

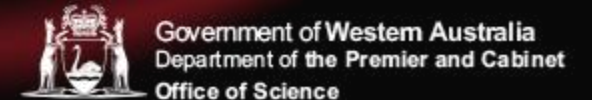


International
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Radio
Astronomy
Research

The 3D Distribution of the Molecular Clouds in the Galactic Centre

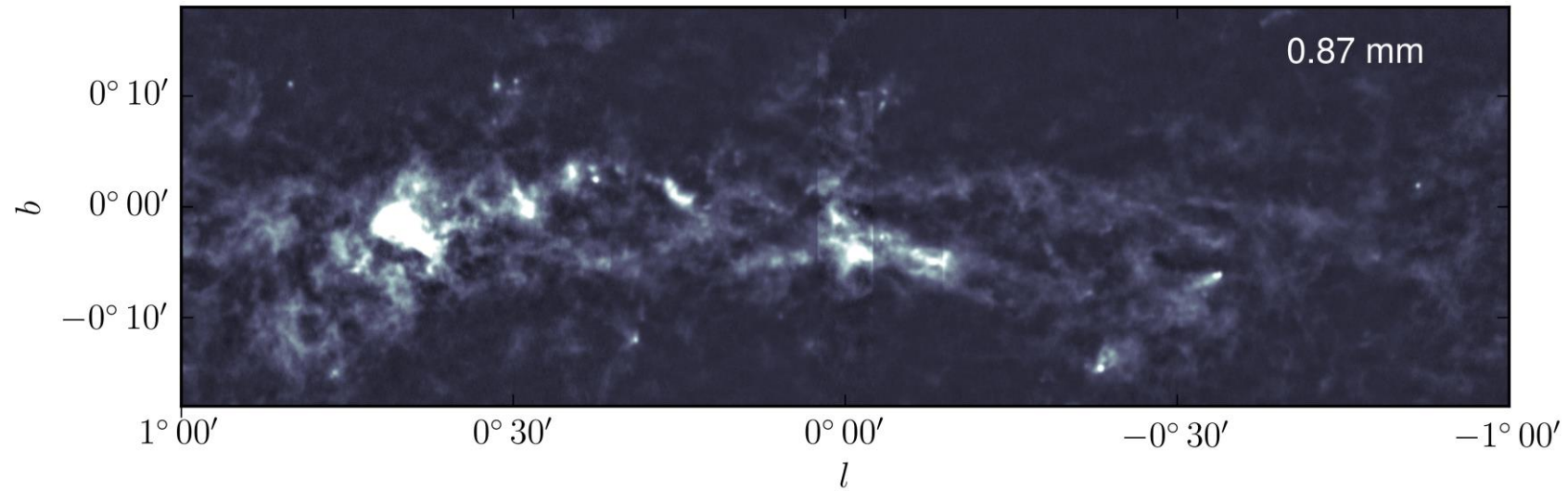
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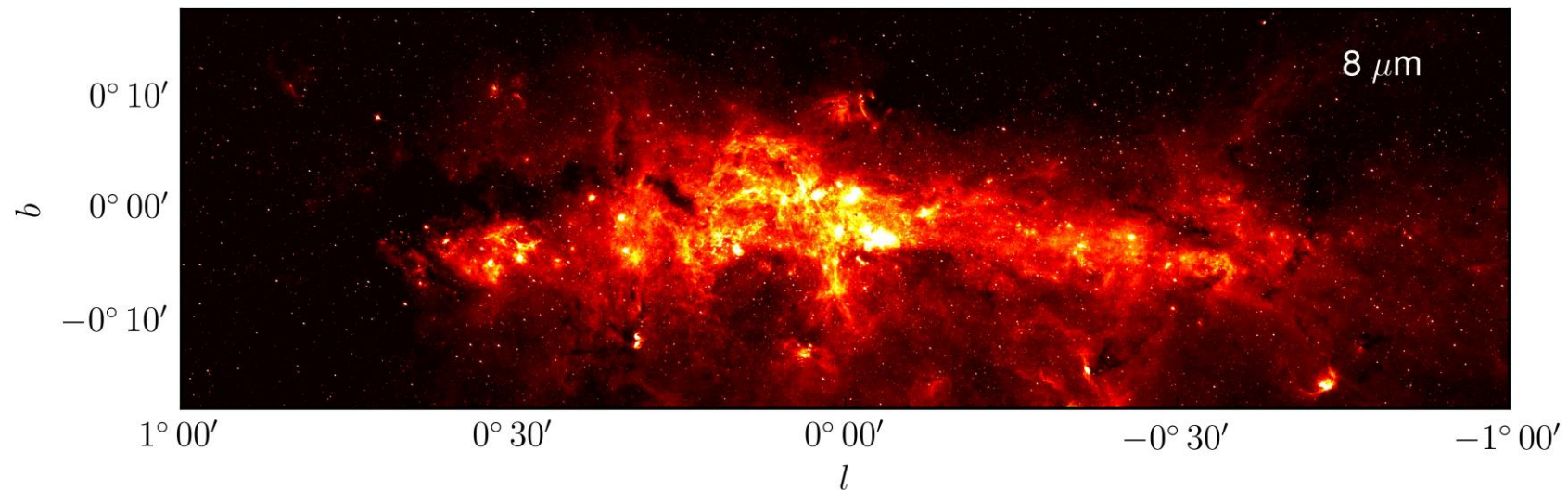




