

Characterising the Expanding Molecular Ring and IR-dark Rings in the Milky Way

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Large-scale galactic outflows

- Often found in star-forming galaxies
- Hundreds of pc to several kpc
- Suppress star formation - negative feedback



Credit: NRAO/AUI/NSF, D. Berry

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Positive feedback?

- Feedback induced star formation (e.g. Gallagher+2019)
- Gas compression - gravitational collapse - fragmentation



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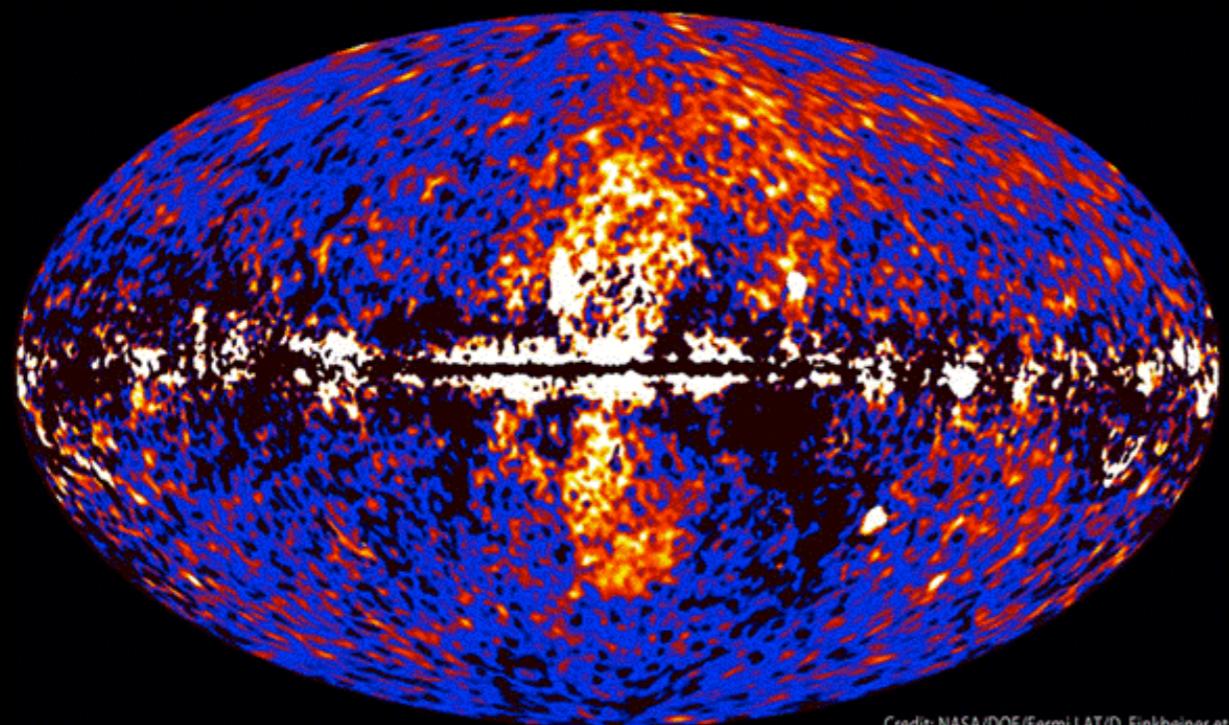
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Milky Way?

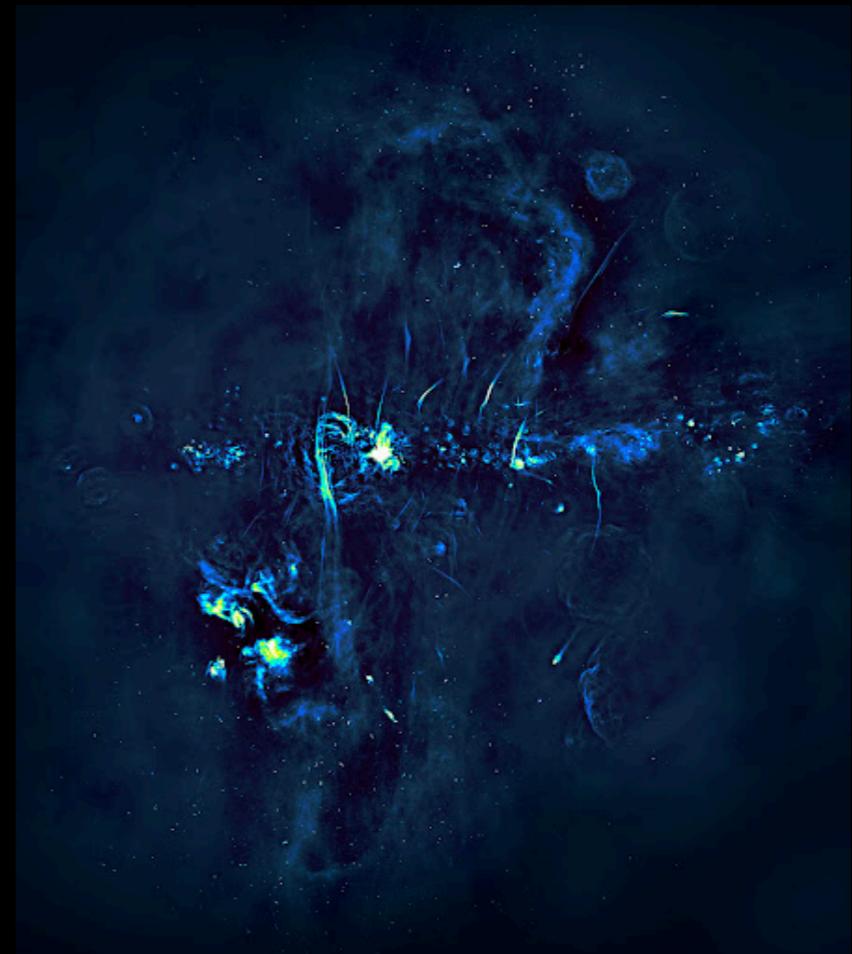


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Outflows in the Galactic Centre



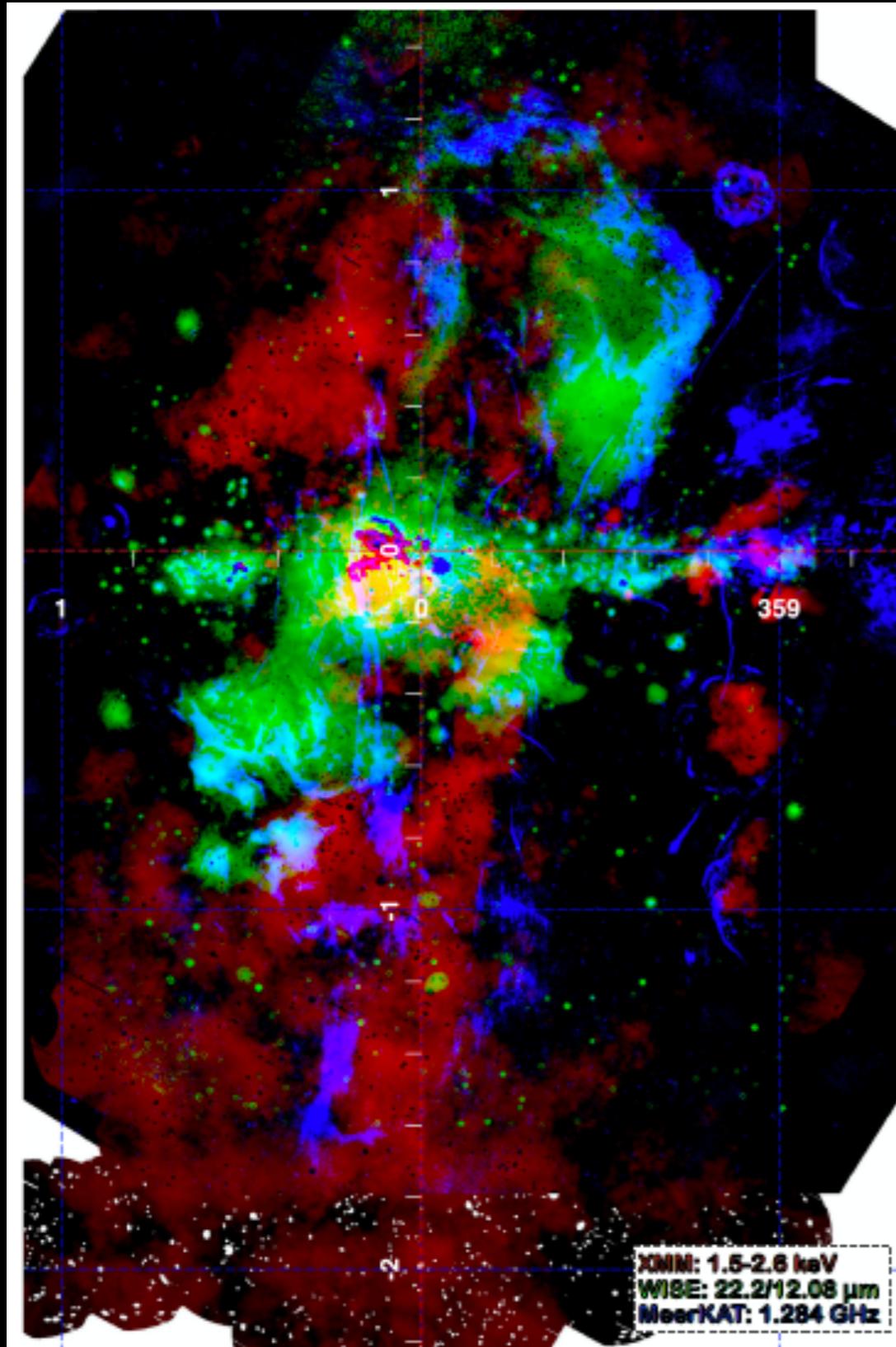
Fermi bubbles (Su Meng+2010)



Radio bubbles (Heywood+2019)

- Energetic events in the GC
- 50 kpc Fermi bubble
- 430 pc radio bubbles

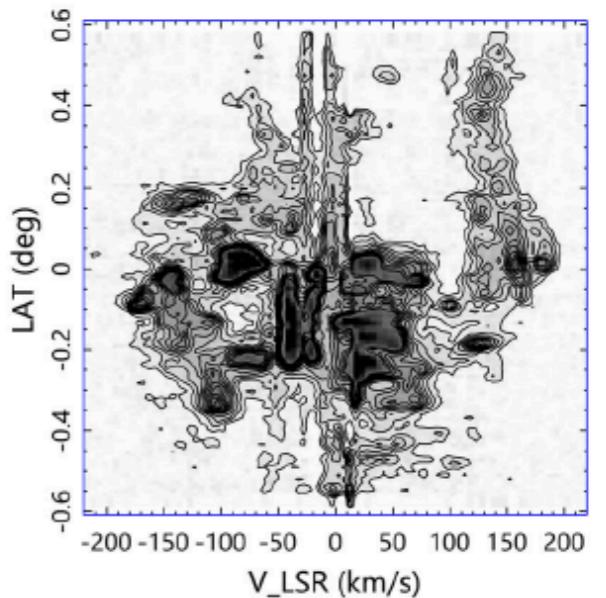
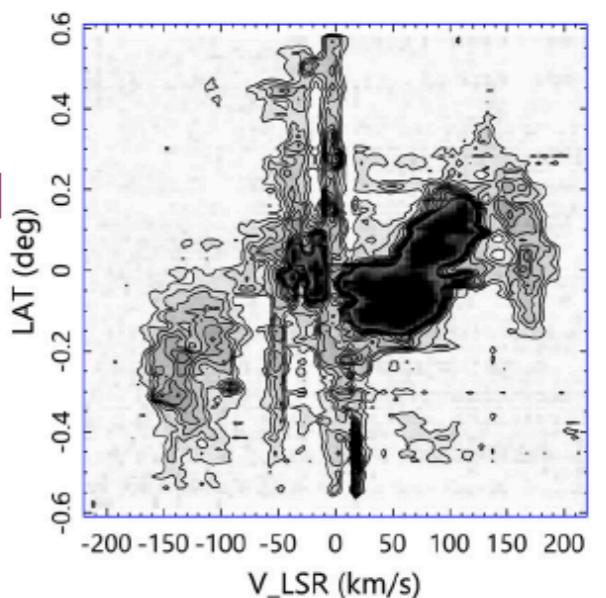
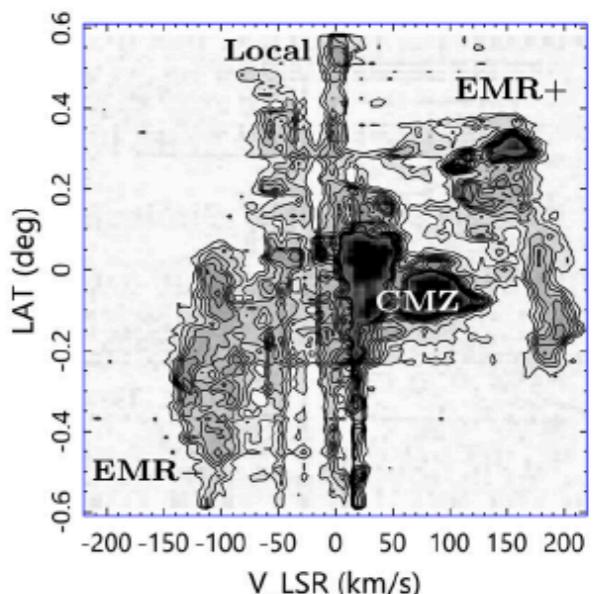
Galactic Chimneys



