How maser observations unravel the gas motions in the Galactic Center

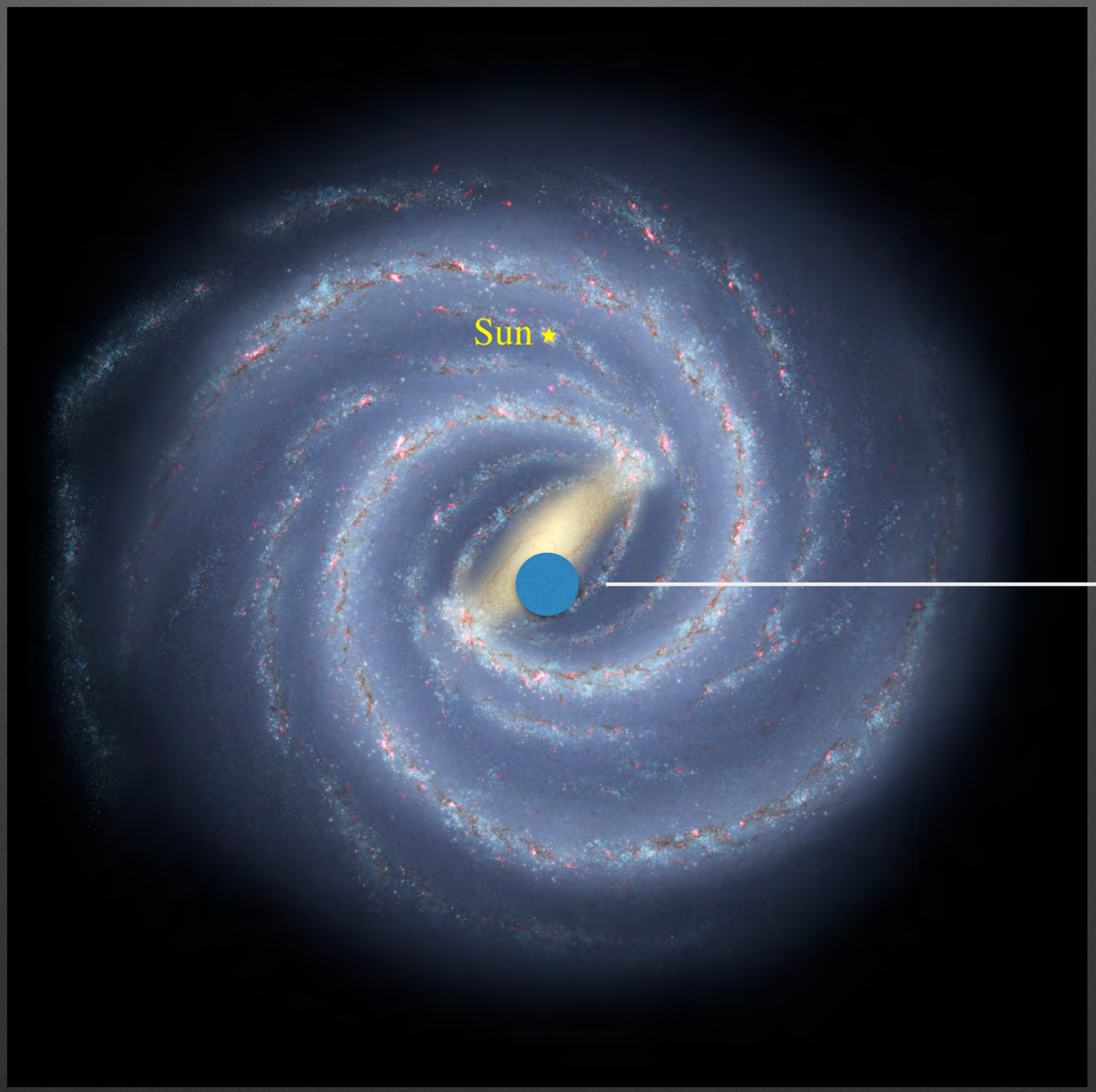
Katharina Immer (JIVE), M. Reid, A. Brunthaler, K. Menten, Q. Zhang, X. Lu, E. Mills, A. Ginsburg, J. Henshaw, S. Longmore, D. Kruijssen, T. Pillai

„Astrophysical masers", IAU Symposium 336

05.09.2017



Central Molecular Zone



Artist impression of the Milky Way (R. Hurt, NASA/JPL-Caltech)

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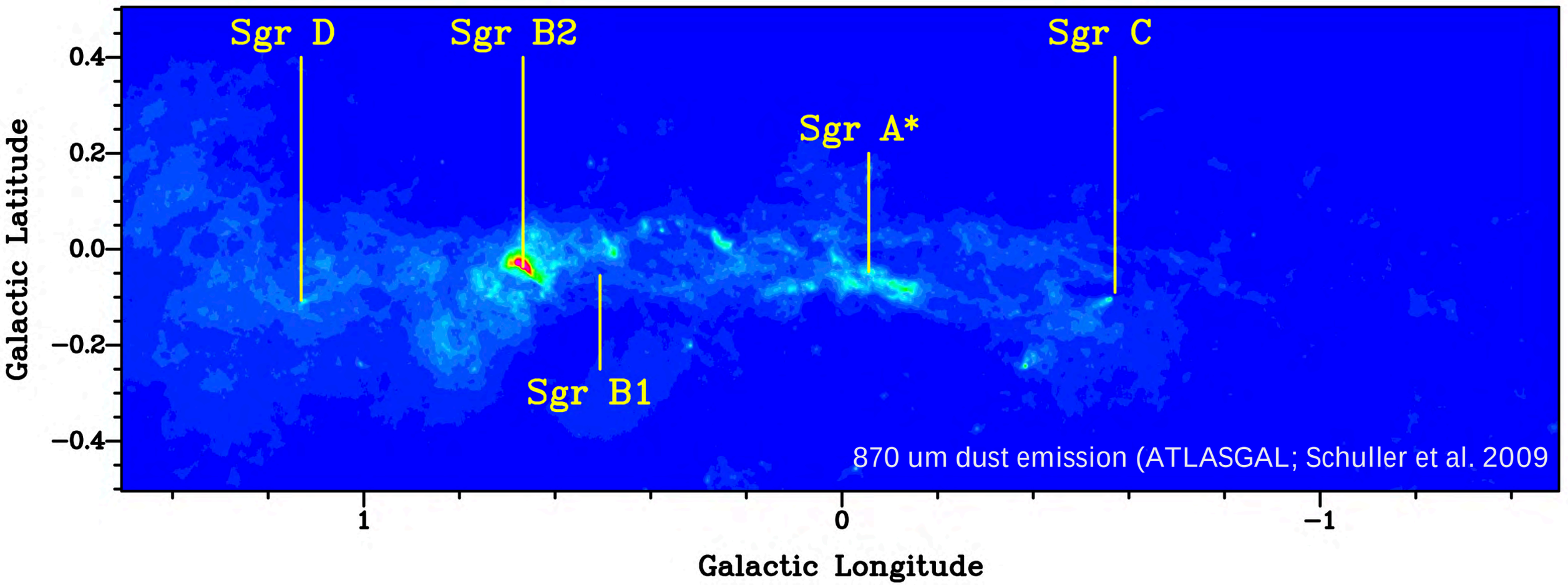

