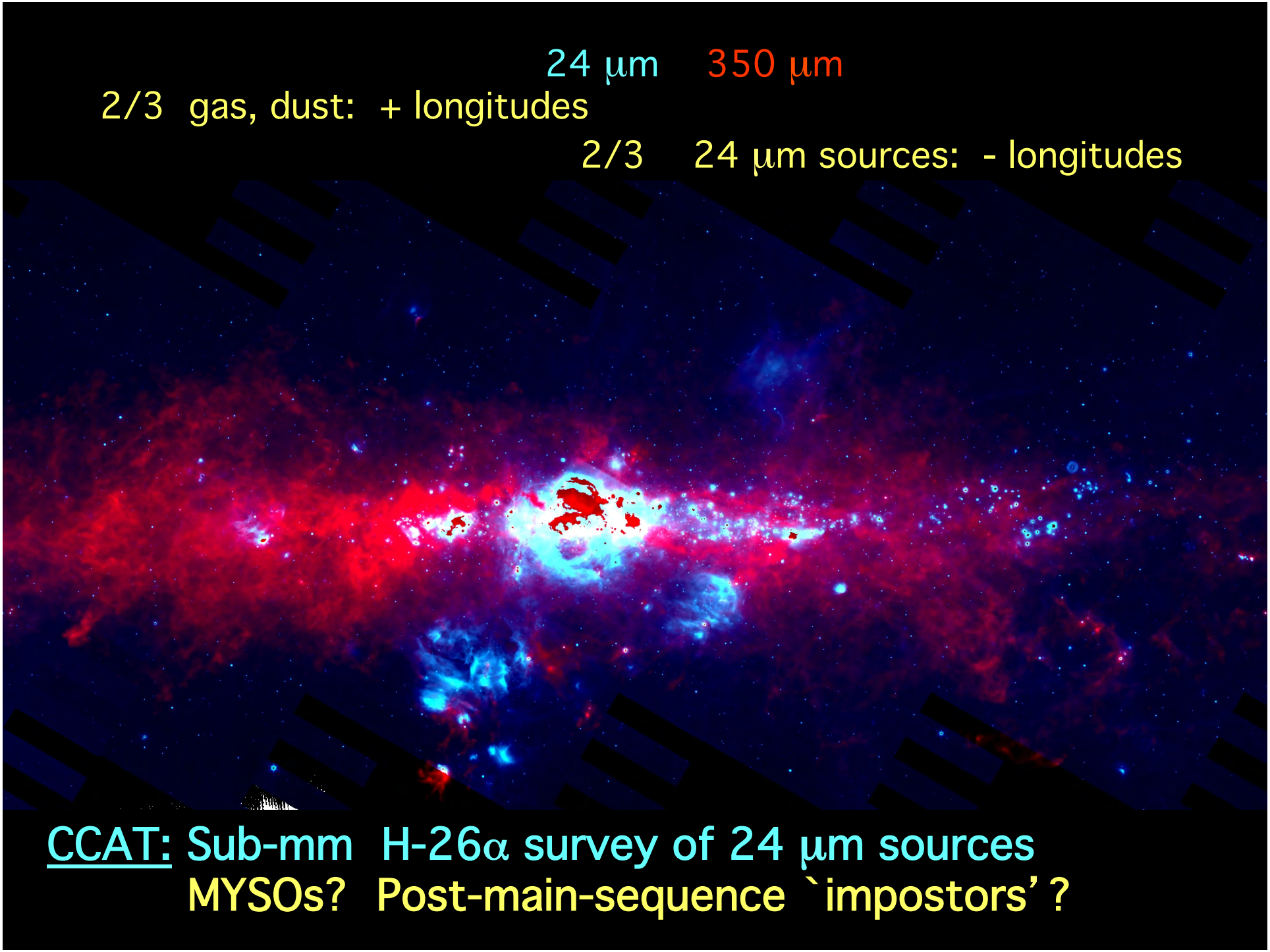
- Asymmetry:

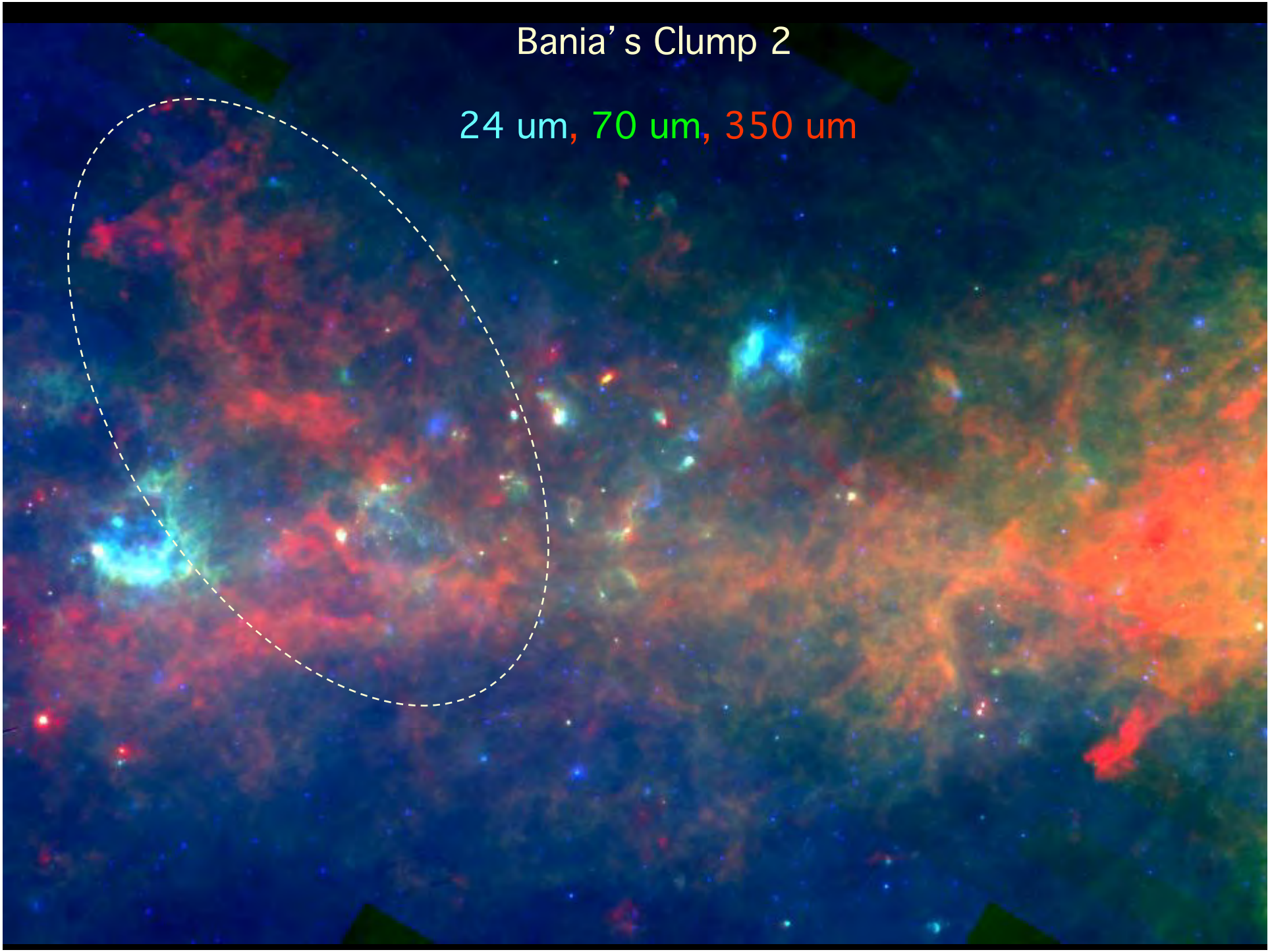
  Gas & cold dust: 2/3 at POSITIVE longitude, velocity

  24 μm sources: 2/3 at NEGATIVE longitude

Note: $t_{orbit} \sim 6$ Myr r_{100} V_{100}^{-1} (+ 3 to 30 Myr)