- X-ray+radio+infrared - coherent features (~Few 100 pc)
- Common physical link
- Quasi-continuous, intermittent activity at GC
- Recent outflow from GC region

The Expanding Molecular Ring (EMR)

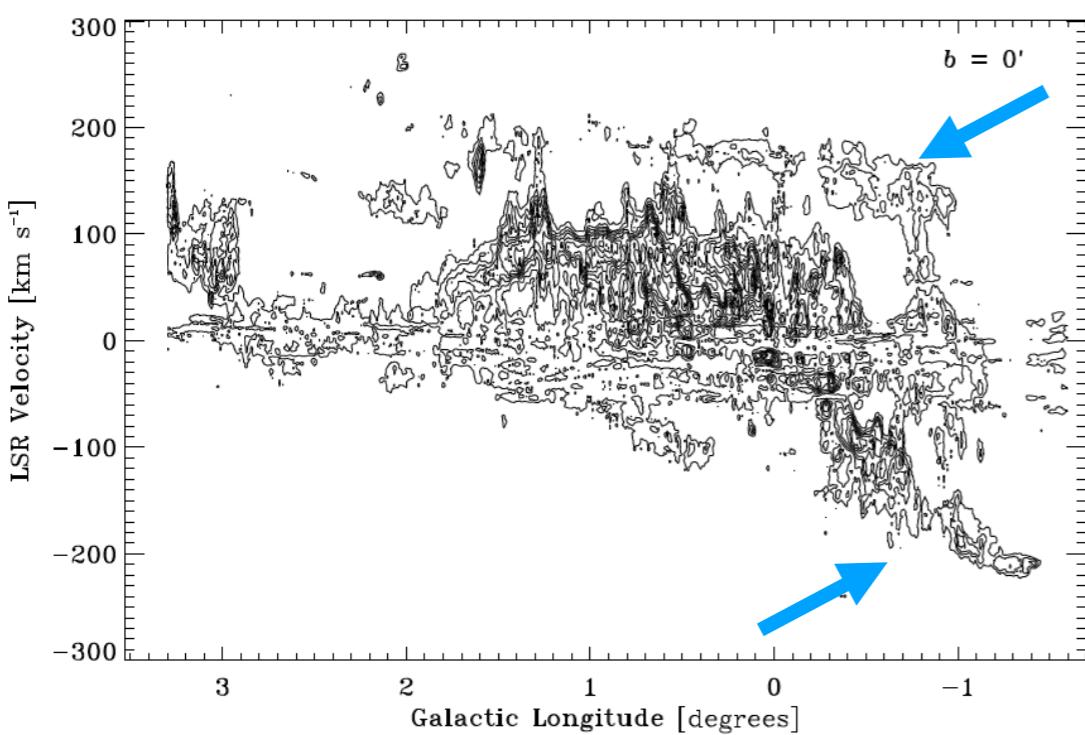
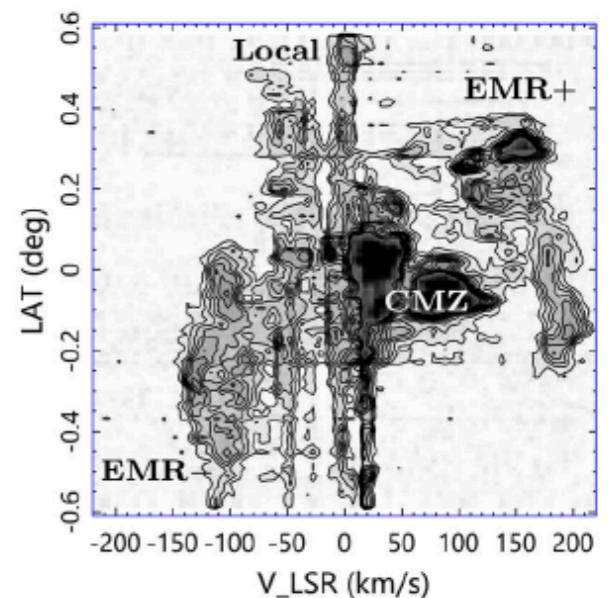
- Extended (200 pc) molecular gas structure in GC
(Kaifu+1972; Scoville 1972; Oort 1977)
- High velocity arcs in I - V diagrams - $|V_{\text{lsr}}| : 150 - 200 \text{ km/s}$
- Latitude - $\pm 0.6^\circ$; 15° tilt
- One order of magnitude fainter than CMZ - kinematically and geometrically different



Top : $I=0.4^\circ$, middle : $I=0^\circ$, bottom: $I=-0.4^\circ$
(Sofue 2017; Oka+1998)

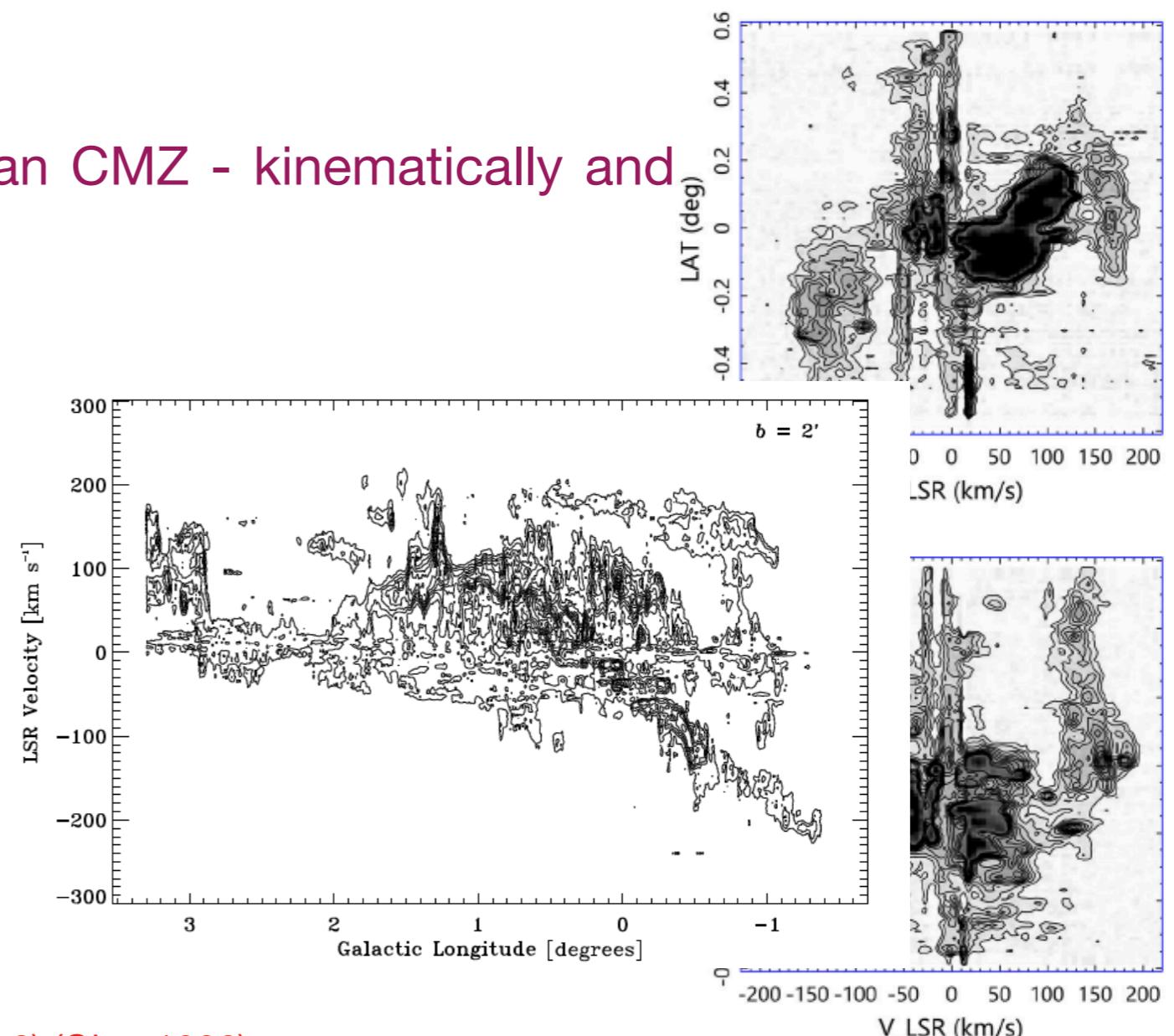
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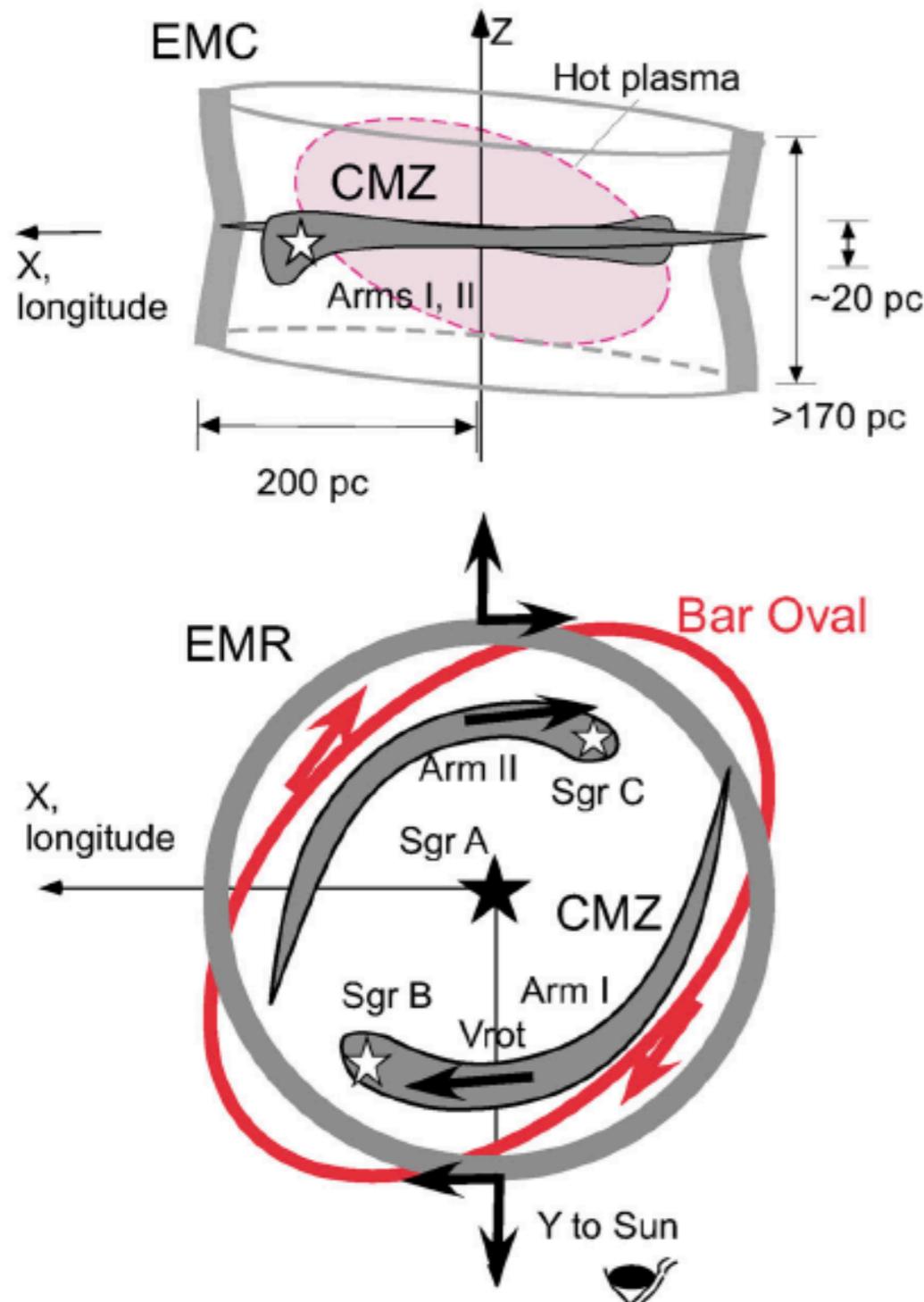
^{12}CO (1-0) (Oka+1998)