The Central Molecular Zone



ATLASGAL



GLIMPSE

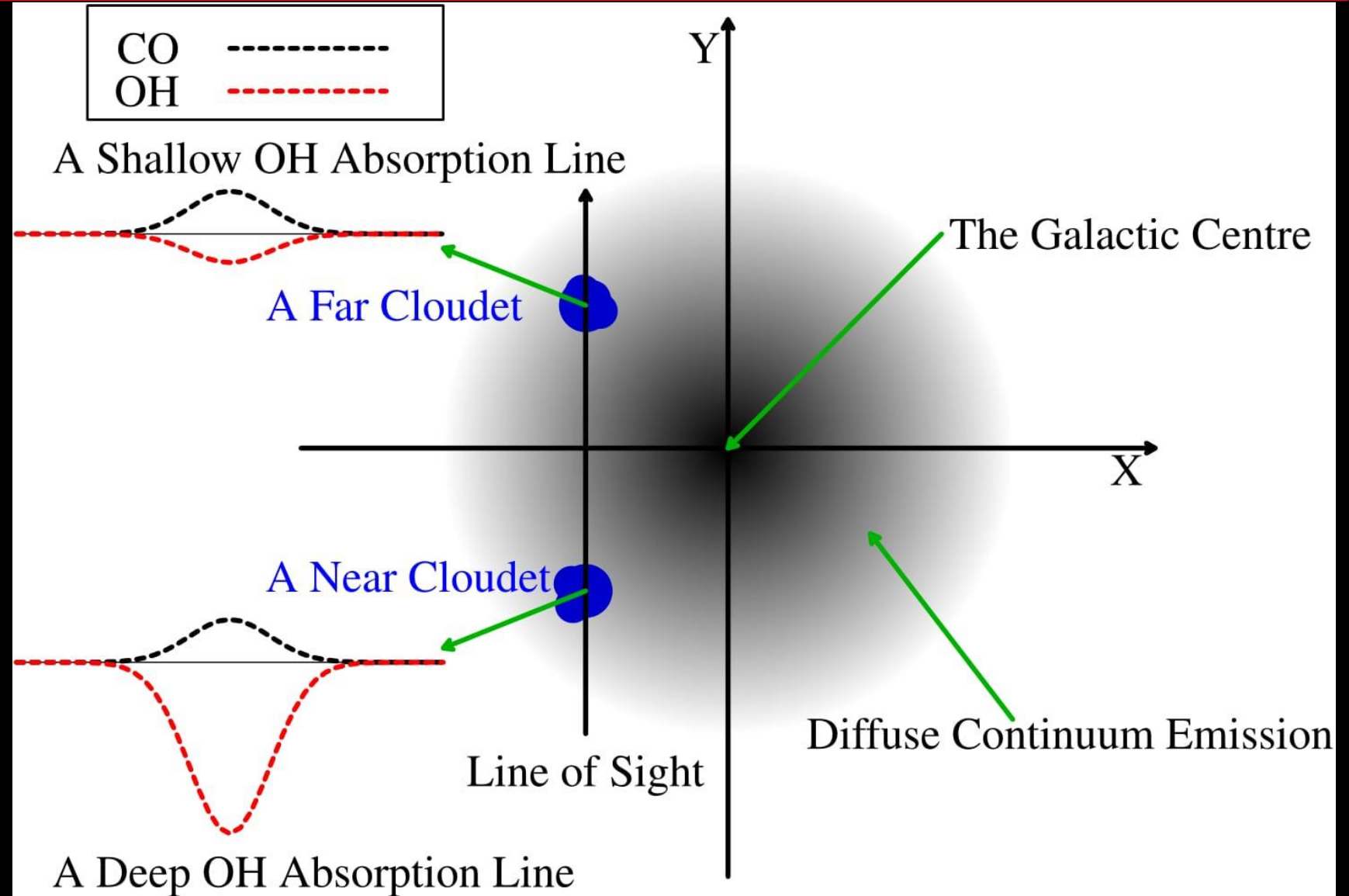


The Principle of Deriving a 3D Structure

Continuum behind clouds

$$T_c = ?$$

Sawada et al. (2004)





The Principle of Deriving a 3D Structure

Excitation temperature: $T_{\text{ex}} = 4 \text{ K}$

?

$$T_{\text{b}} = (T_{\text{ex}} - T_{\text{c}})(1 - e^{-\tau})$$

Brightness Temperature: Observable

$$\text{Optical depth: } \tau = 0.15 \times T_{\text{CO}}$$

Sawada et al. (2004)



The Excitation Temperature

$$\frac{N_{\text{upper}}}{N_{\text{lower}}} = \frac{g_1}{g_3} \exp\left(-\frac{h\nu}{kT_{\text{ex}}}\right)$$

$$T_{\text{ex}} = T_{\text{ex}}(N_{\text{upper}}, N_{\text{lower}})$$

The excitation temperature is a function of column densities.



The Optical Depth

$$\tau_\nu = A \frac{c^3}{8\pi\nu_0^3} \frac{g_{\text{upper}}}{g_{\text{lower}}} N_{\text{lower}} \left(1 - \exp\left(-\frac{h\nu}{kT_{\text{ex}}}\right) \right) \phi_\nu$$

$$\tau_\nu = \tau_\nu(N_{\text{upper}}, N_{\text{lower}})$$

The optical depth is also a function of column densities.