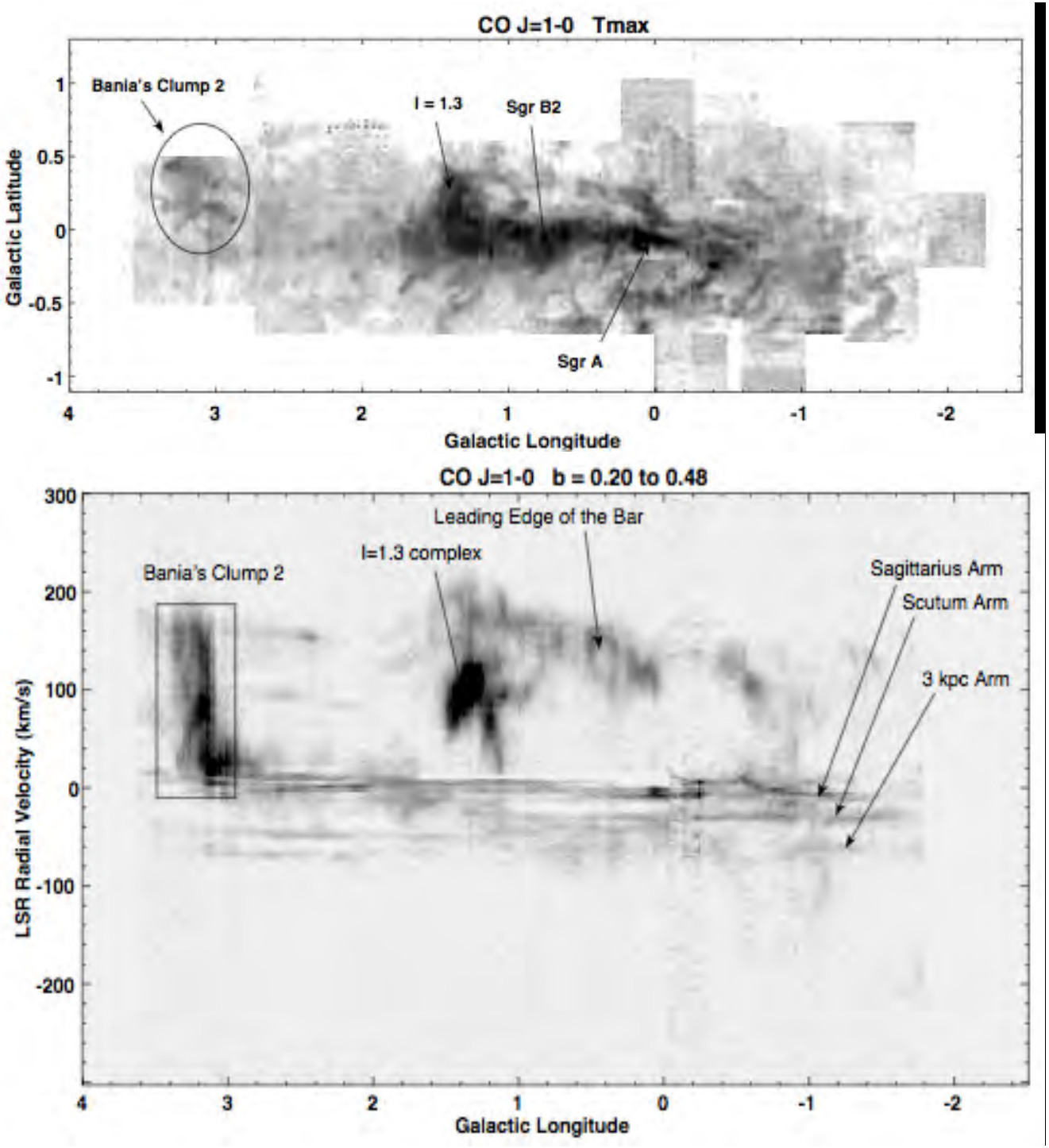

24 μm 350 μm
2/3 gas, dust: + longitudes
2/3 24 μm sources: - longitudes
CCAT: Sub-mm H-26α survey of 24 μm sources
MYSOs? Post-main-sequence `impostors'?


Bania's Clump 2
24 um, 70 um, 350 um

Bania's Clump 2

$l = 3.2^{o}$

$10^{6}\ M_{o}$



Bania's Clump 2 ($l = 3.2^o$) & $l = 1.3^o$

- Little 8, 24 μm emission
- Little or no star-formation
- Strong SiO => shocks?

CCAT:

Compact, narrow-ΔV clumps ?

Dust continuum clumps ?

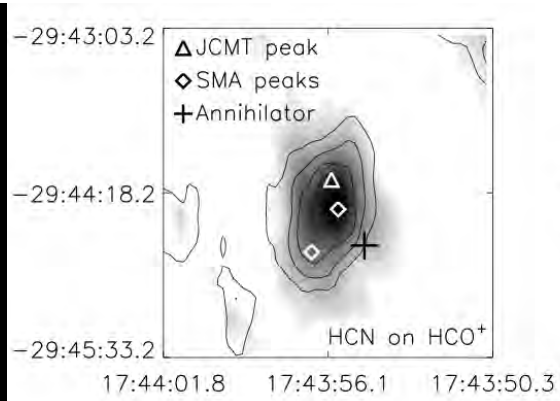
Shocks => SiO ?