5



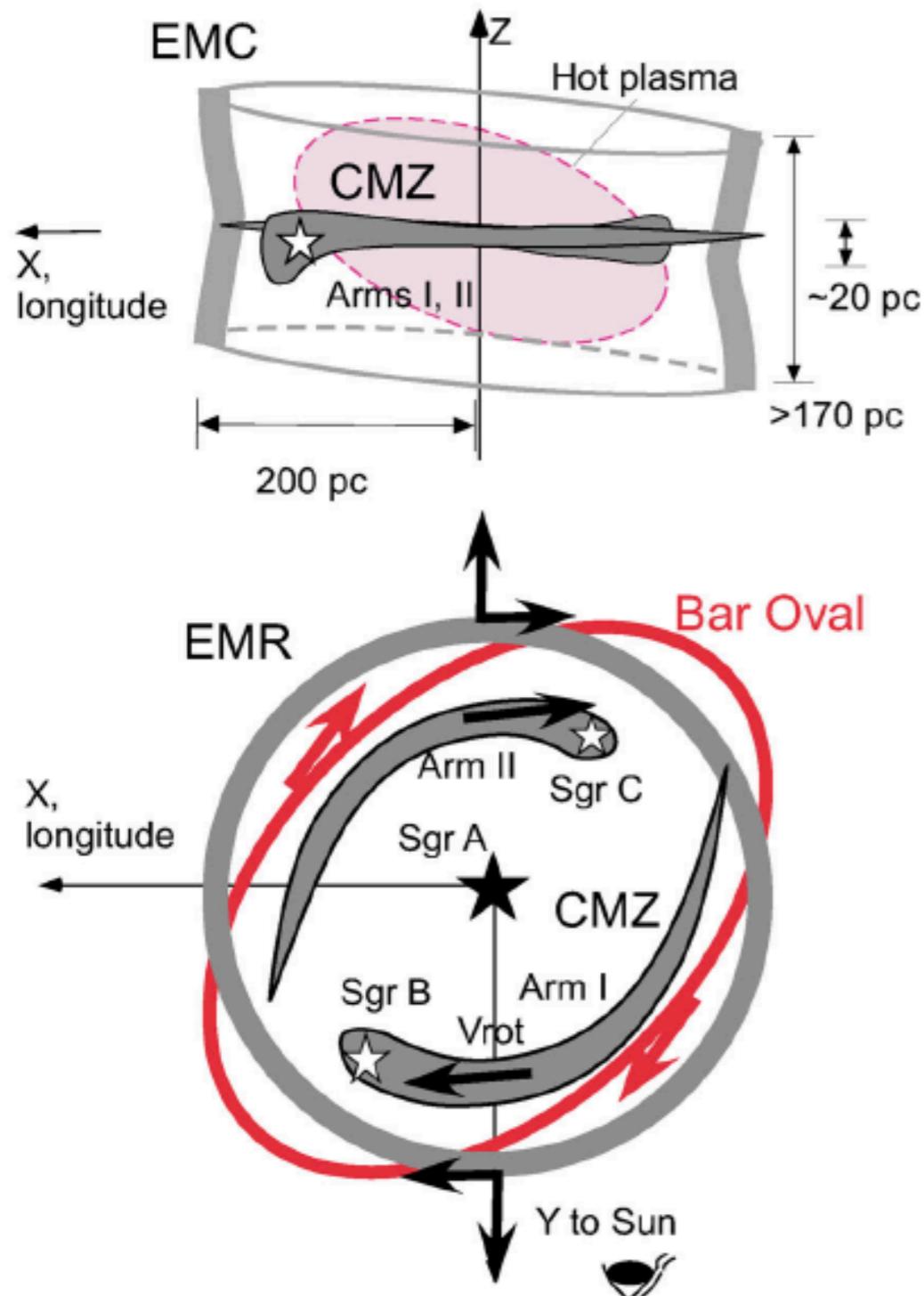
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Hot plasma observed by Yamauchi et al. (1990) is indicated by the ellipse. (Middle) $X-Y$ projection, showing the spatial relationship of the EMC and Arms I and II of the CMZ. The red ellipse illustrates the bar-induced oval orbit. (Bottom) Schematic LV diagram with Arms I and II from Sofue (1995b).

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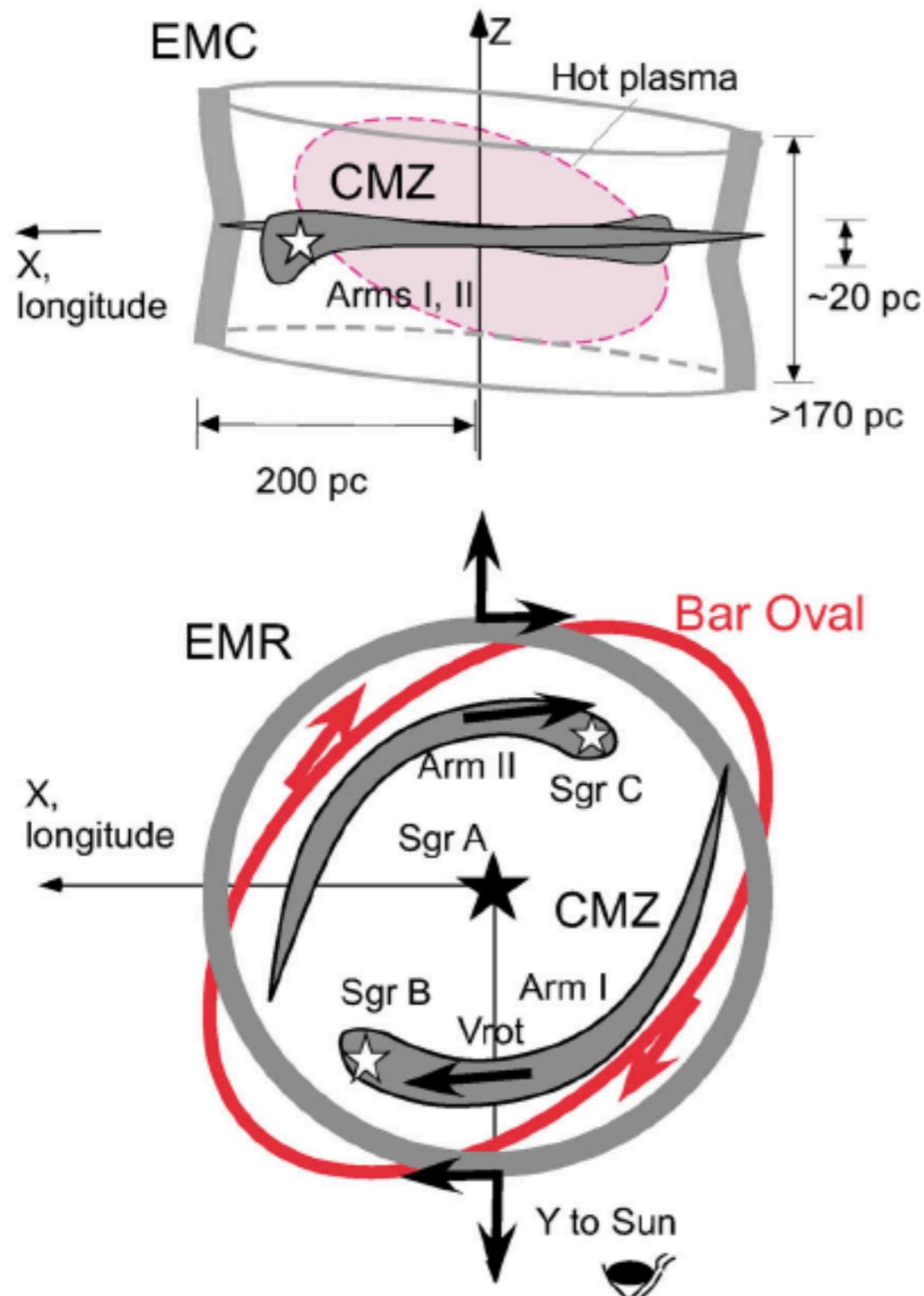


Bar Model (Sofue 2017)

- Bar dynamics - explains non-circular motion - EMR, CMZ, 3-kpc ring
- Simulations - 3D complexity of EMR & CMZ not explained