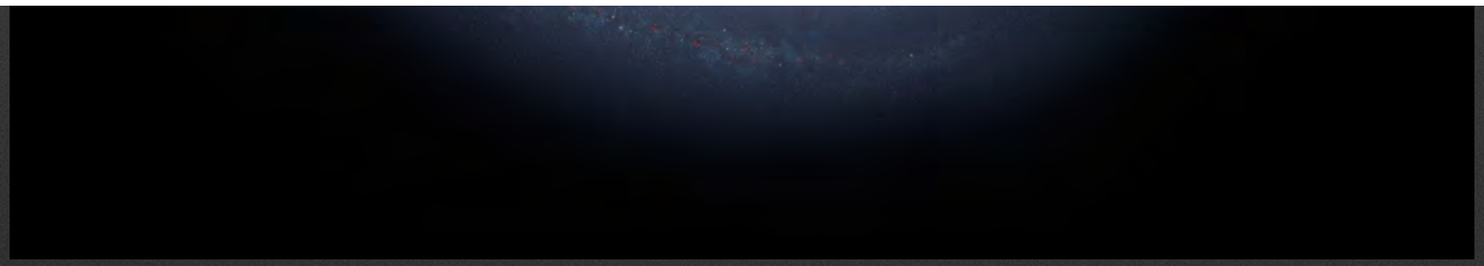

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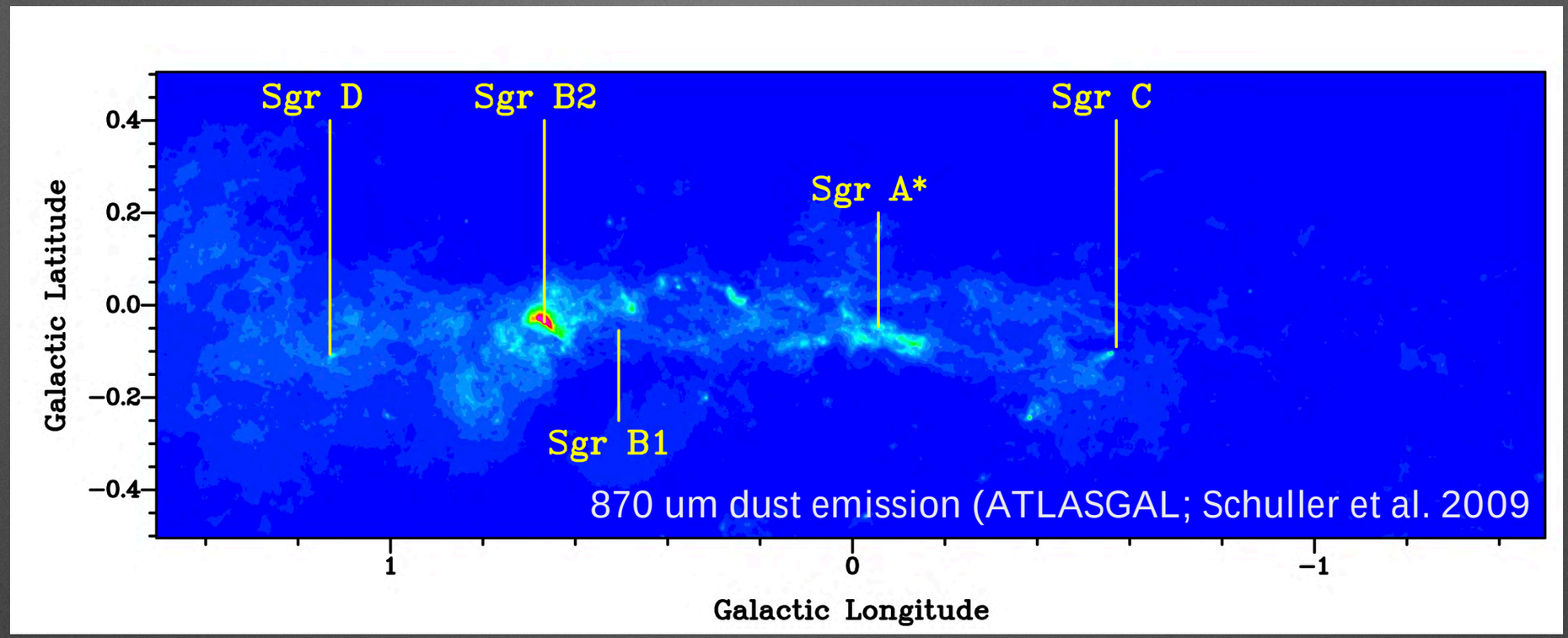
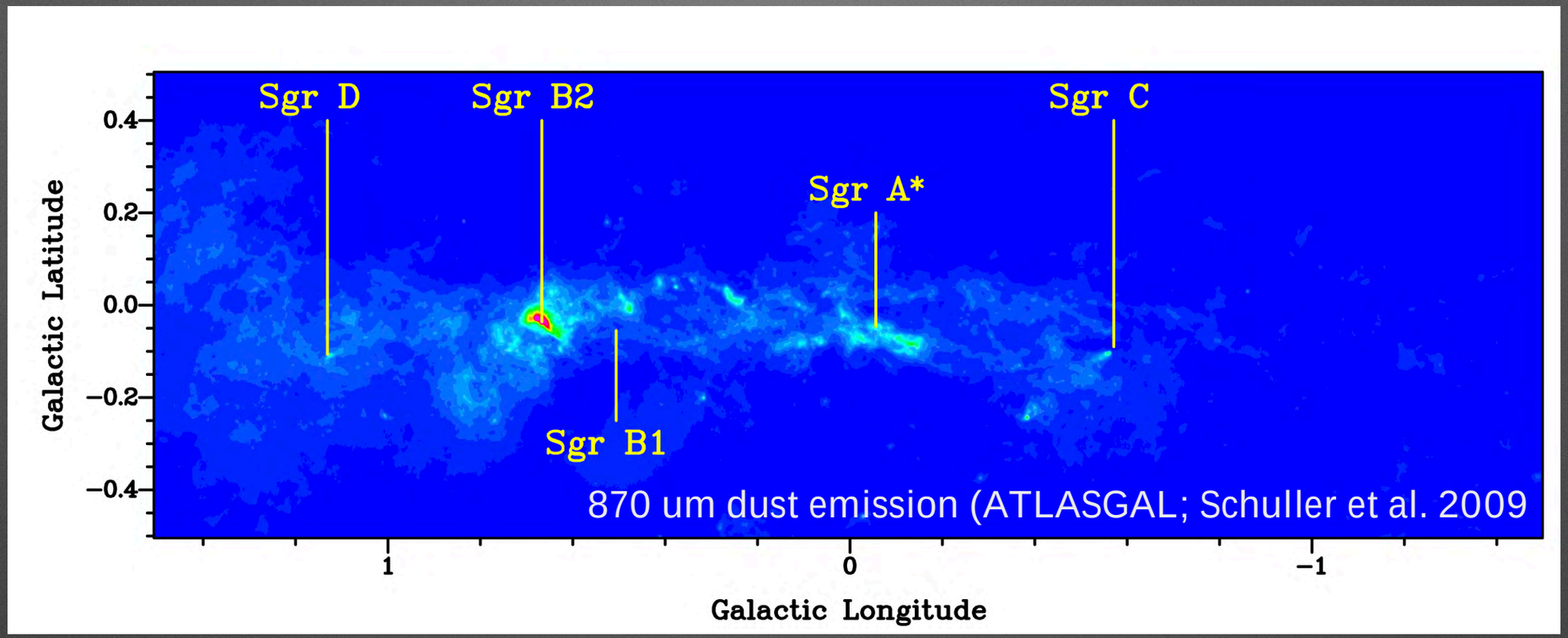


- Distance: 8.4 kpc (Reid et al. 2013); inner ~500 pc of the Galaxy (l=–1° to +1.$^{\circ}$5)
- Extreme conditions: much higher gas volume densities, velocity dispersions, gas temperatures, etc. than in Galactic disk
- Contains < 10% of Galaxy's molecular gas but ~ 80% of dense (>10^3 cm^{-3}) molecular gas
- Gas reservoir of several 10^7 $M_{\odot}$ but present-day star formation rate only equivalent to that in Orion (Longmore et al. 2012)

Central Molecular Zone



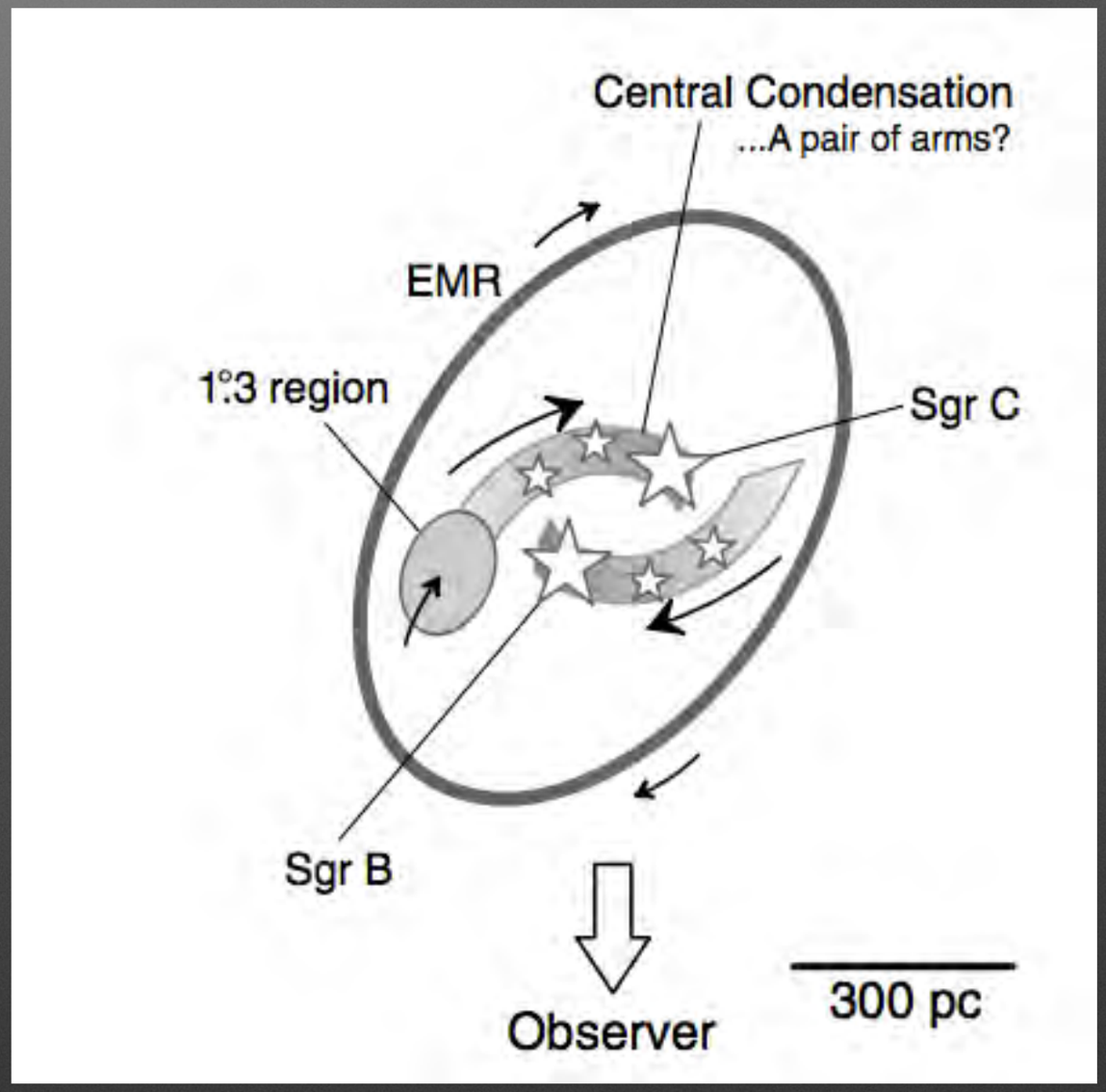
- Close link between the formation of stars and clusters and the orbital dynamics of the gas (e.g. Molinari et al. 2011, Longmore et al. 2013, Kruijssen et al. 2015)?