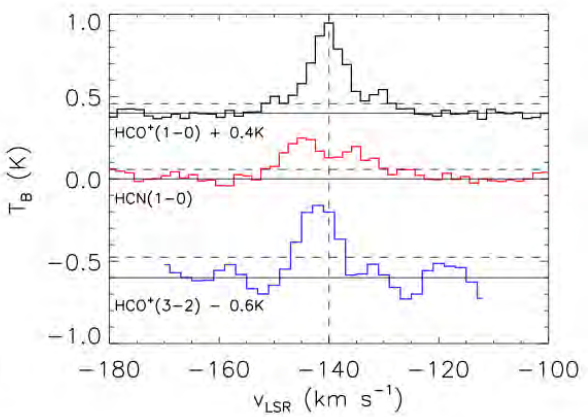
Inter-cloud Medium

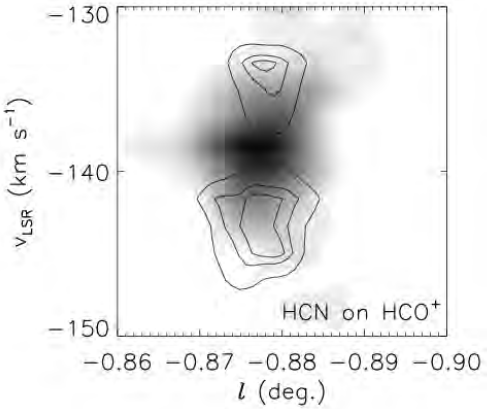
r ~ 1 pc

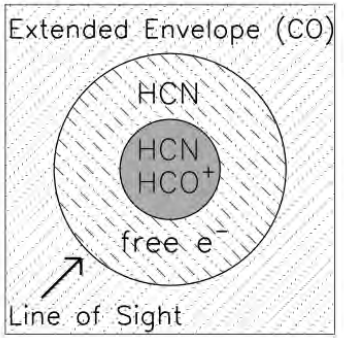
10^4 M_o clumps

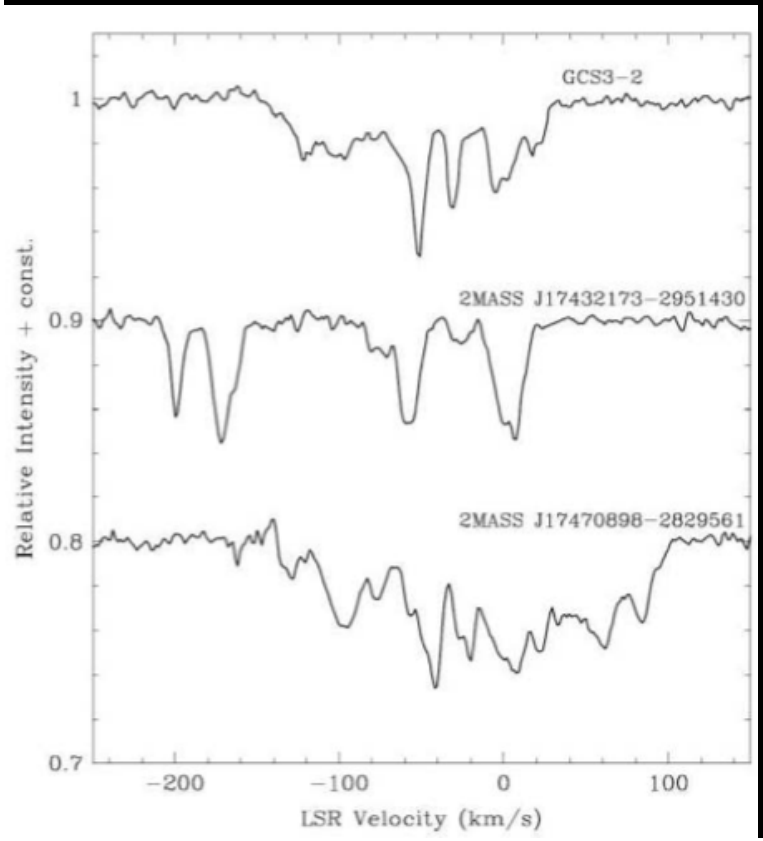
Hodges-Kluck 2011











H_3^+ absorption:

Pervasive, partially molecular

Large C.R. ionization rate:

10^{-14}

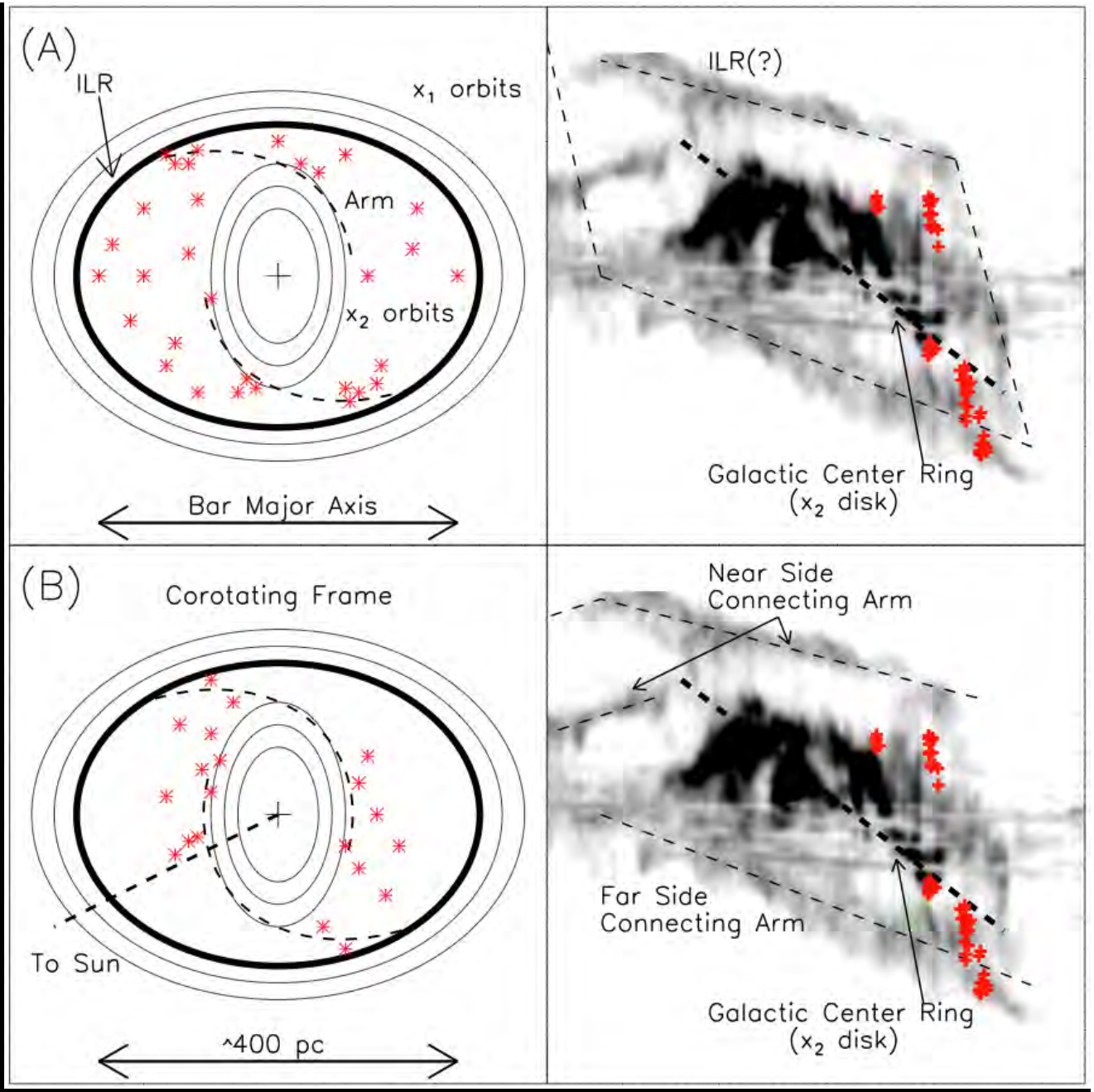
Oka & Geballe 2010

Small, dense clumps between CMZ clouds

<u>CCAT:</u>

- Survey of CMZ inter-cloud medium.

Hodges-Kluck 2011



Galactic Center Bubble

- Brightest super-bubble in Galaxy at 24 μm
- D ~ 30 pc
- Arches, Pistol clusters, Sgr A East SNR

A nested set of Bubbles?