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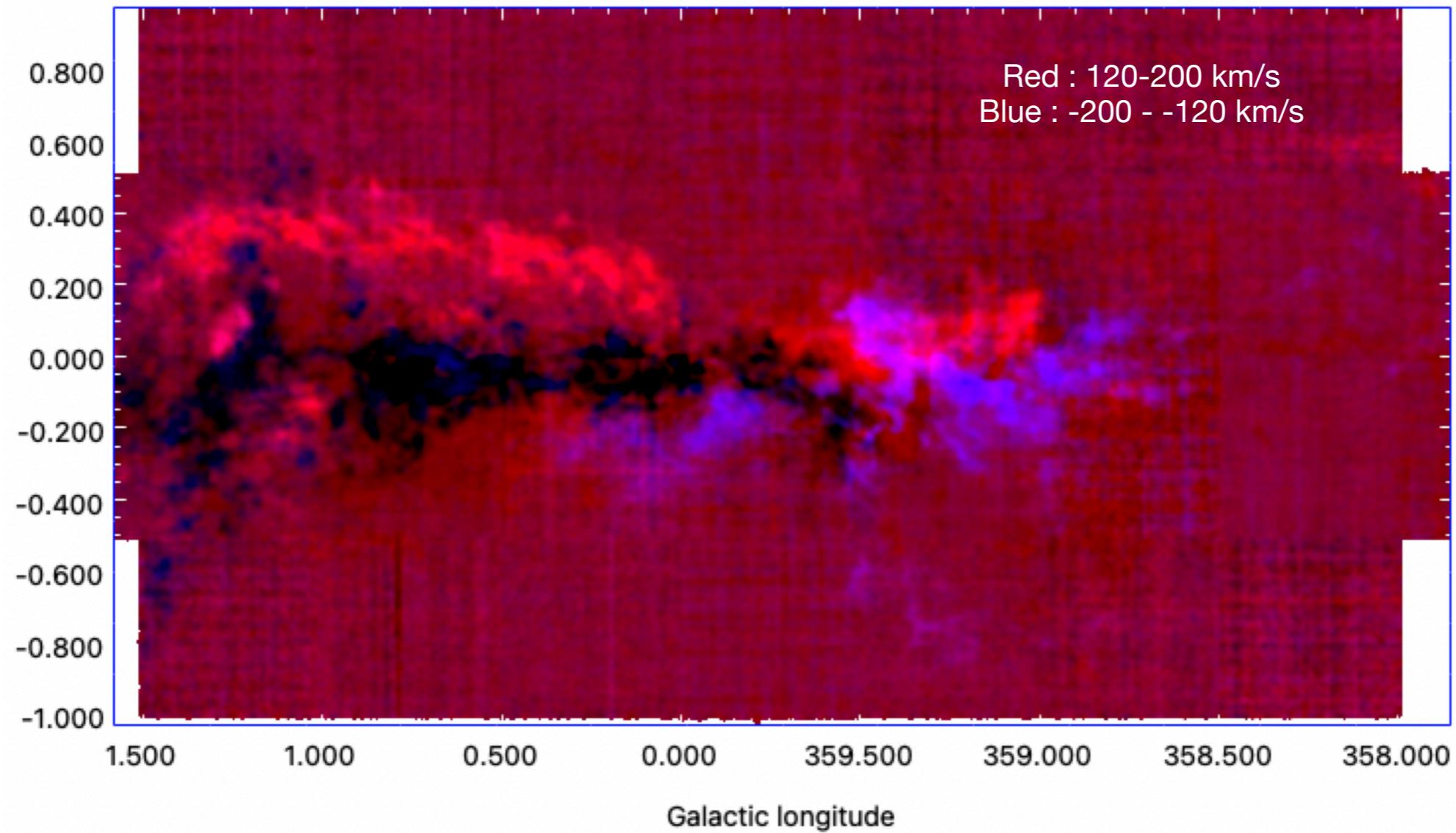
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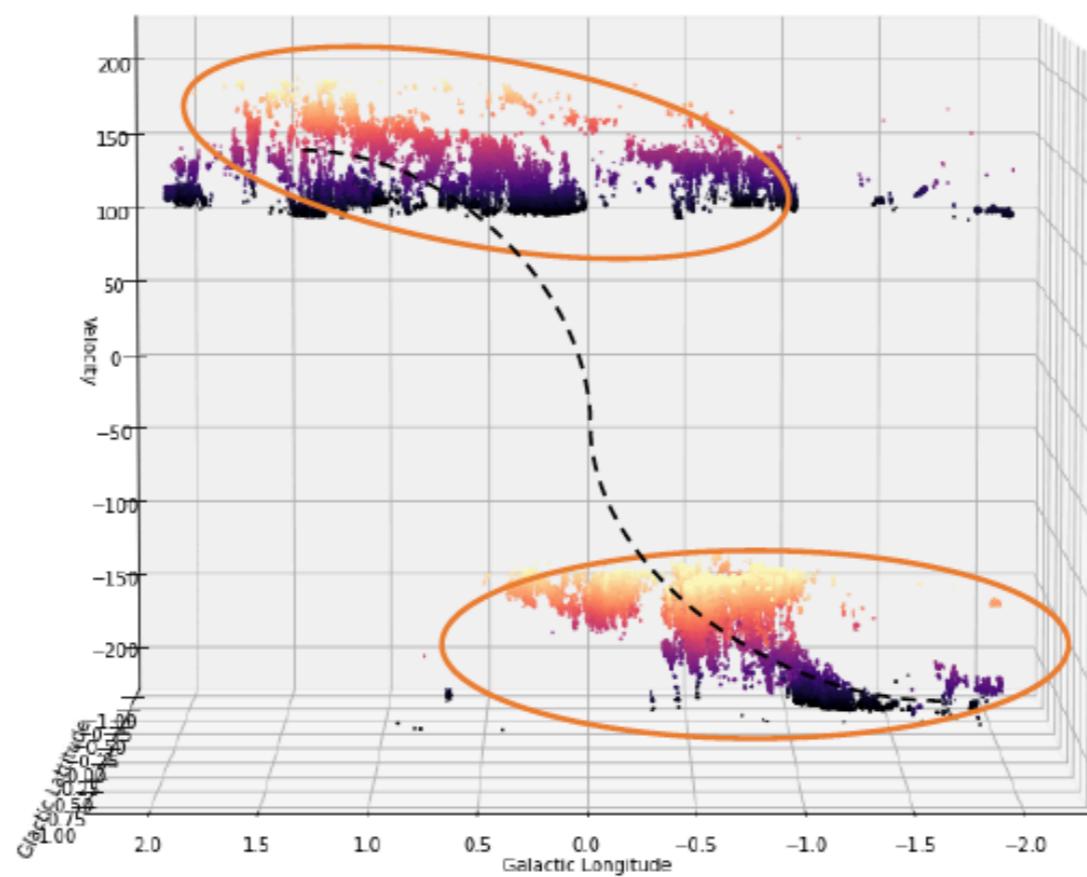
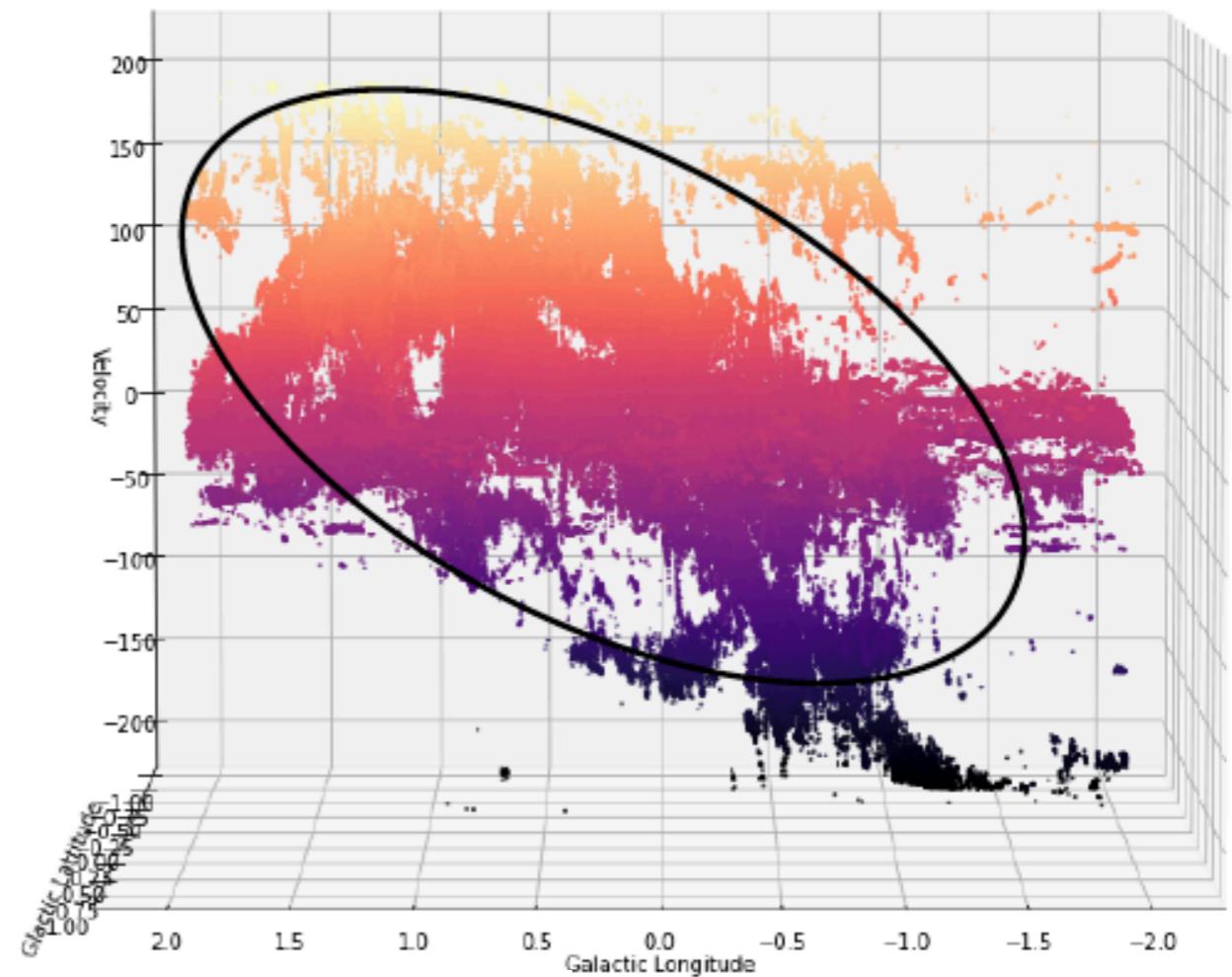
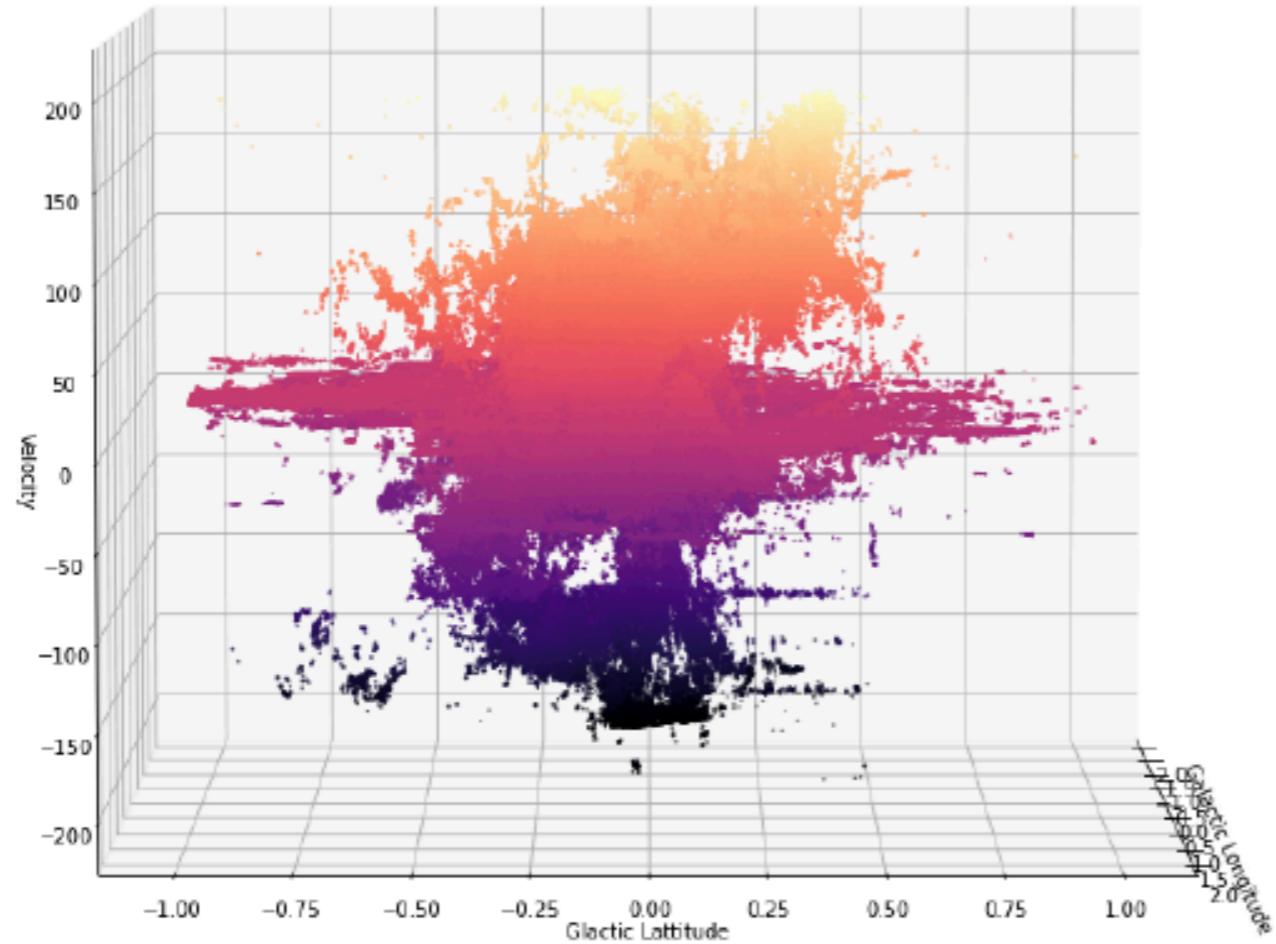
Explosion Model (Sofue 2017)

- Propagation of shock wave from GC
- Explosive activity in GC - reproduced observed cylindrical structure