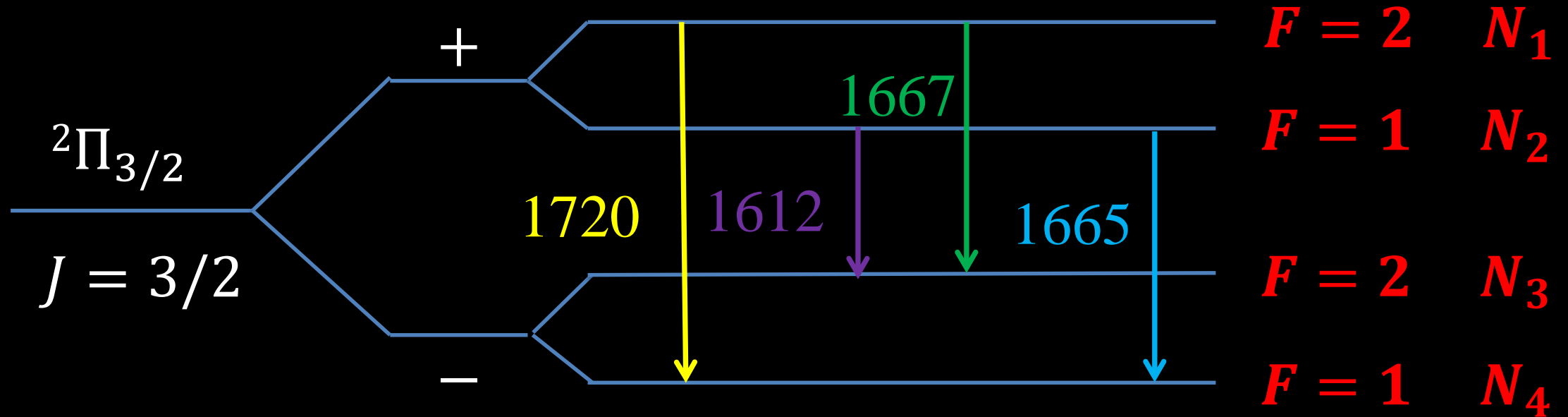
Case of knowing background continuum

$$T_b = (T_{ex} - T_c) (1 - e^{-\tau})$$

The brightness temperature is a function of column densities.



OH Ground States



Observations of four lines can solve four column densities.

The Equations

$$T_{b1665} = (T_{\text{ex } 1665}(N_2, N_4) - T_{c1665})(1 - e^{-\tau_{v1665}(N_2, N_4)})$$

$$T_{b1667} = (T_{\text{ex } 1667}(N_1, N_3) - T_{c1667})(1 - e^{-\tau_{v1667}(N_1, N_3)})$$

$$T_{b1612} = (T_{\text{ex } 1612}(N_2, N_3) - T_{c1612})(1 - e^{-\tau_{v1612}(N_2, N_3)})$$

$$T_{b1720} = (T_{\text{ex } 1720}(N_1, N_4) - T_{c1720})(1 - e^{-\tau_{v1720}(N_1, N_4)})$$