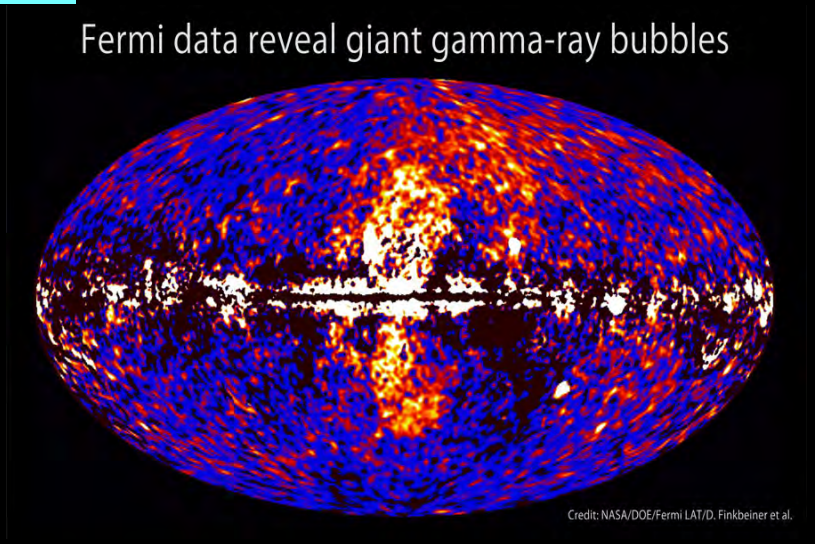
Sgr A East: 1 pc

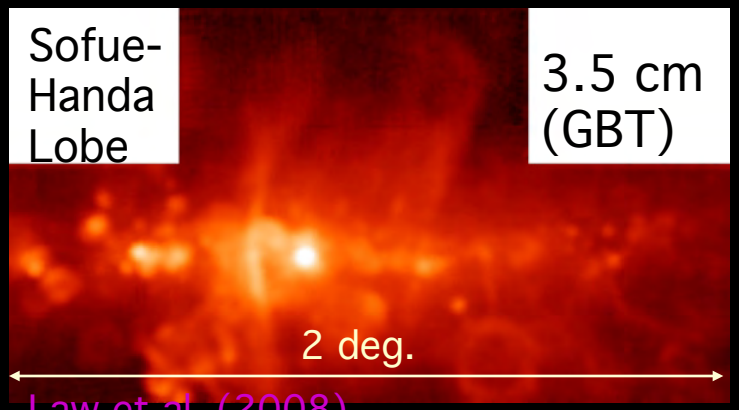
GCB: 30 pc

Sofue-Handa (84) lobe: 150 pc

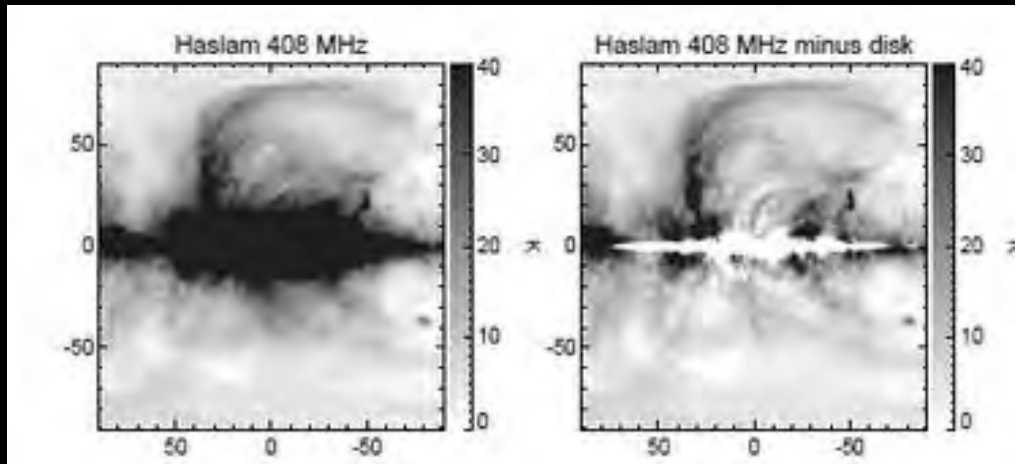