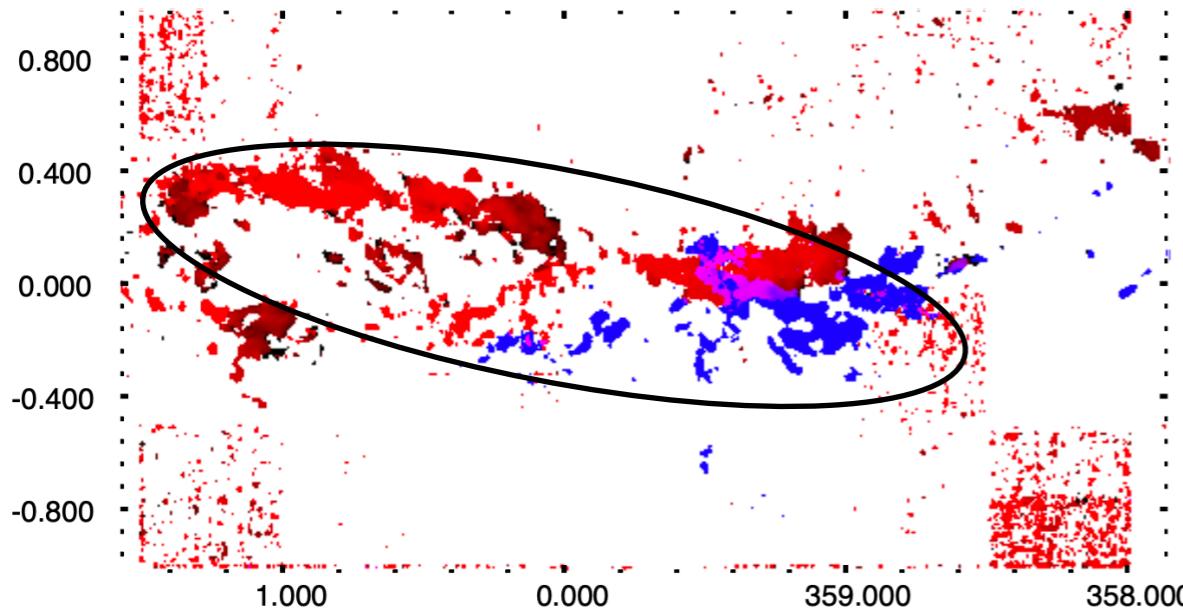
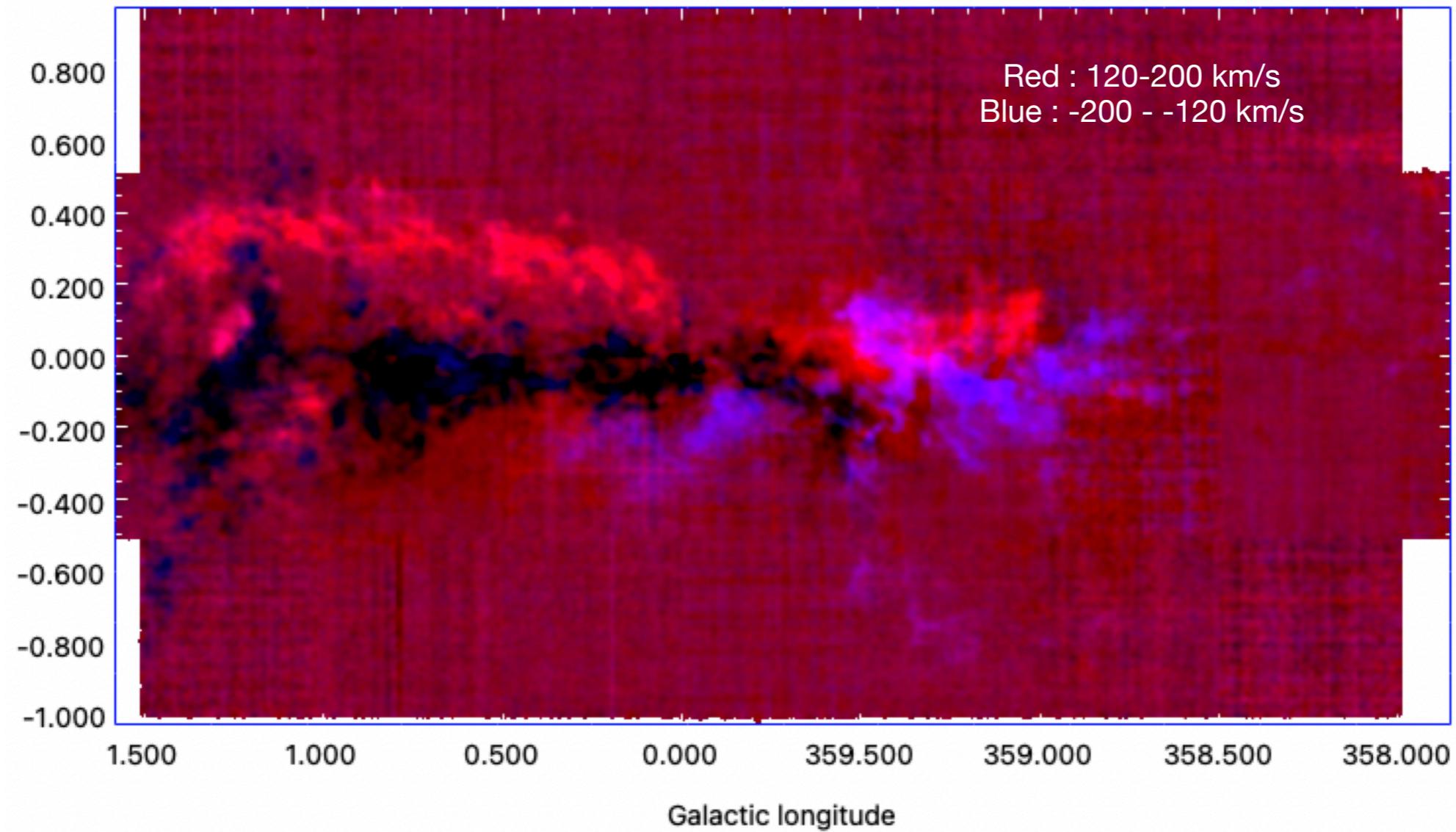
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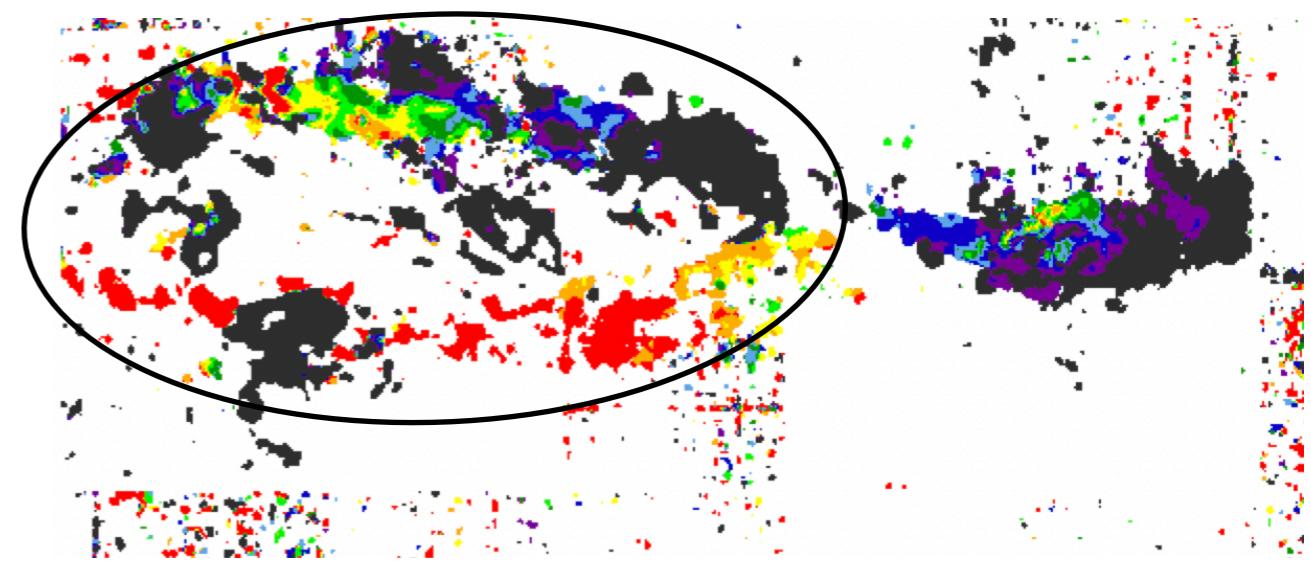
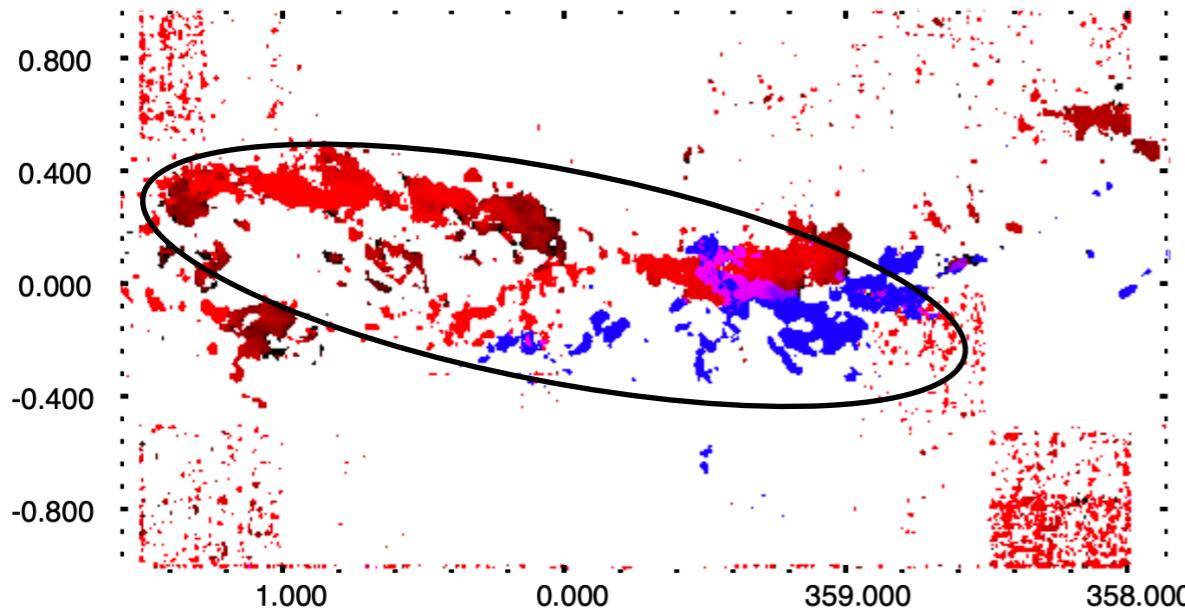
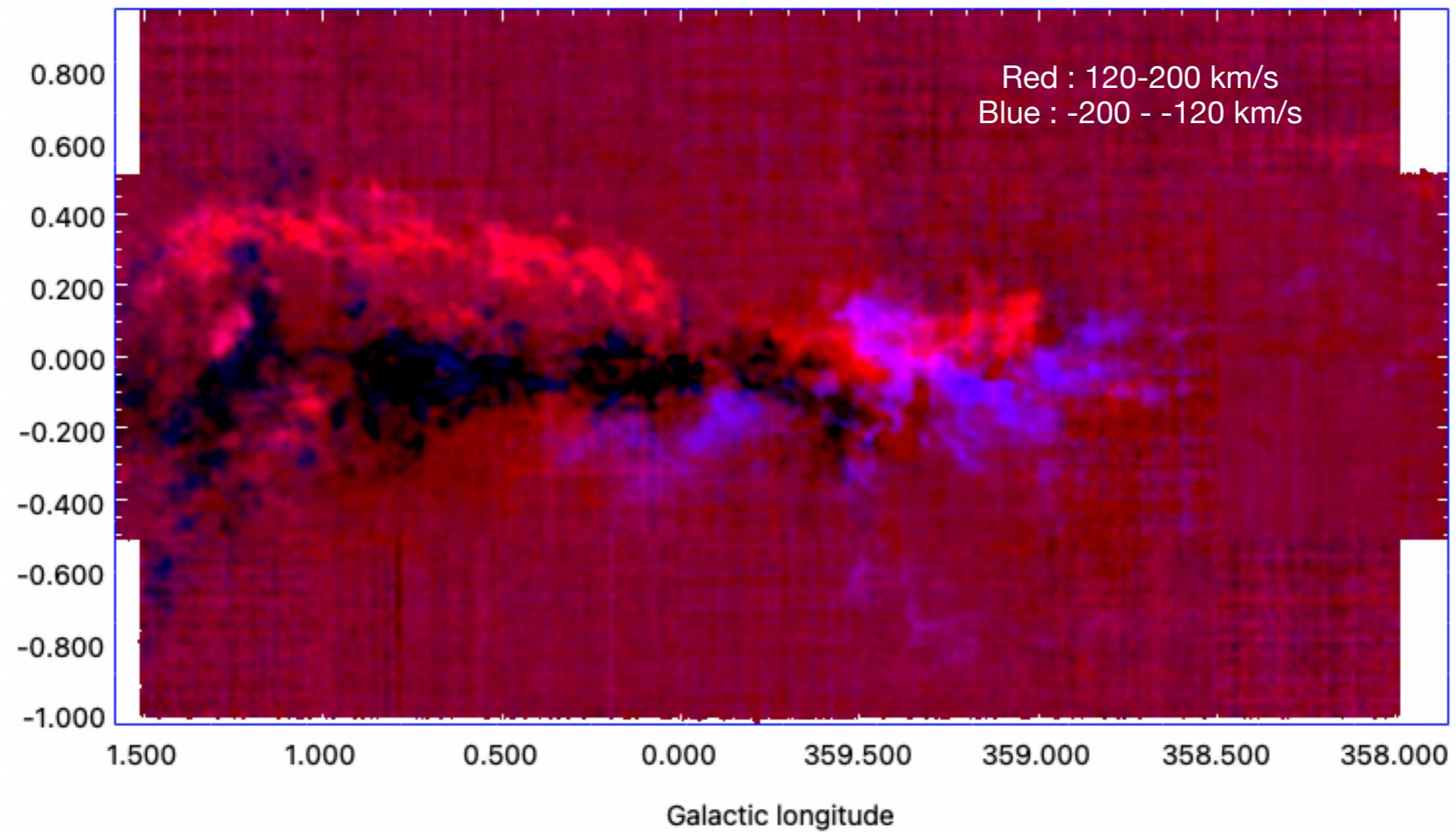