- Complex kinematic structure of the molecular gas in position-position-velocity space (e.g. Bally et al. 1988, Sofue 1995, Tsuboi et al. 1999, Oka 1998): several coherent gas streams spanning ~200 km/s in velocity

- Different models: two spiral arms (e.g. Sofue 1995), closed elliptical orbit (Molinari et al. 2011); open streams (e.g. Kruijssen et al. 2015)

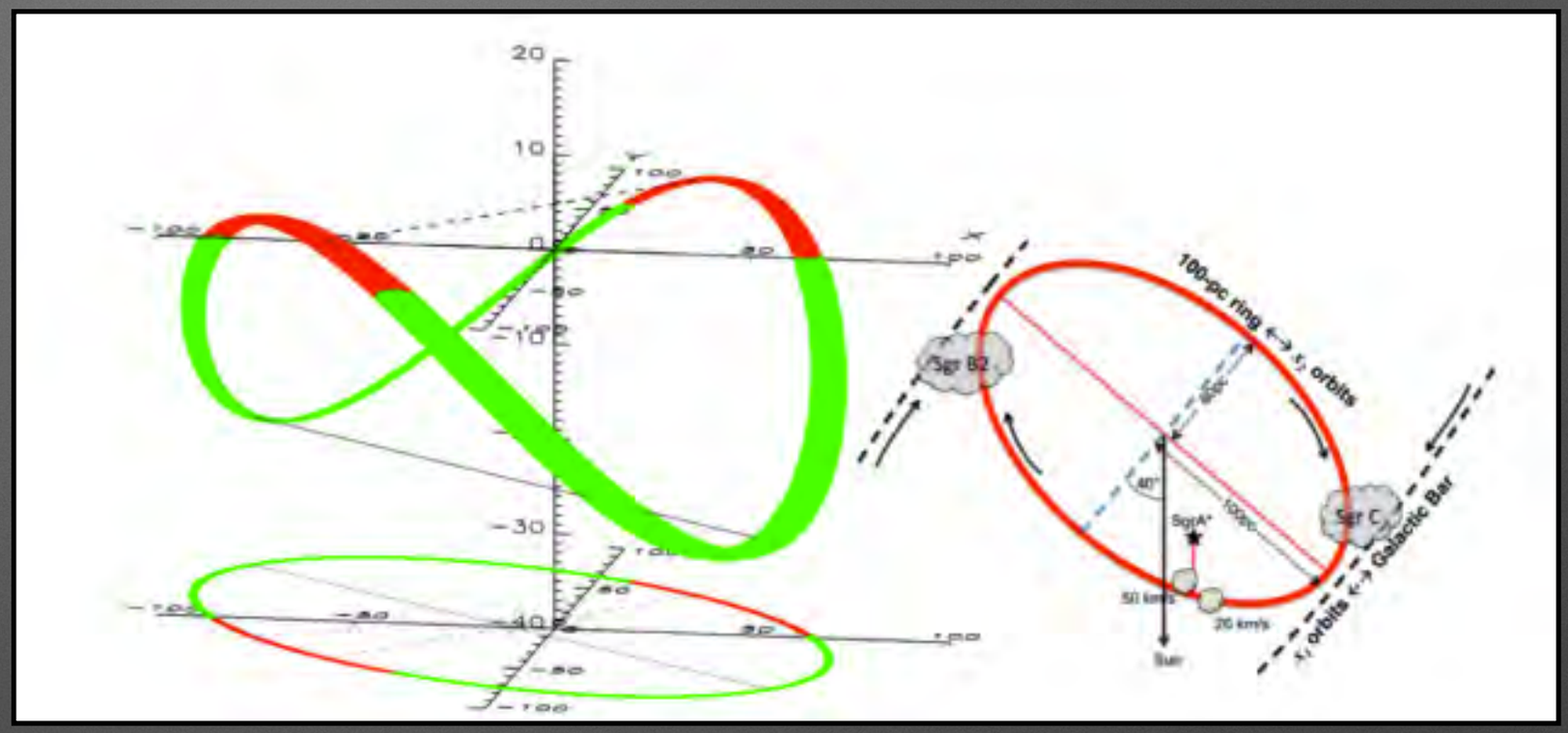
Two spiral arms

- e.g. Sofue 1995, Sawada et al. 2004, Ridley et al. 2017
- Sawada et al. 2004: Location of gas clouds via comparison of CO emission and OH absorption
- Sgr B and Sgr C at leads of spiral arms
- Time lag between arrival of gas on orbit and onset of star formation?



Sawada et al. 2004

Closed elliptical orbit

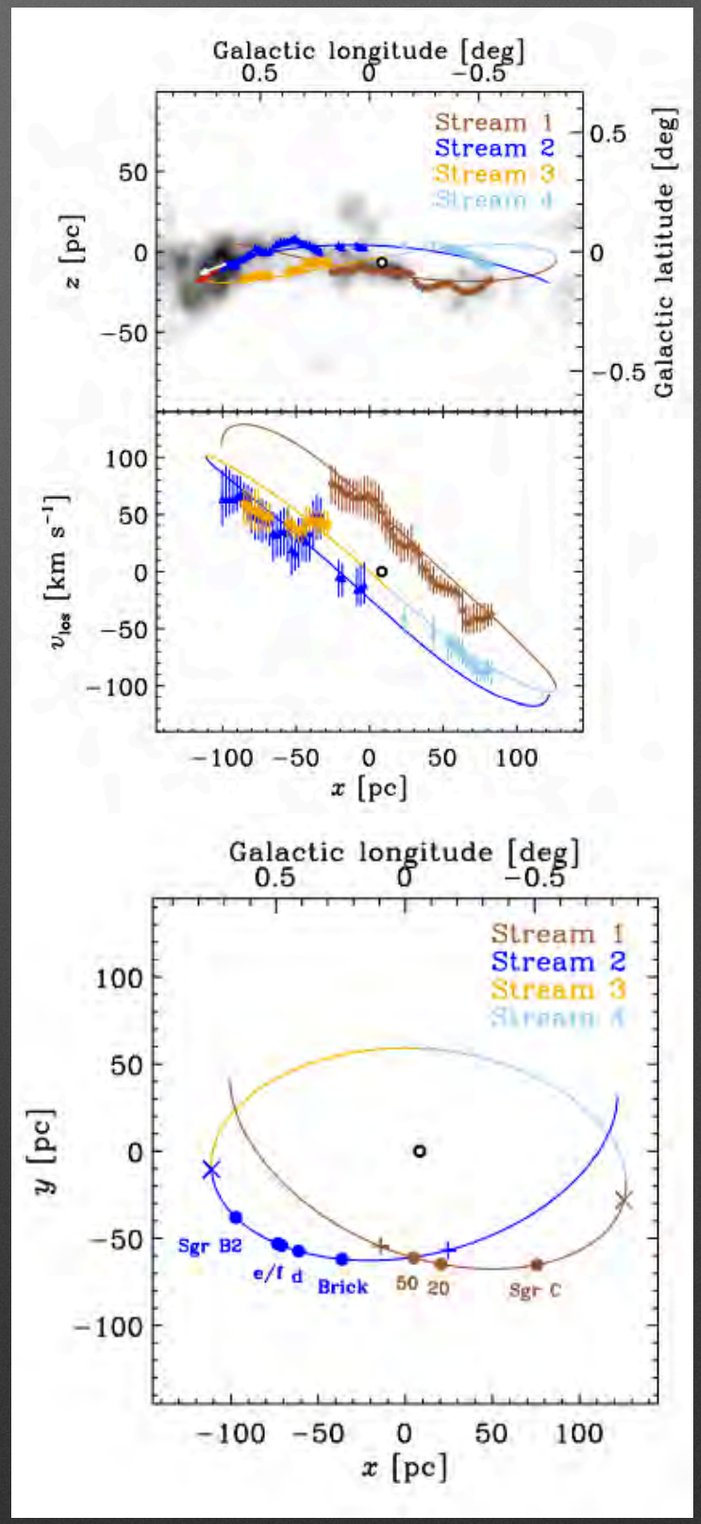


Molinari et al. 2011

- Molinari et al. 2011
- Based on Herschel Hi-GAL observations of the cold dust and the CS survey by Tsuboi et al. 1999
- ∞-shaped feature („100 pc ring“), modelled as an elliptical closed orbit; orbit is fit to radial velocities of 20 positions along the feature
- 100 pc ring located on x2 orbit system, Sgr B2 and Sgr C located at colliding points of inflowing material on x1 and x2 orbits