Fermi-LAT bubble: 5,000 pc

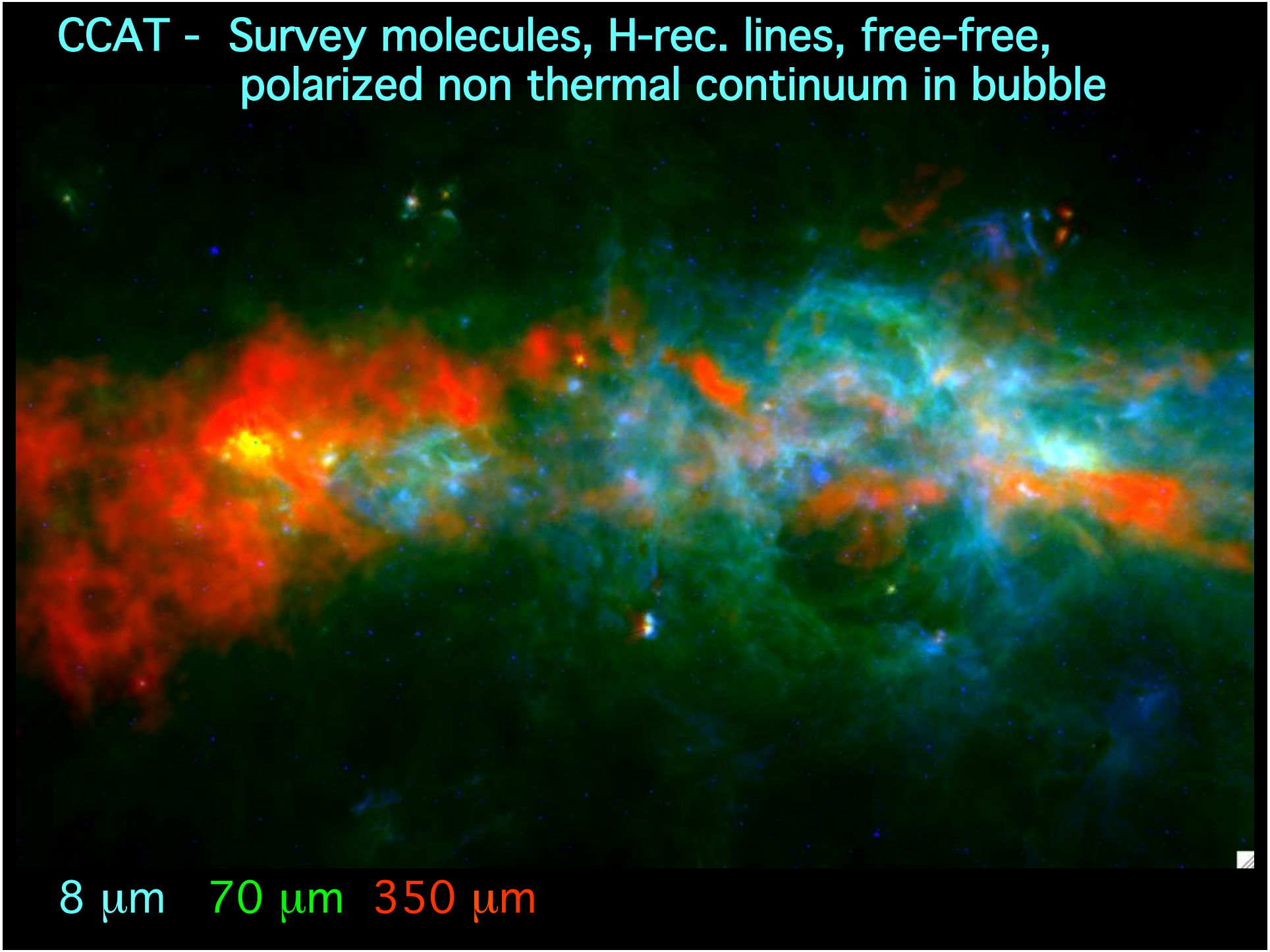
A `nuclear super-wind' ?



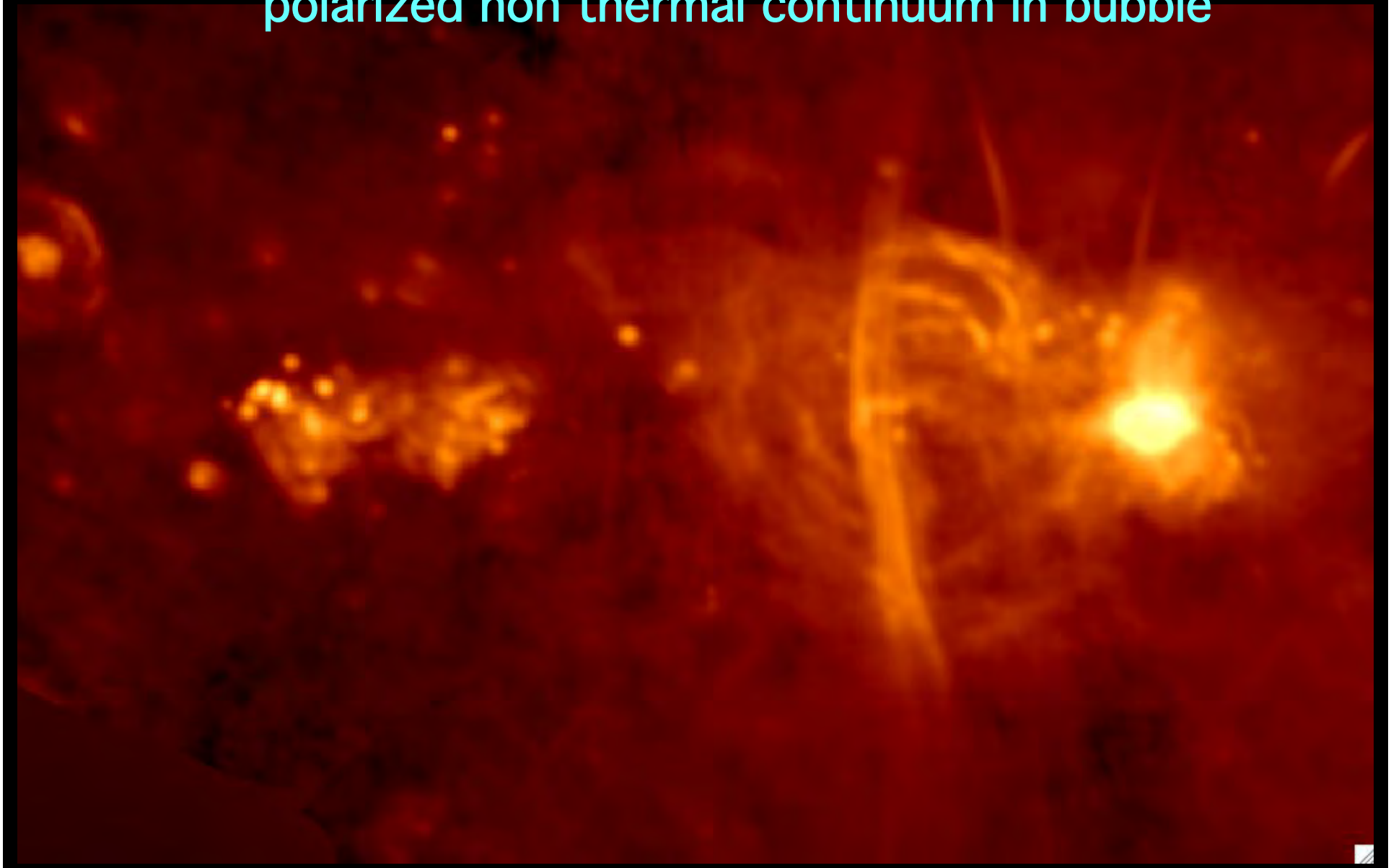


Law et al. (2008)