SEDIGISM ^{13}CO

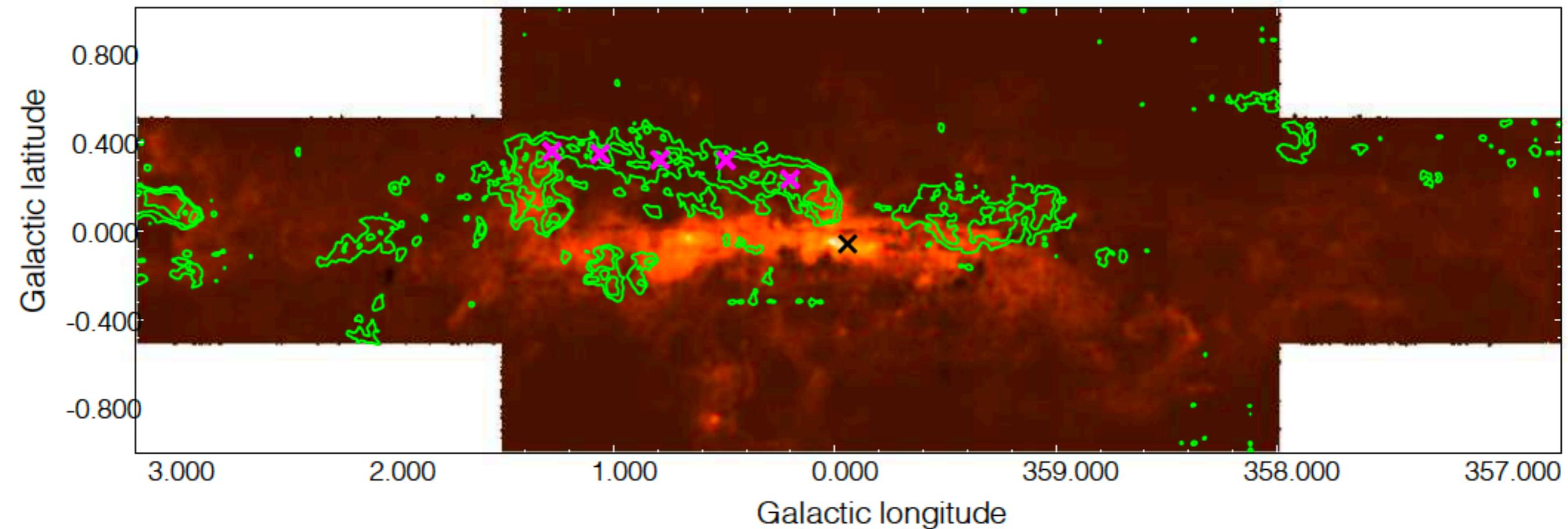


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IRAM 30 m observations - EMR feedback effects



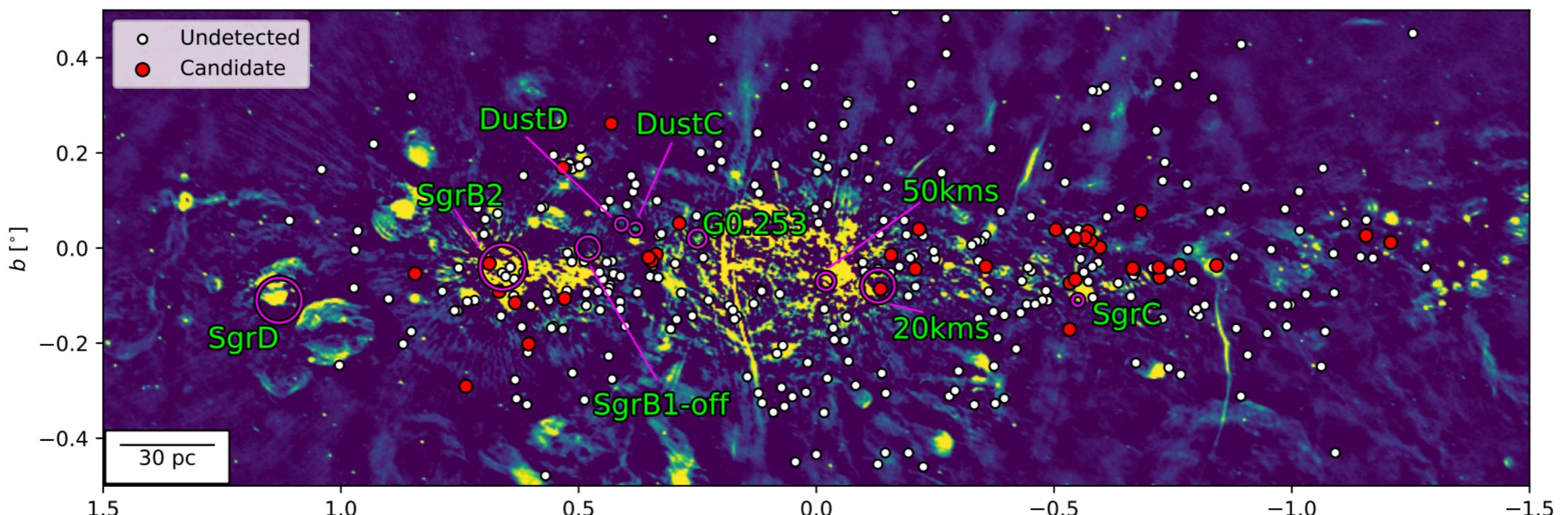
- Search for shock and/or dense gas tracers
- ~10 molecular species identified along the EMR
- Shock (SiO, HNCO....), dense gas (N_2H^+ , H^{13}CO^+ )

EMR feedback effects

- Multiwavelength analysis
- SEDIGISM (kinematics) + IRAM (chemistry)
- Continuum - Radio, IR (star formation)

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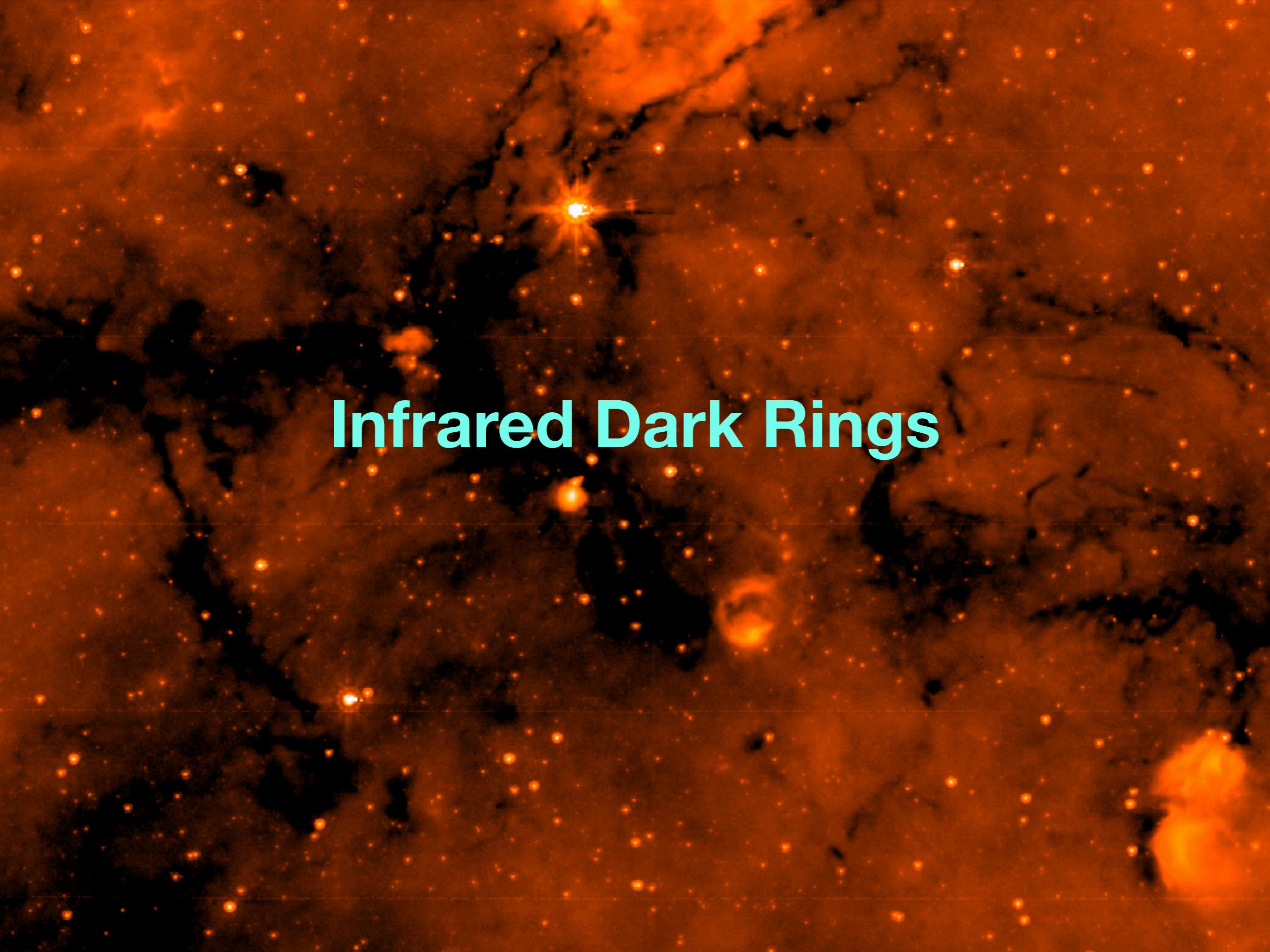
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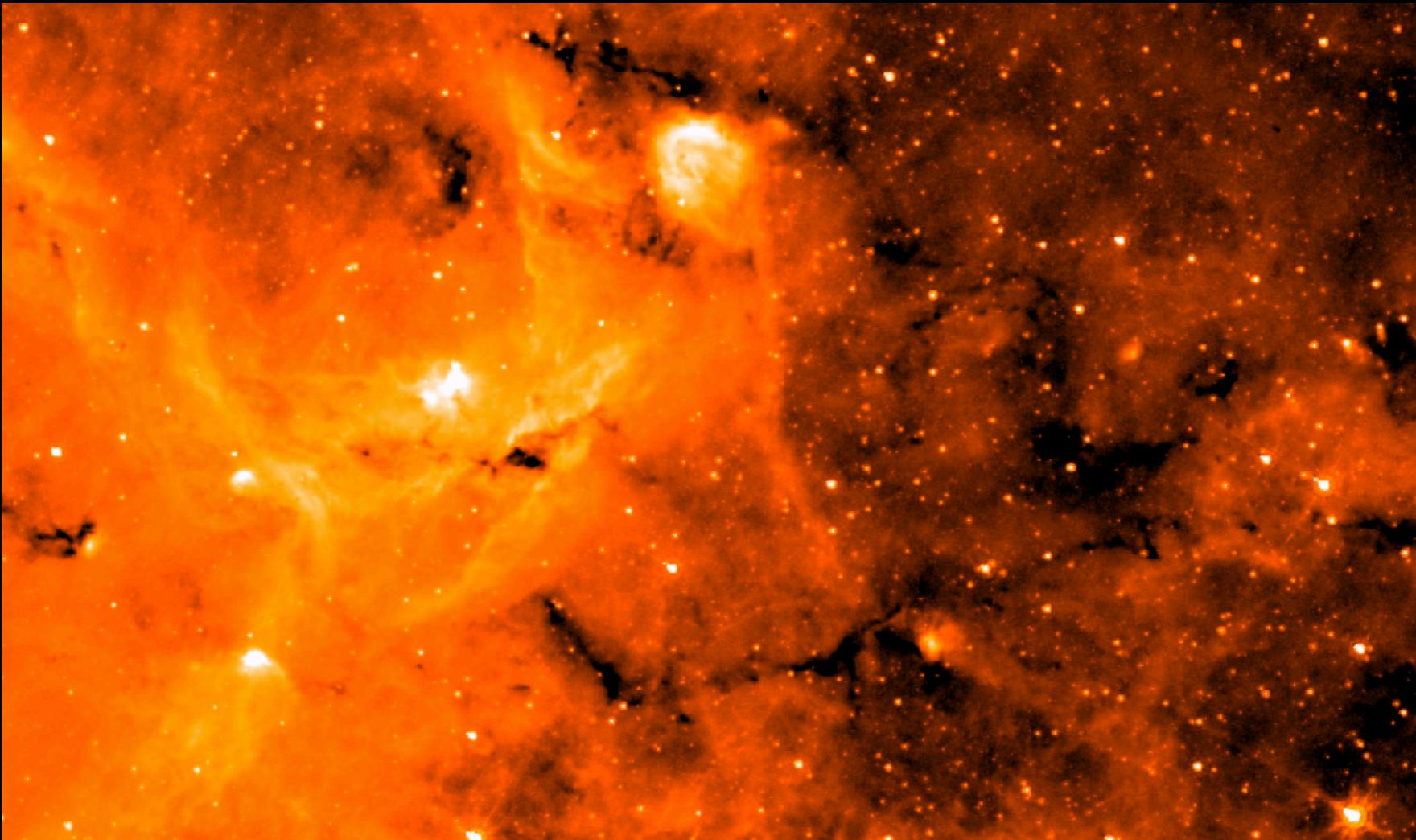
A global view on star formation: The GLOSTAR Galactic plane survey