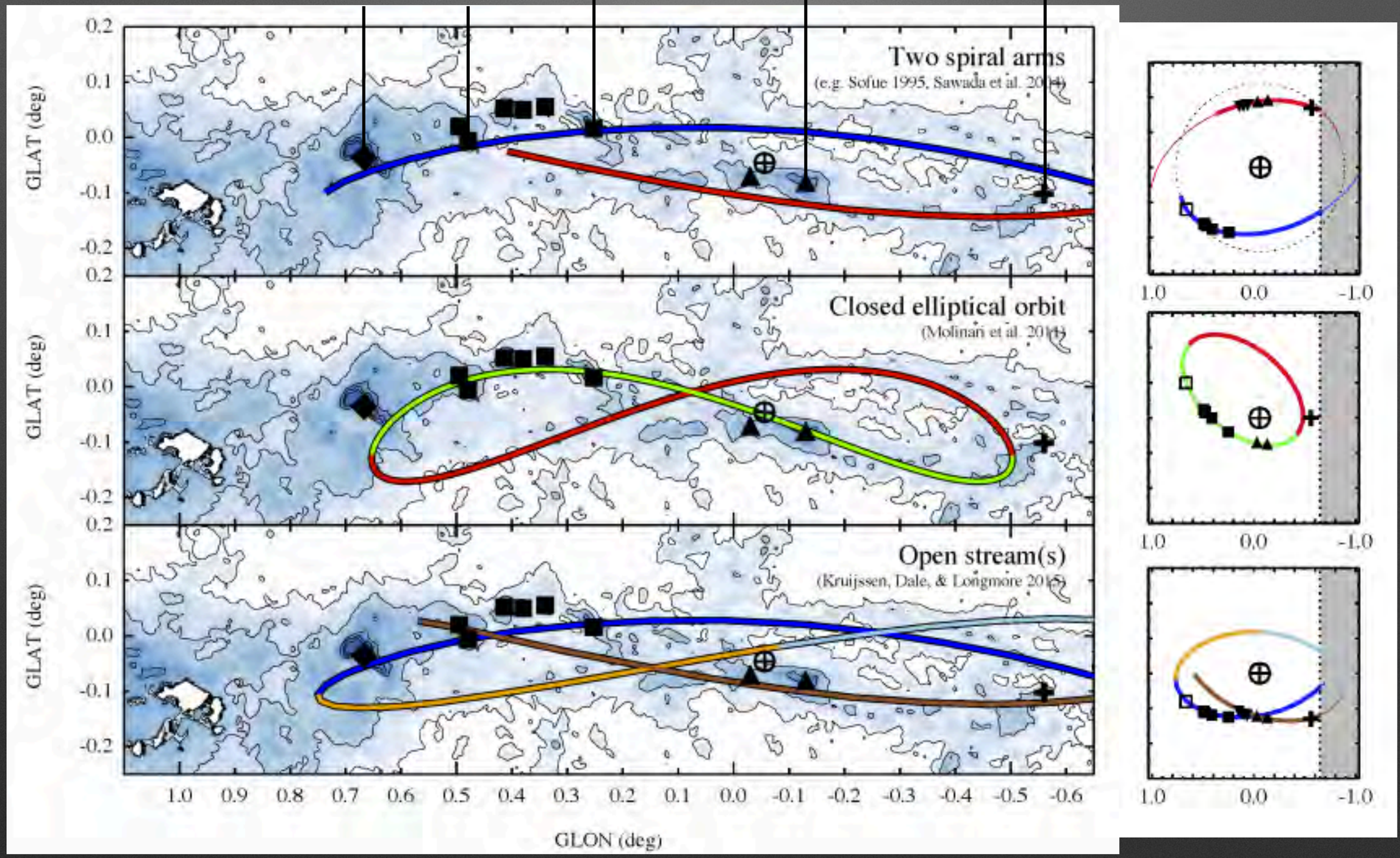
Open streams

- Kruijssen et al. 2015, Henshaw et al. 2016
- Based on NH3 observations from the HOPS survey (Walsh et al. 2011) and HNCO observations from the Mopra CMZ survey (Jones et al. 2012)
- Continuous open orbit, divided into four „streams“
- Variable orbital velocity



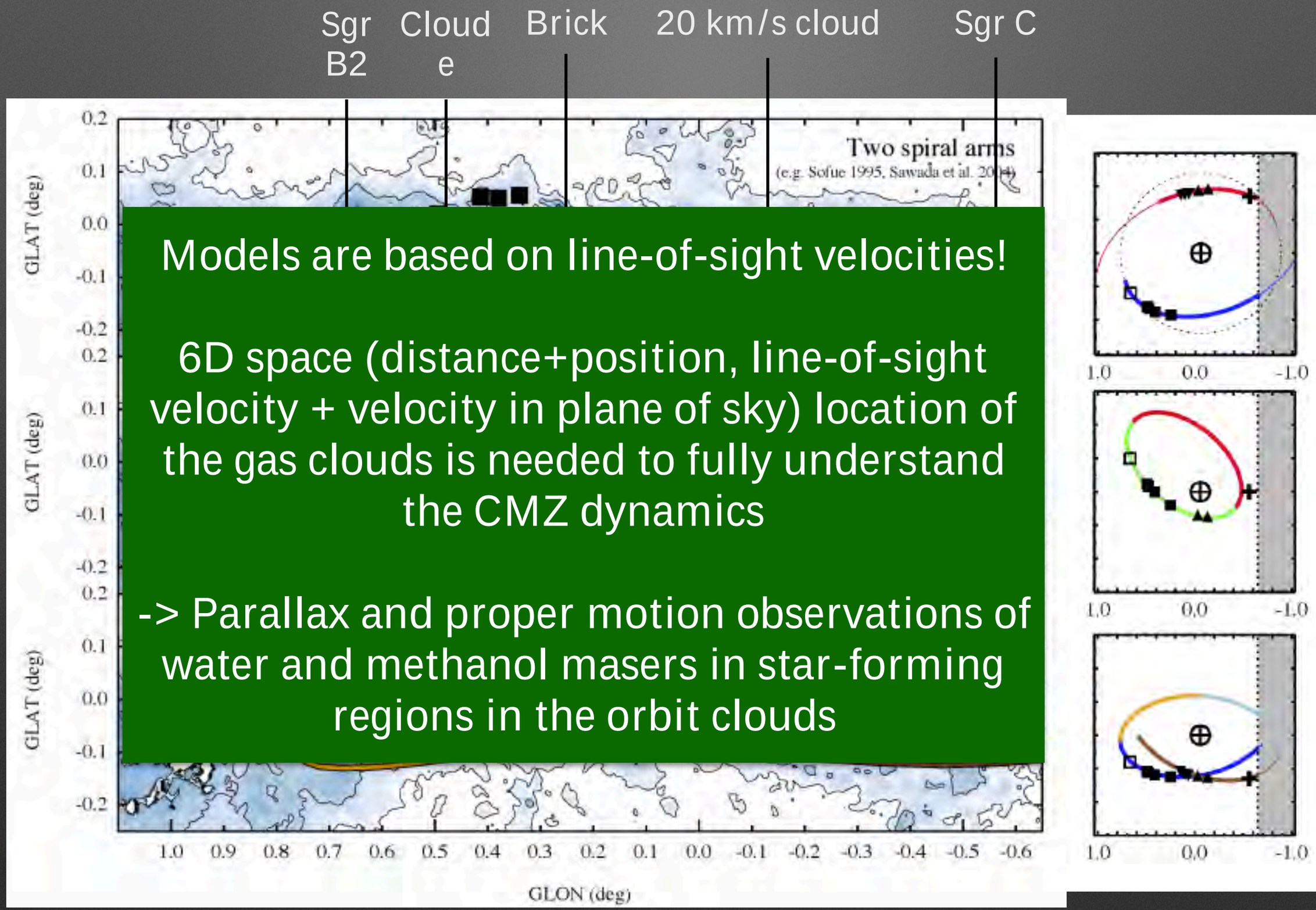
Kruijssen et al. 2015

Model gas orbits



Henshaw et al. 2016

Model gas orbits



Models are based on line-of-sight velocities!