CCAT - Survey molecules, H-rec. lines, free-free,
polarized non thermal continuum in bubble
8 μm 70 μm 350 μm

CCAT - Survey molecules, H-rec. lines, free-free, polarized non thermal continuum in bubble



20 cm

Outline

- The Bolocam Galactic Plane Survey (BGPS):

  Lessons Learned

- Need for CCAT sub-mm continuum

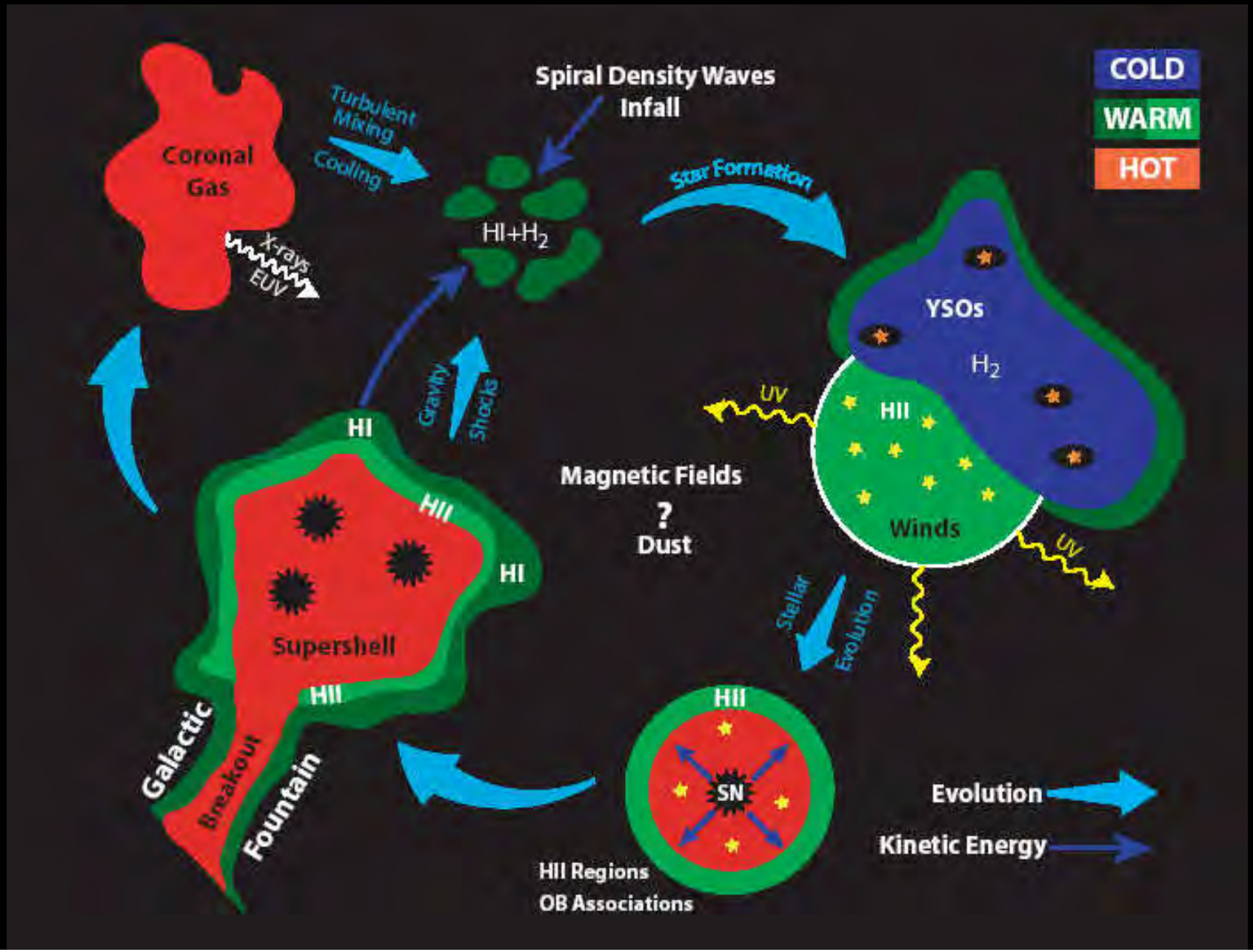
  3" Beam @350 mm, Polarization, Variability