IV. Radio continuum detections of young stellar objects in the Galactic Centre region

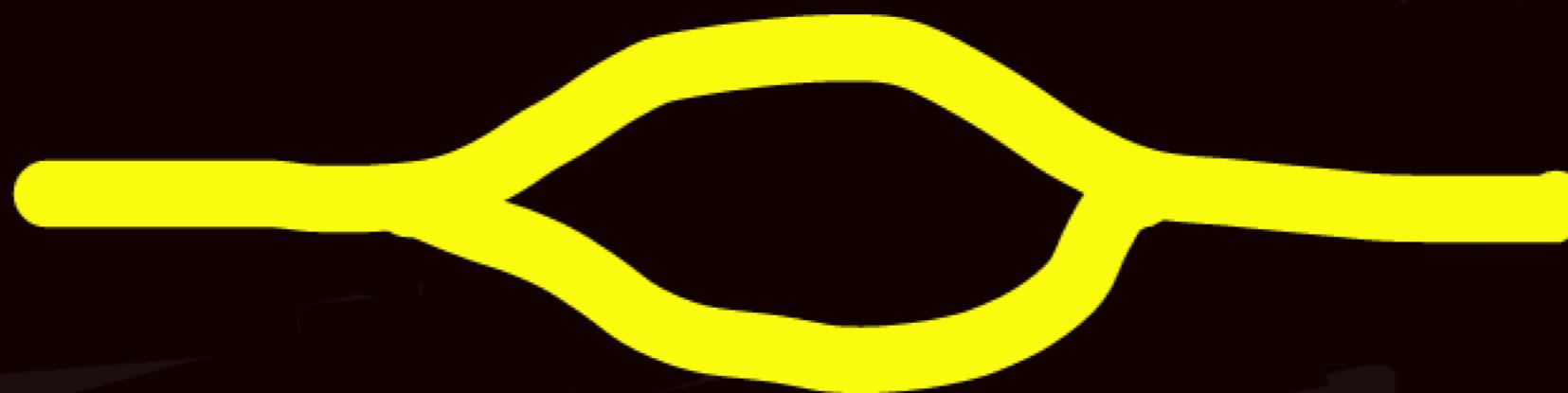
H. Nguyen^{1,*}, M. R. Rugel¹, K. M. Menten¹, A. Brunthaler¹, S. A. Dzib¹, A. Y. Yang¹, J. Kauffmann², T. G. S. Pillai^{3,1}, G. Nandakumar^{4,5}, M. Schultheis⁶, J. S. Urquhart⁷, R. Dokara^{1,*}, Y. Gong¹, S-N. X. Medina¹, G. N. Ortiz-León¹, W. Reich¹, F. Wyrowski¹, H. Beuther⁸, W. D. Cotton^{9,10}, T. Csengeri¹¹, J. D. Pandian¹², and N. Roy¹³



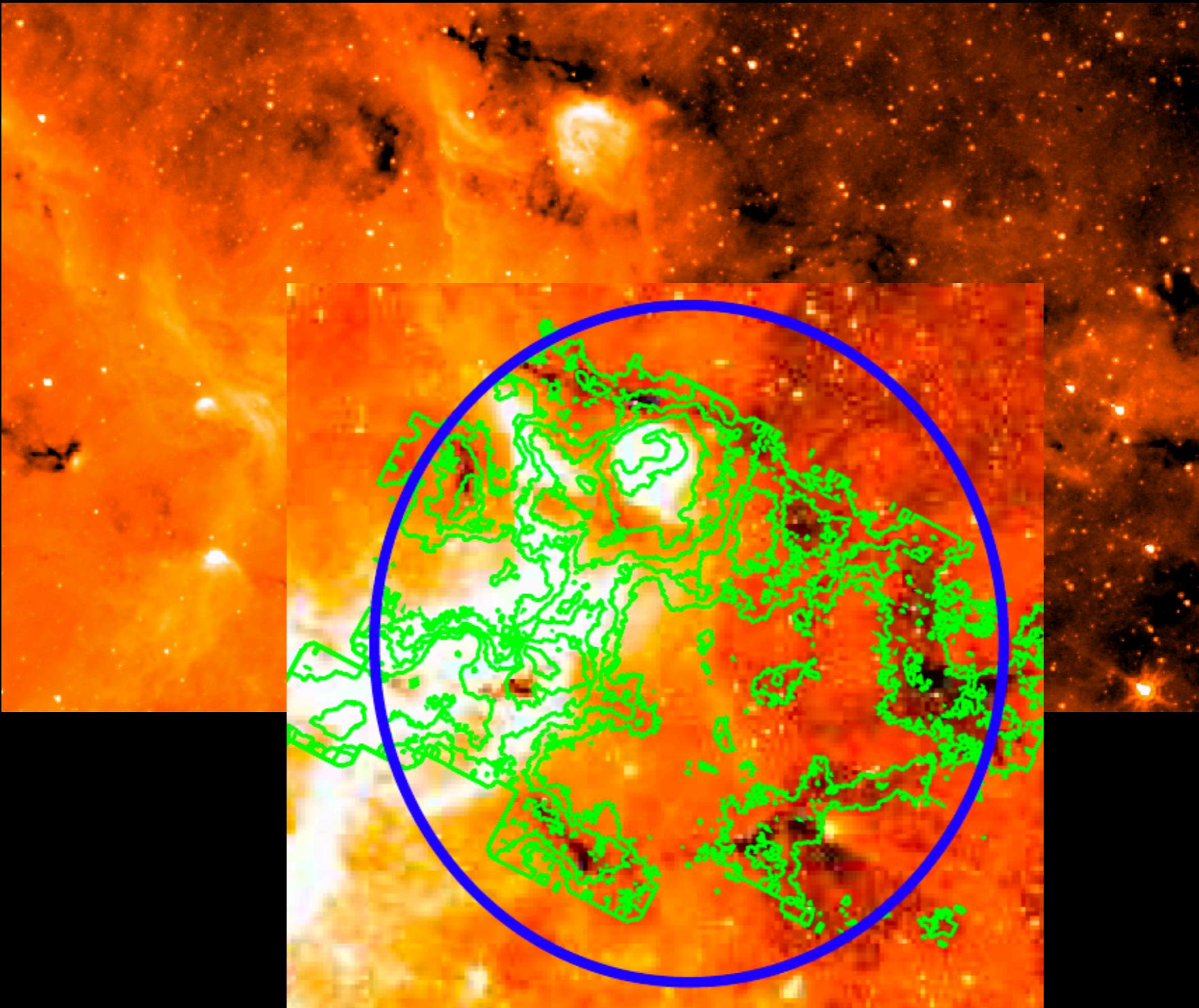
Infrared Dark Rings



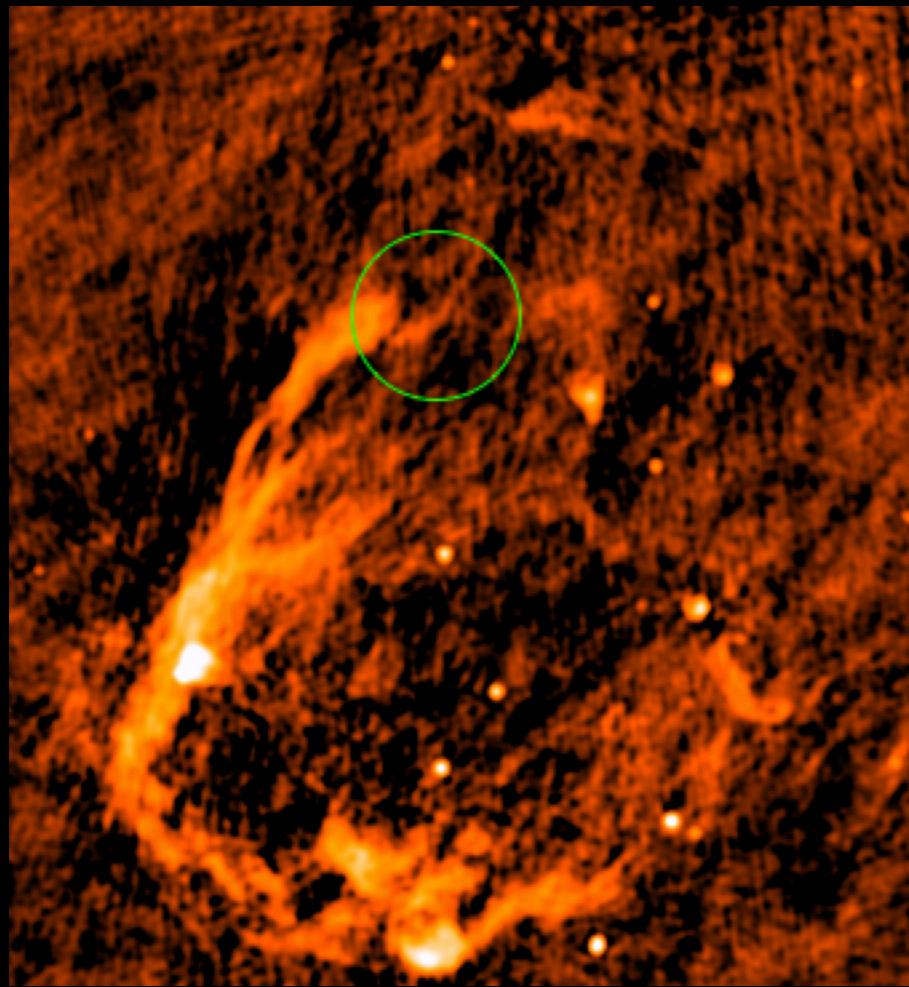
Spitzer 8 micron map towards the centre of a Galactic bone candidate



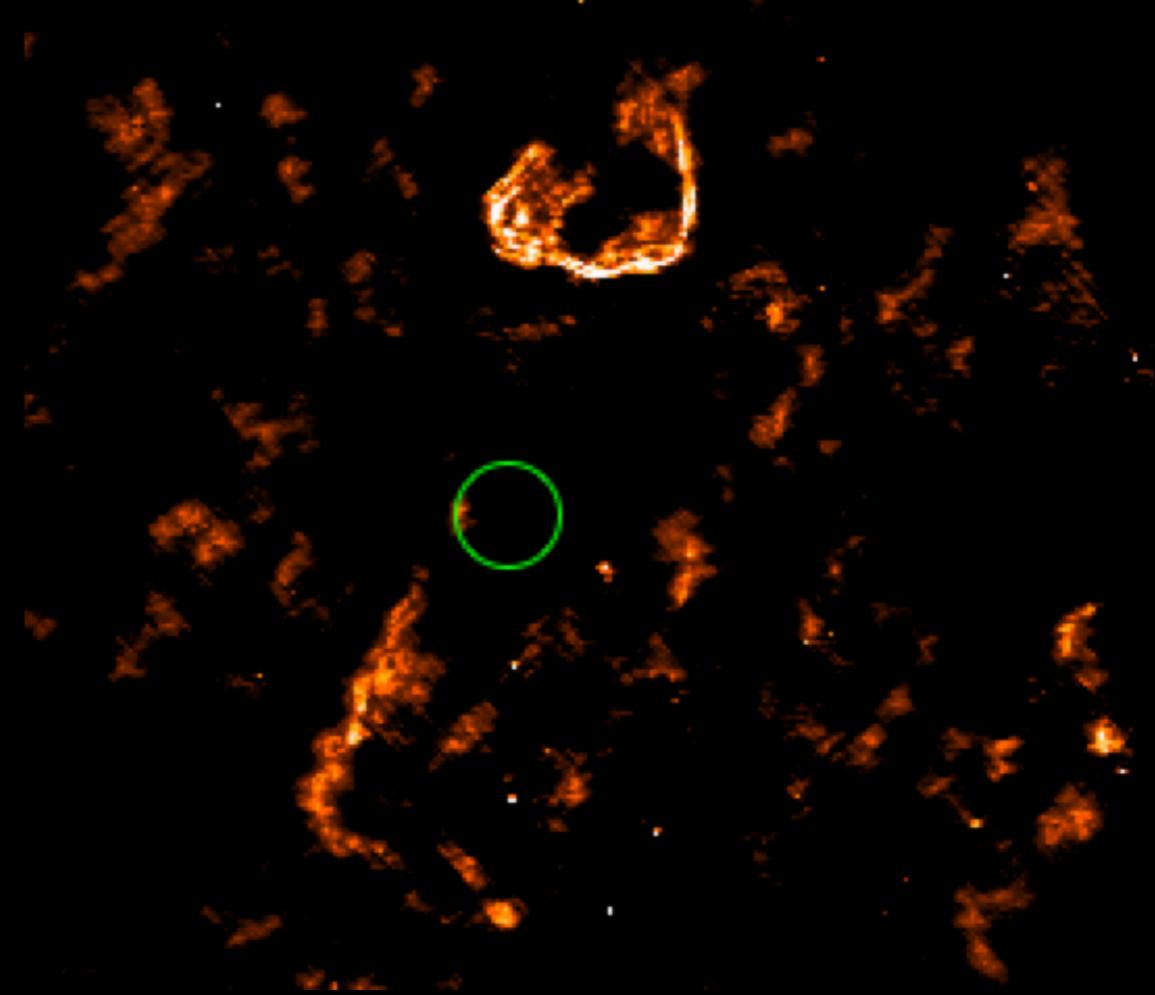
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8 micron warm dust overlaid with CO contours.