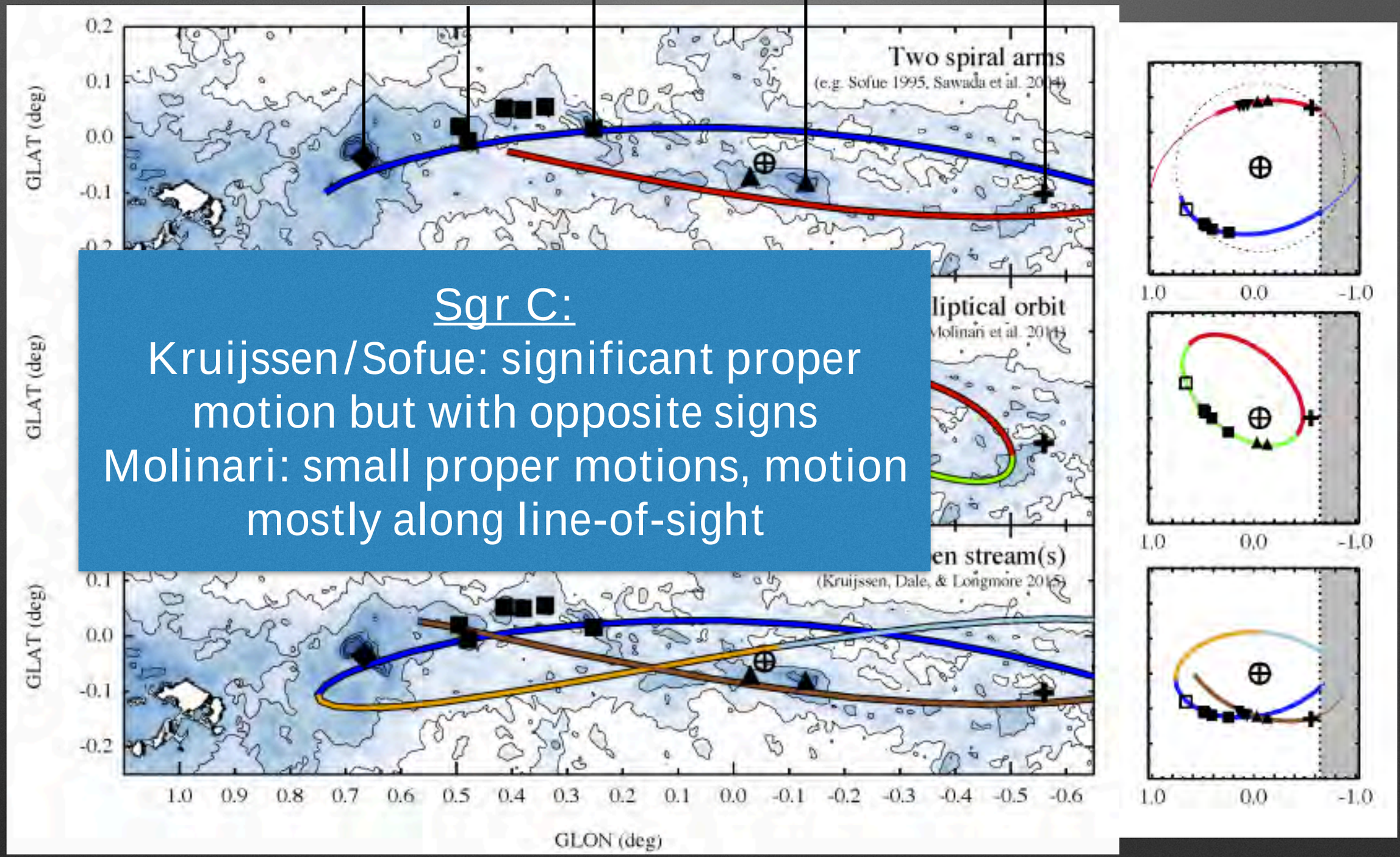
6D space (distance+position, line-of-sight velocity + velocity in plane of sky) location of the gas clouds is needed to fully understand the CMZ dynamics

-> Parallax and proper motion observations of water and methanol masers in star-forming regions in the orbit clouds

Henshaw et al. 2016

Model gas orbits - Predictions

Sgr B2 | Cloud e | Brick | 20 km/s cloud | Sgr C



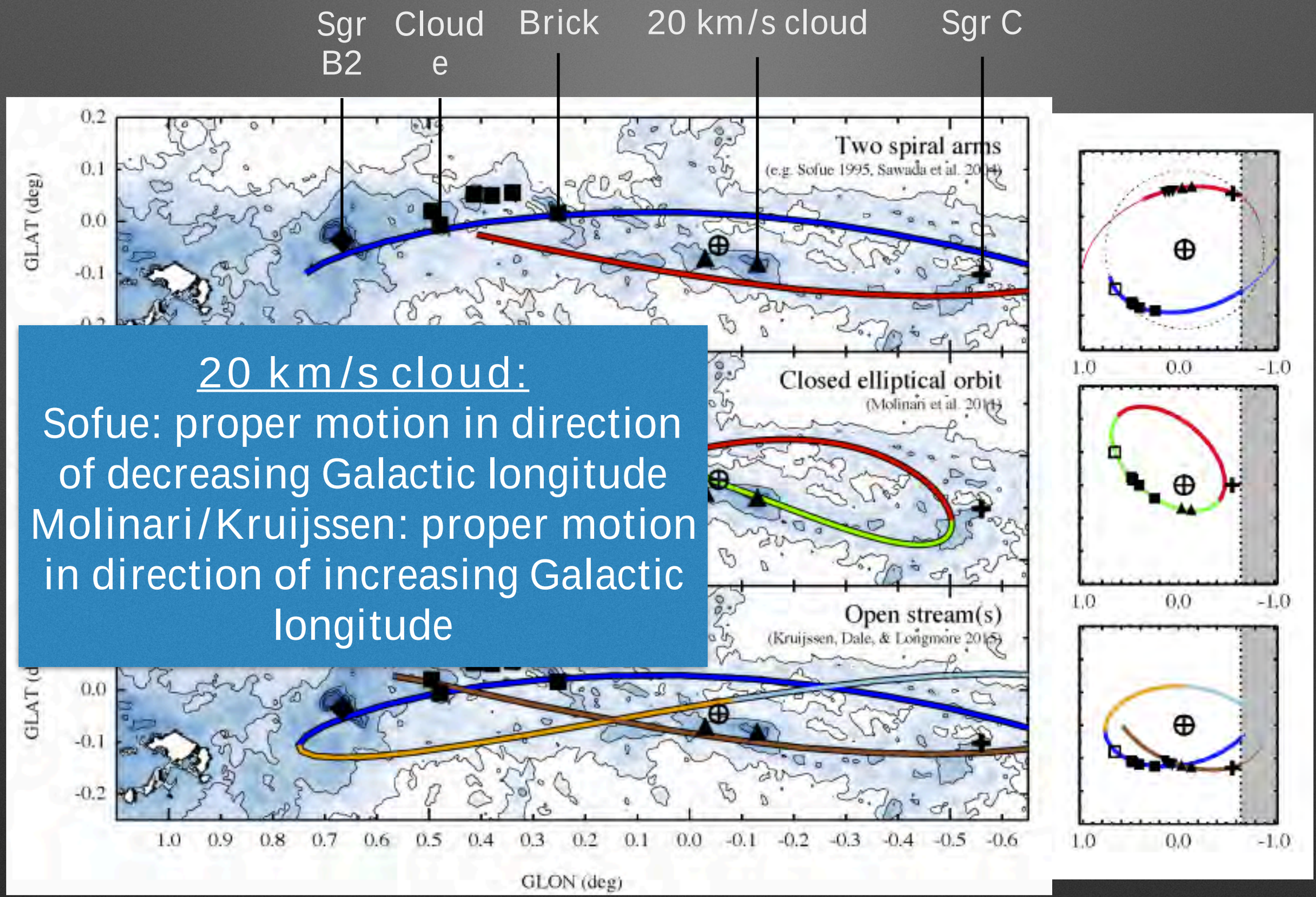
Sgr C:

Kruijssen/Sofue: significant proper motion but with opposite signs

Molinari: small proper motions, motion mostly along line-of-sight

Henshaw et al. 2016

Model gas orbits - Predictions



20 km/s cloud:

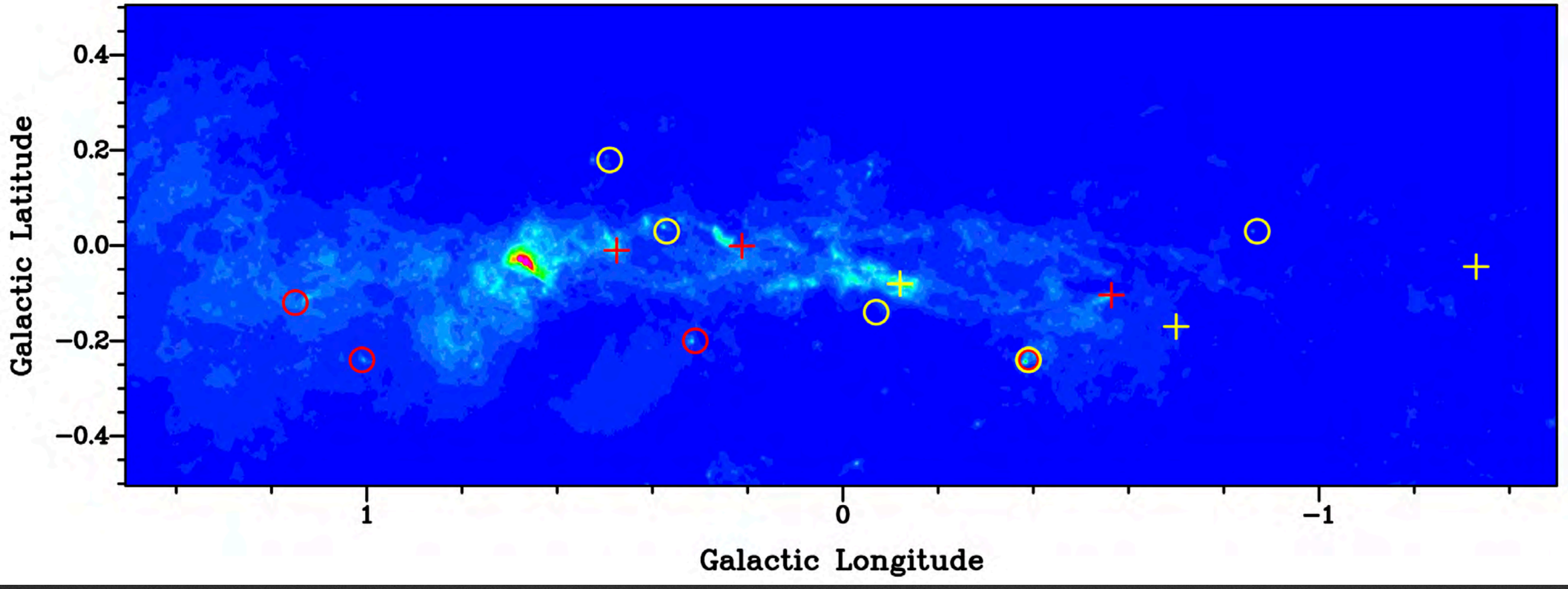
Sofue: proper motion in direction of decreasing Galactic longitude

Molinari/Kruijssen: proper motion in direction of increasing Galactic longitude

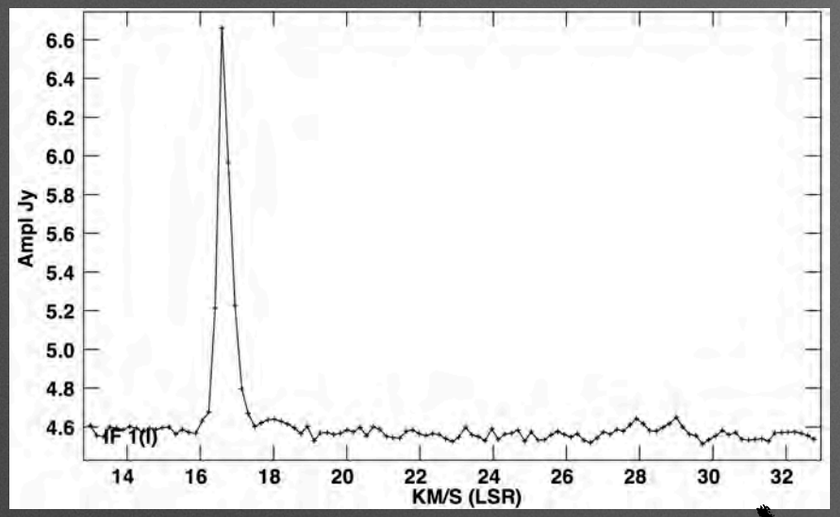
Henshaw et al. 2016

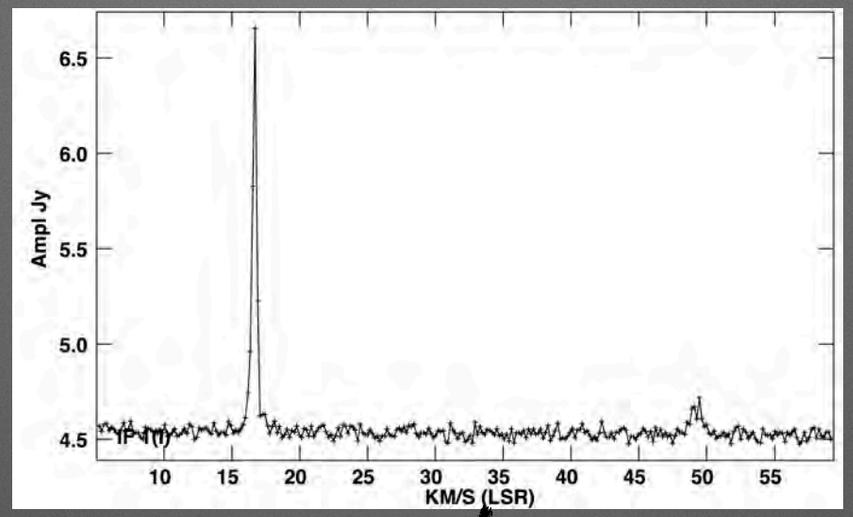
Observations

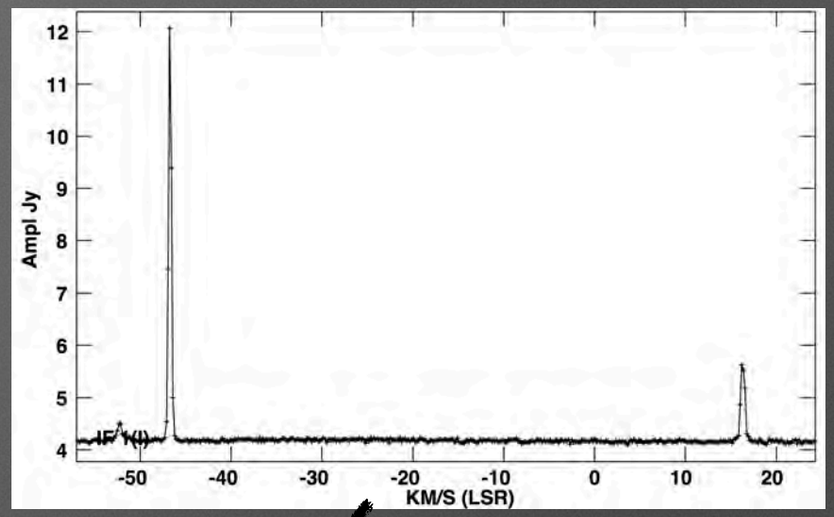
- Very Long Baseline Array; 4 epochs over one year for 6.7 GHz methanol masers; 4/6 epochs for 22 GHz water masers
- VLBA-Project BI042: 3 methanol and 3 water masers (crosses)
- BeSSeL survey: 4 methanol and 5 water masers (circles)