Background continuum



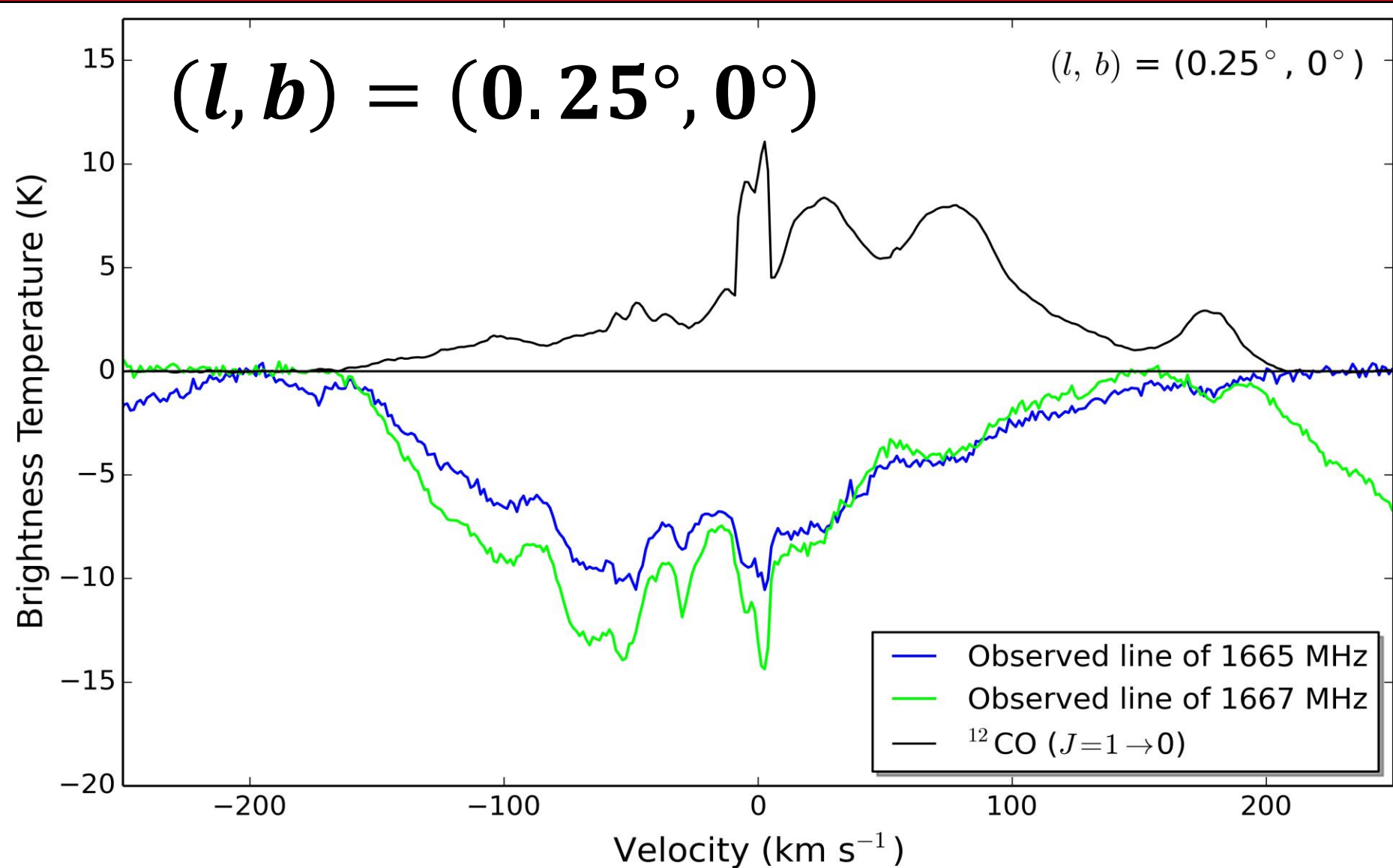


Case of the Galactic Centre

- $T_b = (T_{\text{ex}} - T_c)(1 - e^{-\tau})$
- 1665- and 1667-MHz lines blend together.

We need two more equations.

Case of the Galactic Centre





Assumption 1

The excitation temperatures of 1665- and 1667-MHz lines are equal.

$$T_{\text{ex } 1665} = T_{\text{ex } 1667}$$

Assumption 2

The column density of OH is proportional to the column density of ^{13}CO .

$$N_3 + N_4 = f \times T_{^{13}\text{CO}}$$


$$4.7 \times 10^{18} \times \left[\frac{T_{\text{CO}}}{1 \text{ K}} \right] \text{m}^{-2}$$

Case of the Galactic Centre

$$T_{b1667} = (T_{\text{ex } 1667}(N_1, N_3) - T_f T_{c1667})(1 - e^{-\tau_{v1667}(N_1, N_3)})$$

$$T_{b1612} = (T_{\text{ex } 1612}(N_2, N_3) - T_f T_{c1612})(1 - e^{-\tau_{v1612}(N_2, N_3)})$$

$$T_{b1720} = (T_{\text{ex } 1720}(N_1, N_4) - T_f T_{c1720})(1 - e^{-\tau_{v1720}(N_1, N_4)})$$

$$\frac{hv_{1665}/k}{\ln(N_4) - \ln(N_2)} = \frac{hv_{1667}/k}{\ln(N_3) - \ln(N_1)}$$

Fraction of continuum
behind molecular clouds.

$$N_3 + N_4 = f \times T_{\text{co}}$$



OH Data (SPLASH, Dawson et al. (2014))