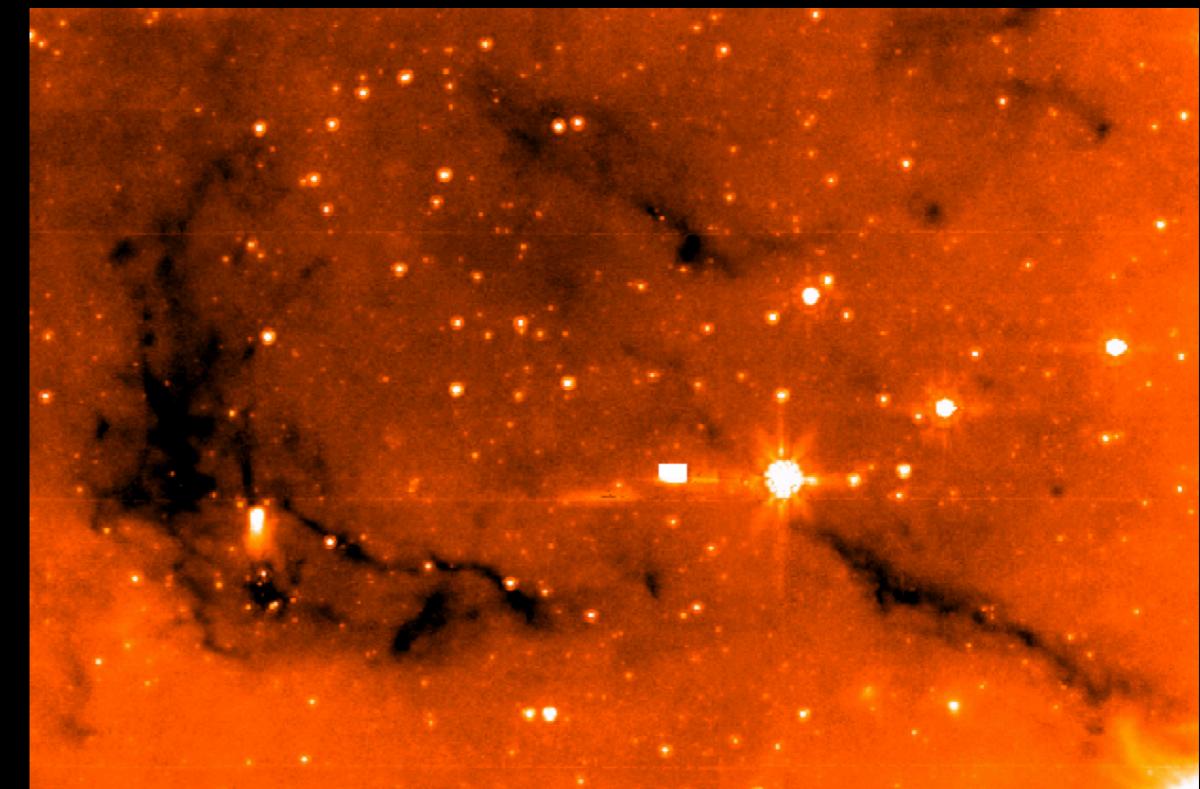
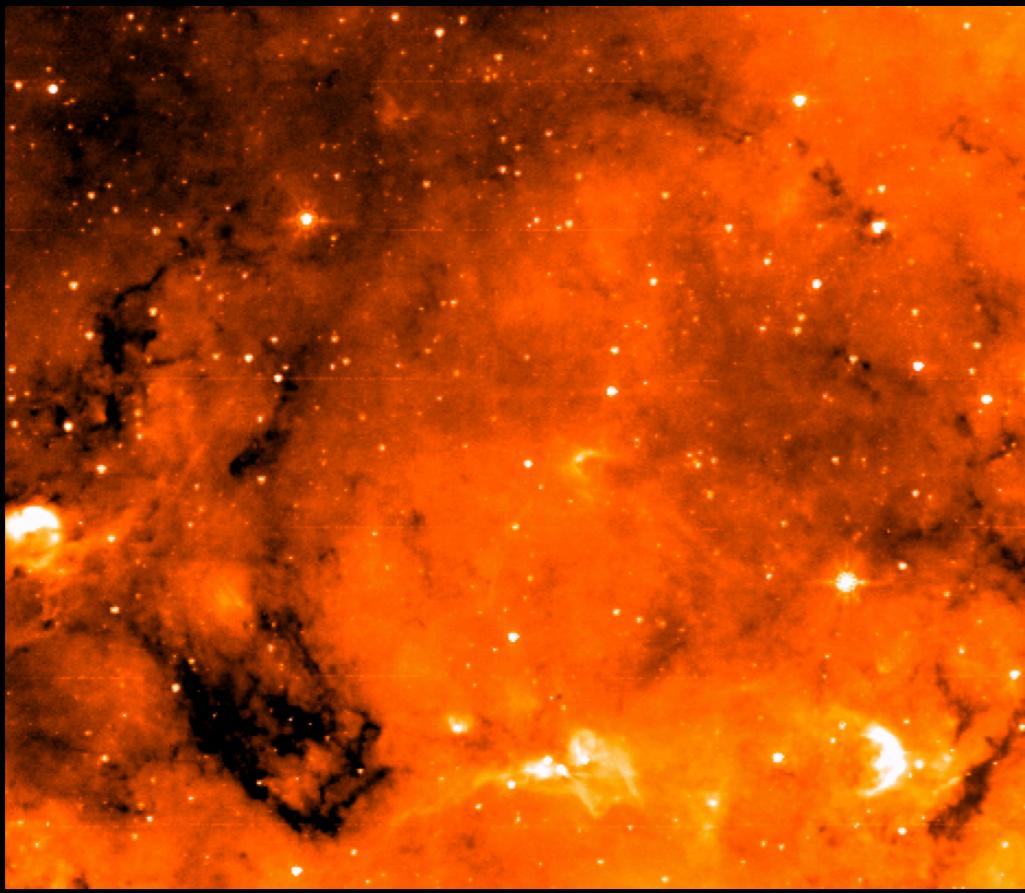
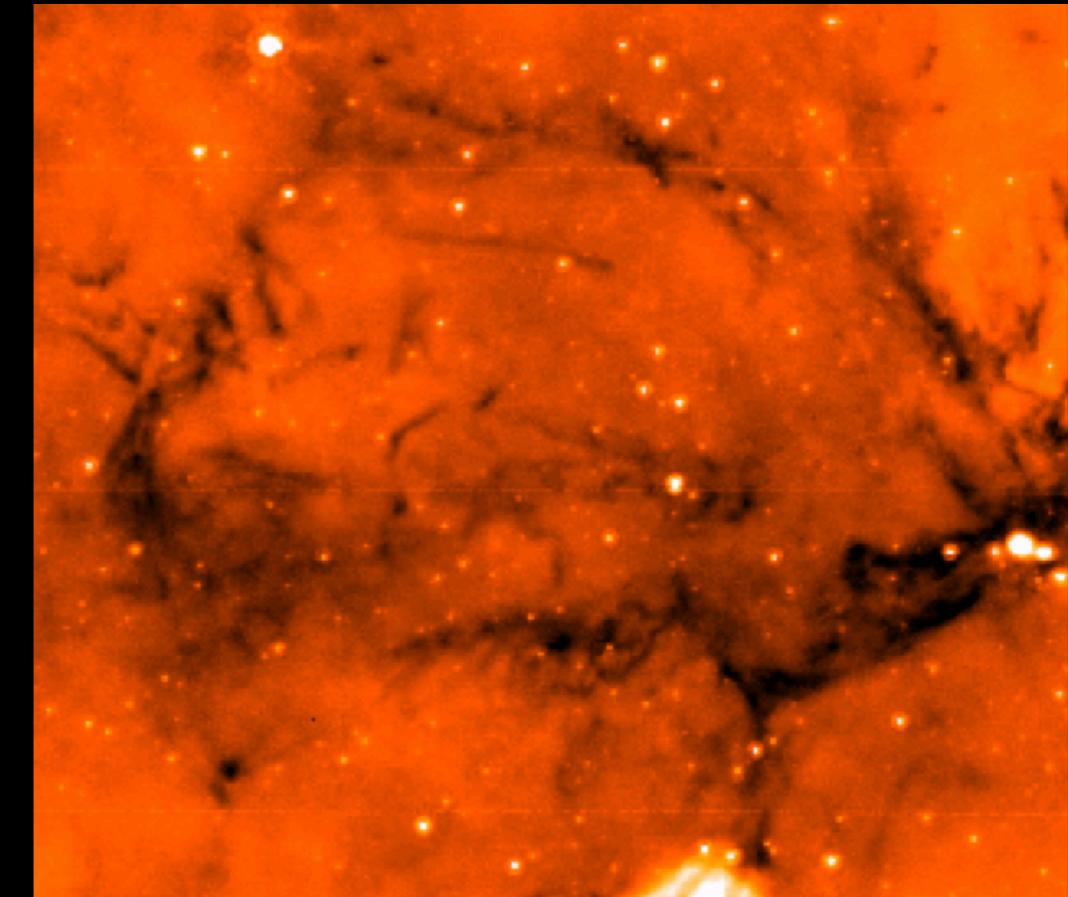
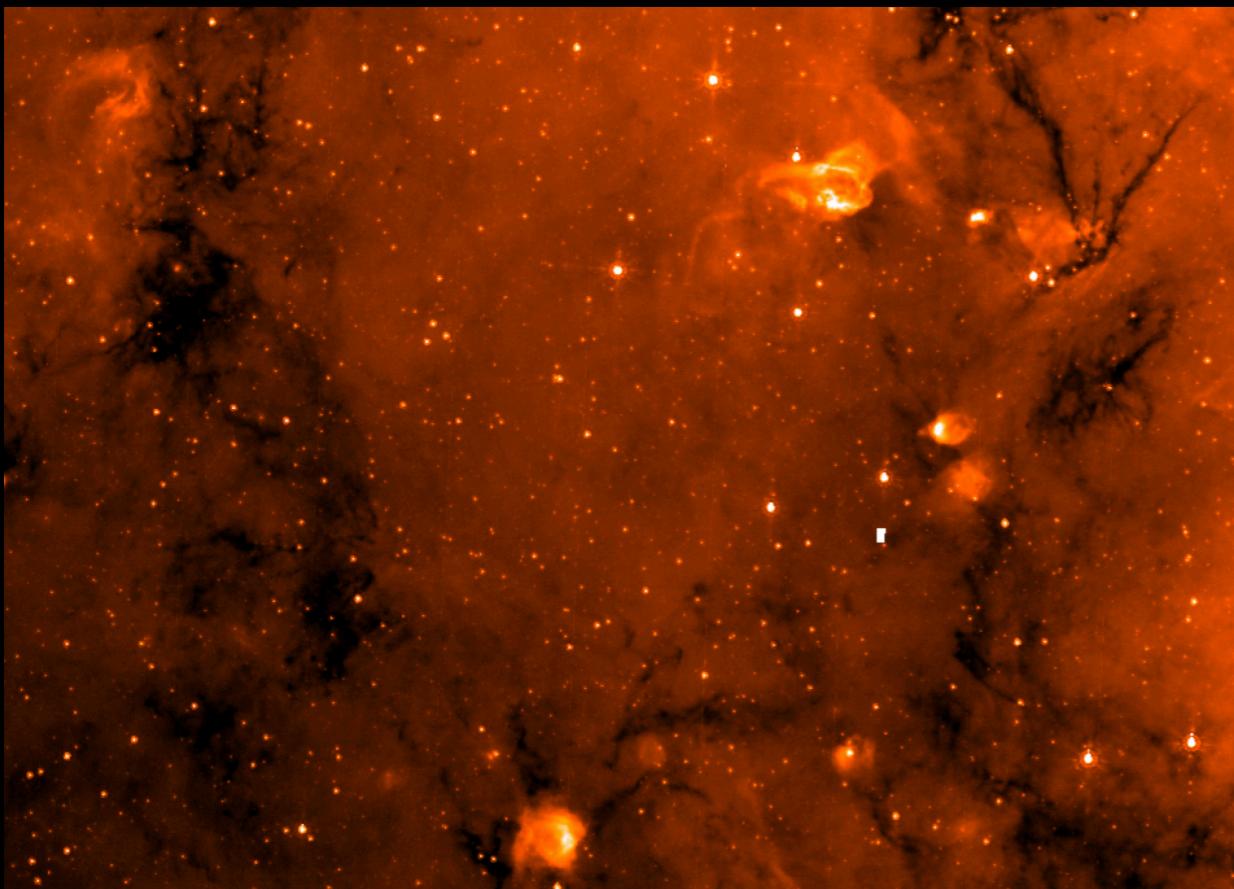


THOR 1 GHz



GMRT 325 MHz

- 11 pc cavity ($d=3.5$ kpc)
- Stellar winds from massive stars/supernova remnants
- Radio flux upper limit from THOR - 3mJy (spectral type later than B1)
- Absence of HII regions, star cluster or SNRs



Characterisation of IR Dark Rings

- Velocity coherence, mass and kinematics - SEDIGISM (+ThrUMMS, GRS)
- Location in the Galaxy, association with spiral arms
- Multiwavelength association - archival surveys (Ionised gas - THOR, GLOSTAR, SUMSS; IR - Spitzer, 2MASS; Submm - Herschel)
- Specific morphological class of IRDC? - Search near GC with SEDIGISM

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Thank you