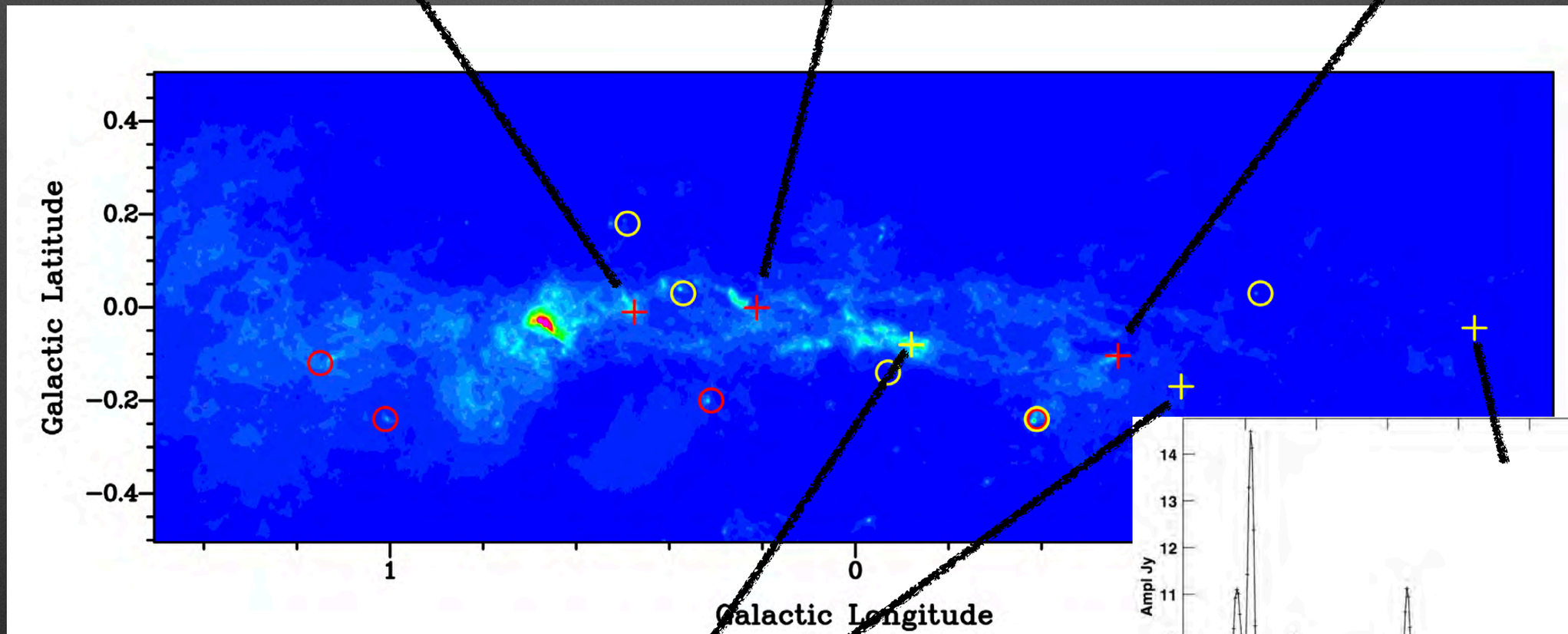


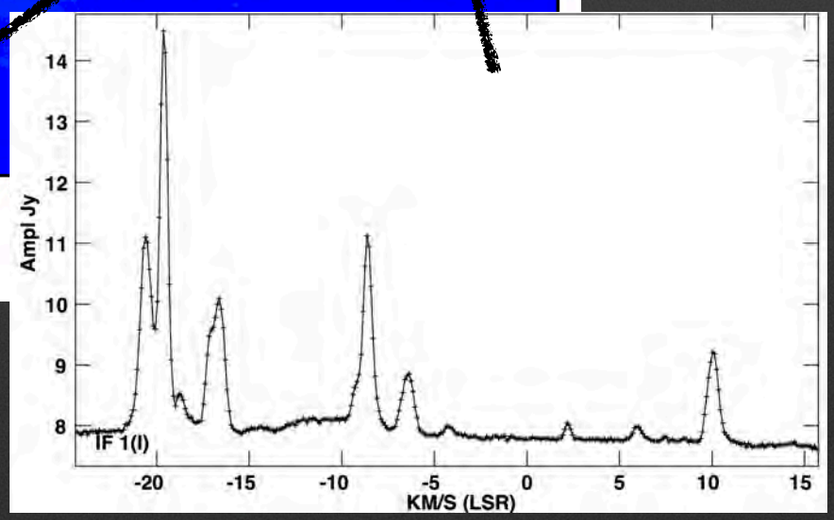
BI042 - 1. Epoch





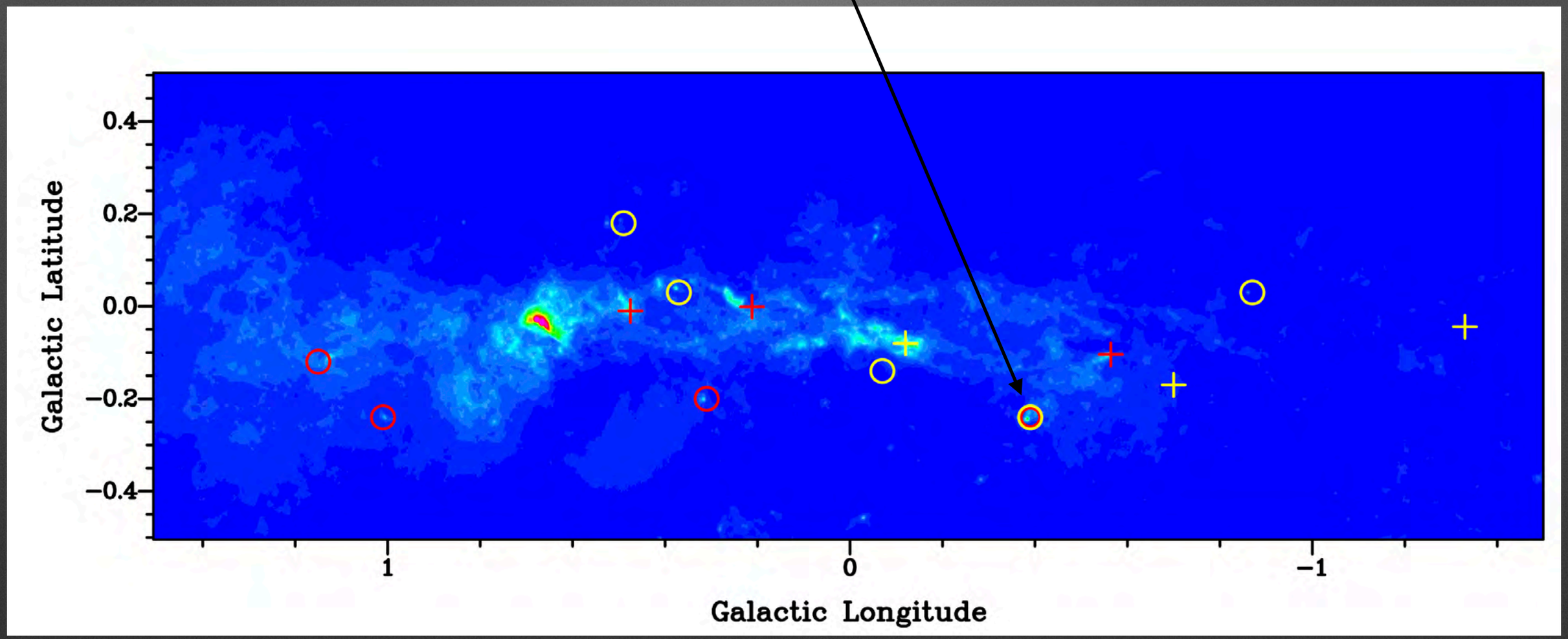






Not detected

Preliminary results - G359.61-0.24



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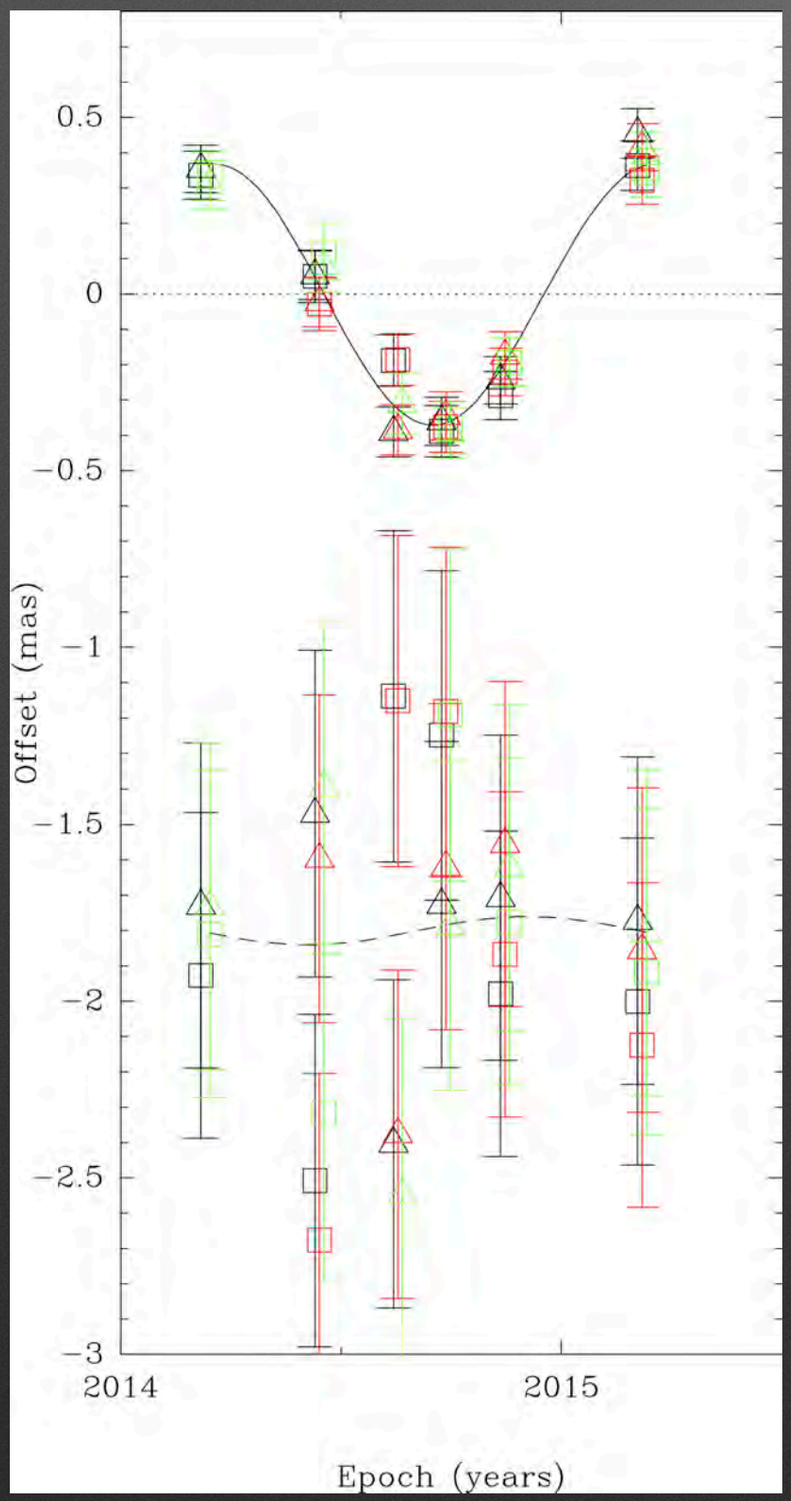