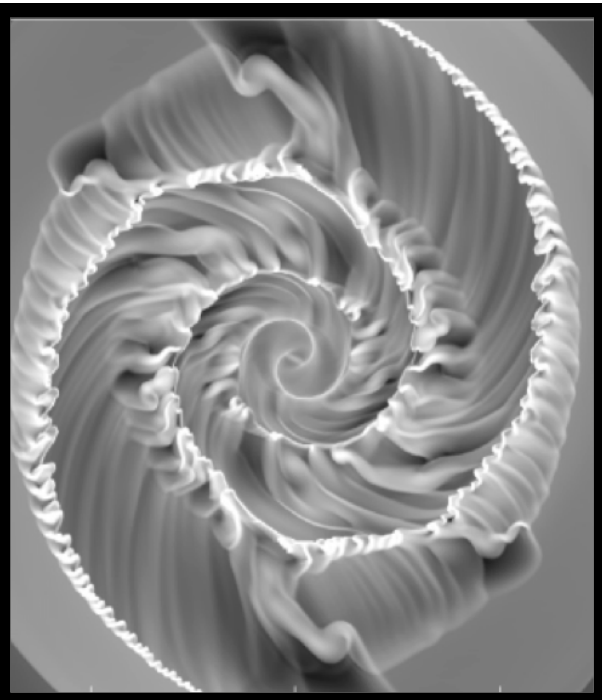
- Need for Wide-field heterodyne surveys

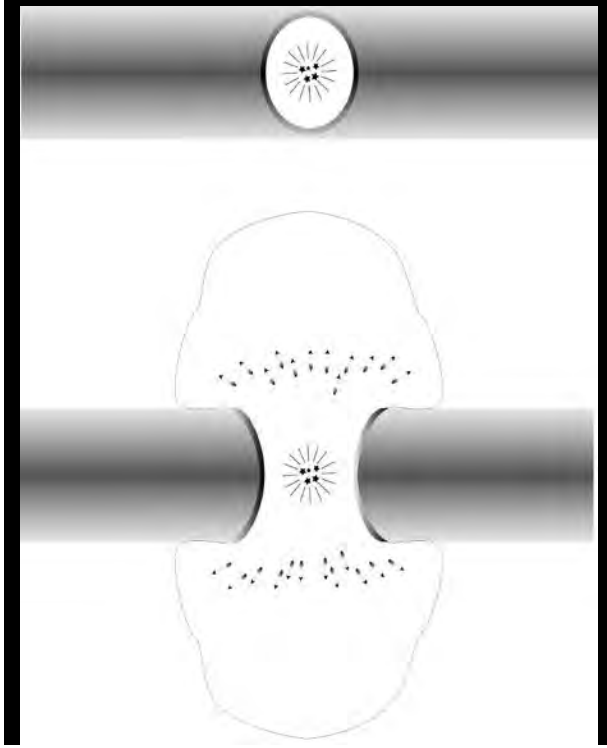
  Physical parameters of ISM components

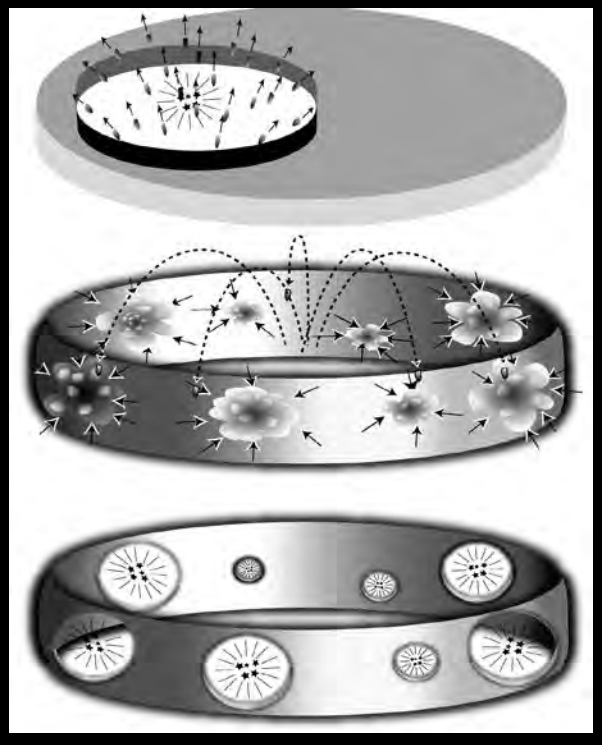
- Science in the ALMA / LSST/ JWST era

Galactic Ecology: Star Formation & the Interstellar Medium









Galactic Ecology:
Cloud formation

Powered by spiral arms ?

Gravo-thermal Instability ?

Super-bubbles ?

Questions for CCAT Galactic Science

Tracing the Galactic Ecology with CCAT

- Mode of cloud formation:
  - Compression by Convergent flows?
    - Super-rings (vertical filaments)
    - Sprial arms (parallel filaments)
  - Cooling instabilities ?
  - Gravity (Toomre Q) ?
- Mode of Cluster & MYSO formation:
  - Massive precursor clump ? Massive precursor clump
  - Continuous infall ? No massive precursor clump
- Cloud Destruction
  - Feedback ladder: Outflows, FUV, LyC, Rad. P. , Winds, SNe
  - Chemical chronology: Age dating clouds
  - C.R. and X-ray effects: CMZ, SNR, nearby starbursts
  - Post-main sequence recycling: LBVs, RSGs, …

Conclusions

Tracing the Galactic Ecology with CCAT

- Multi-band continuum surveys: Galactic plane, Local Group

  Cloud structure: from 0.01 - 10 kpc scales

  Polarization: Magnetic fields

  Variability - flares: Embedded low-M YSOs, MYSOs, black-holes

  Dynamics in dense star forming environs

- Large-scale Heterodyne-Camera Surveys:

  Cloud kinematics: distances, outflows, filaments

  Chemical chronology: Age dating clouds

  C.R. and X-ray effects: CMZ, SNR, nearby starbursts

  Post-main sequence recycling: LBVs, RSGs, ...

CCAT: panoramic view of the sub-mm sky