Parallax: 0.370 +/- 0.029 mas

Distance: 2.7 +/- 0.2 kpc

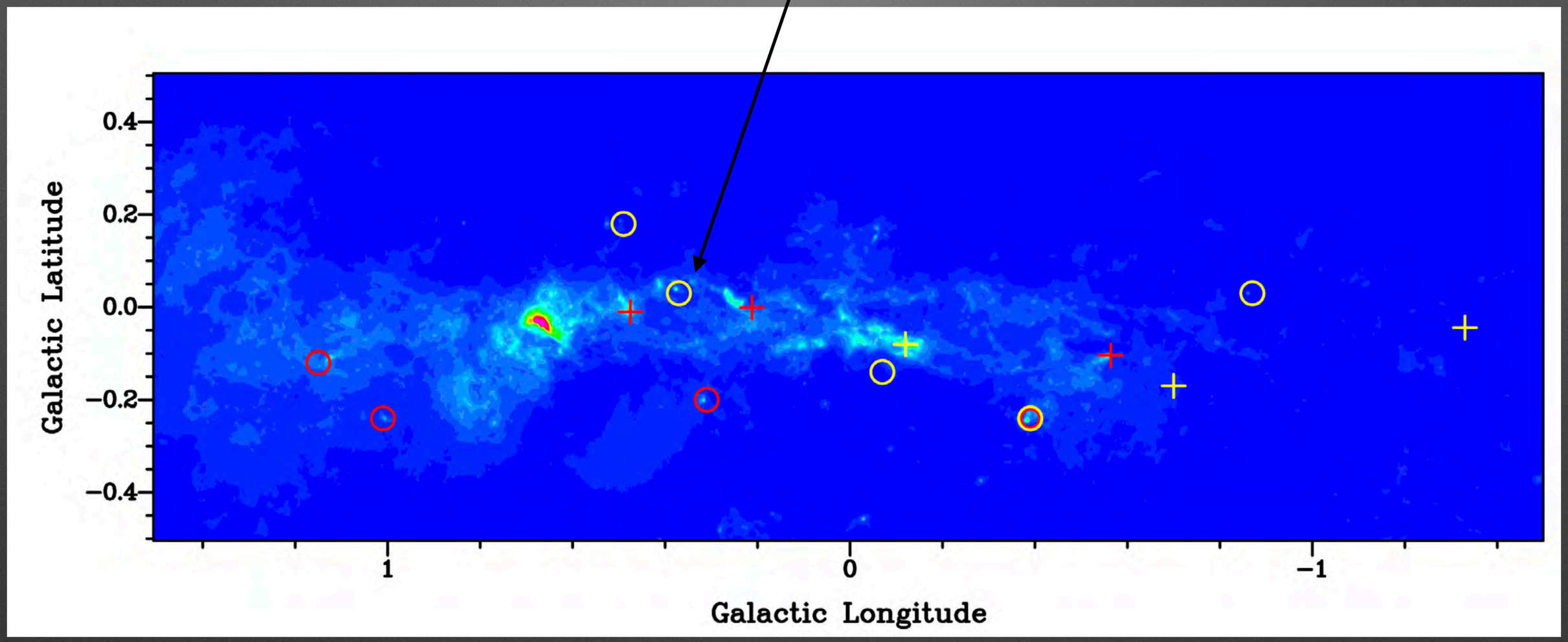
μ_x = 0.224 +/- 0.072 mas/yr

μ_y = -1.975 +/- 0.476 mas/yr

Not at CMZ distance!

Parallax measurements are important to determine if masers are located in CMZ

Preliminary results - G000.37+0.03



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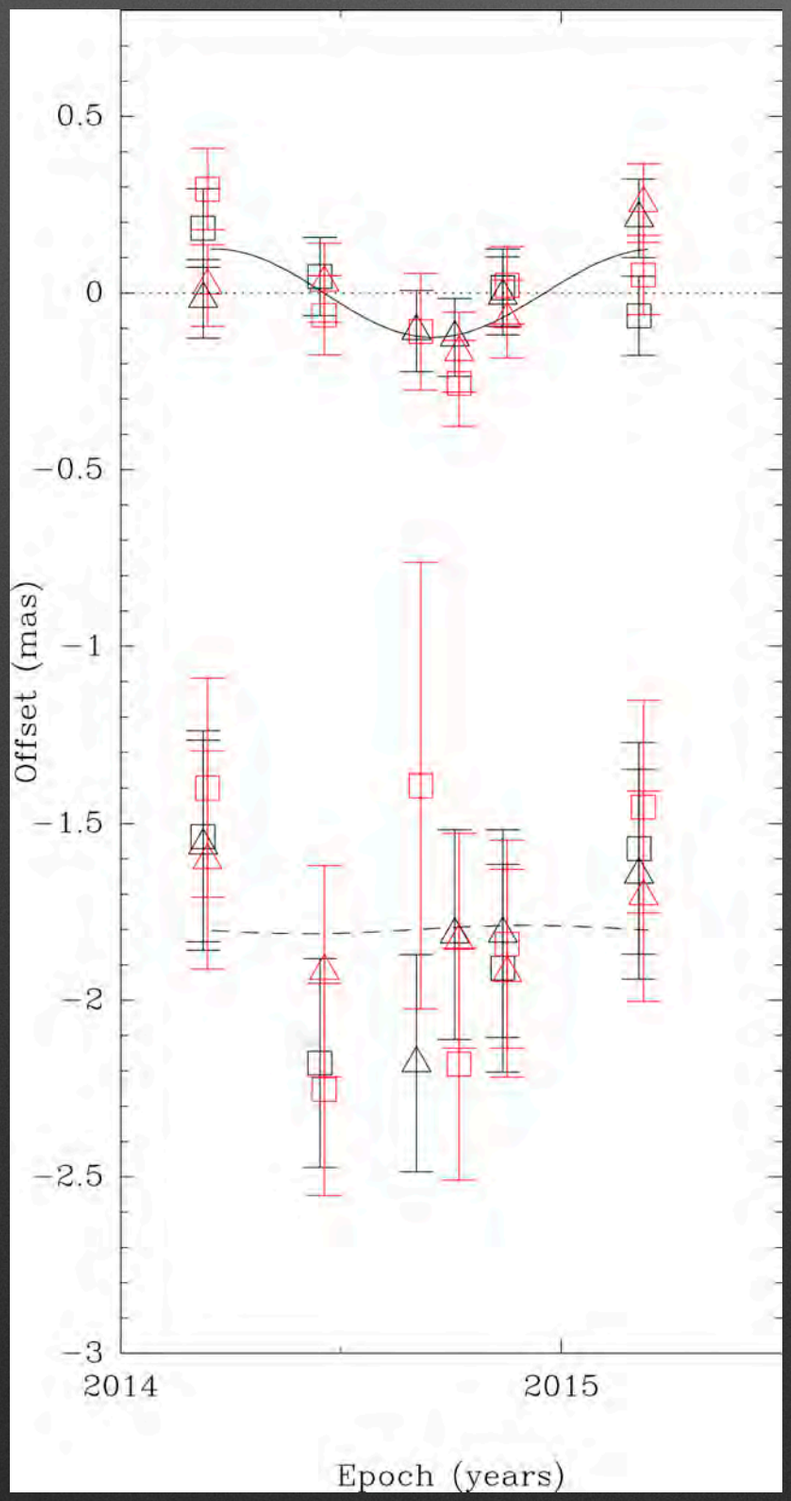

Parallax: 0.125 +/- 0.047 mas

Distance: 8.0 +/- 3.0 kpc

μ_x = -1.004 +/- 0.108 mas/yr

μ_y = -2.474 +/- 0.288 mas/yr

Consistent with Kruijssen et al. 2015 predictions:

$\mu_x = -0.76^{+0.36}_{-0.78}$ mas/yr

$\mu_y = -2.88^{+0.84}_{-0.78}$ mas/yr

Conclusion

- Orbital dynamics of gas clouds in CMZ can give insights into the star formation processes in this region
- 6D space information of gas clouds is needed to understand dynamics and test different models
- Parallax and proper motion observations of methanol and water masers in star-forming regions in the gas clouds
- First results are promising