Parkes
64m

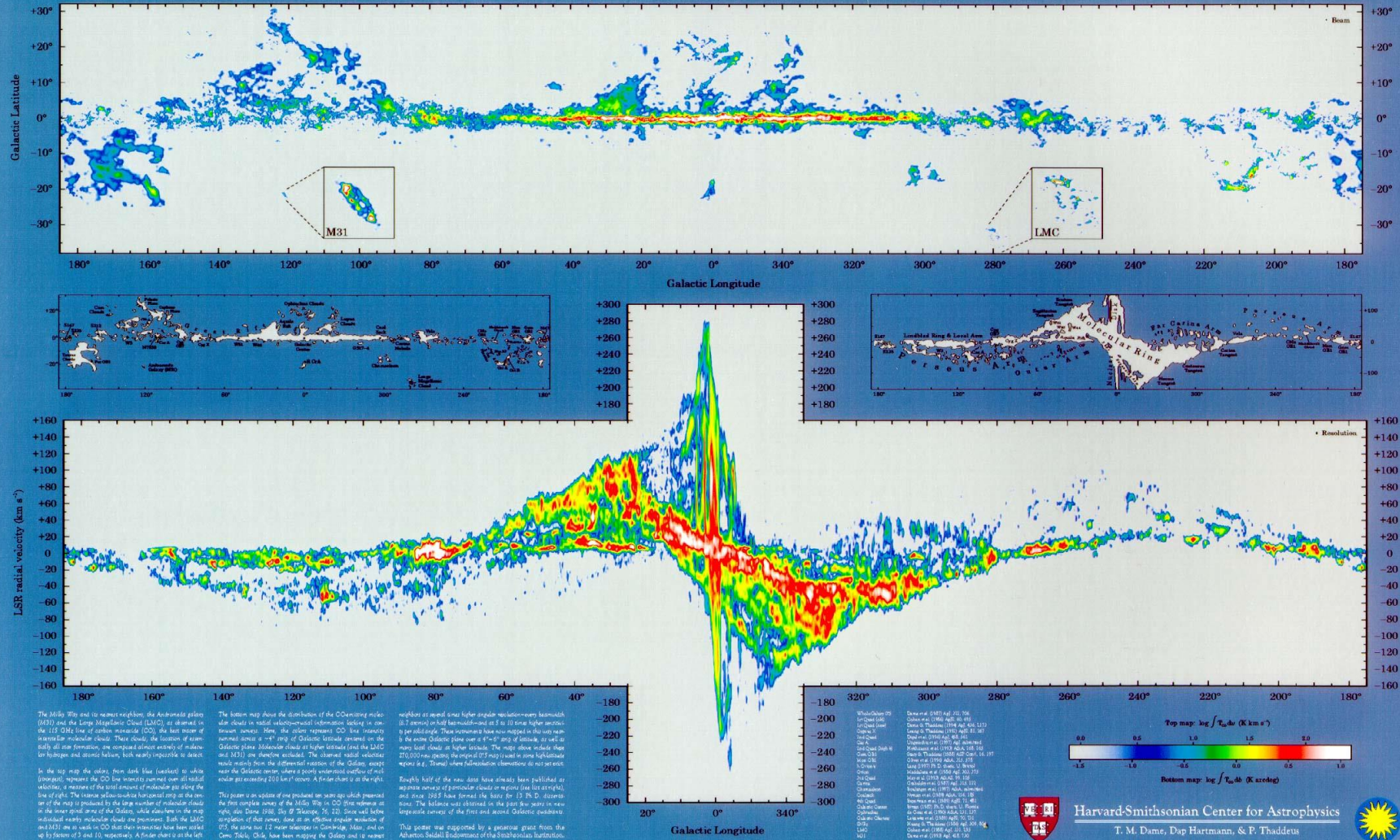




CO Data (Dame et al. (2001))

CfA
1.2m

The Milky Way in Molecular Clouds



The Milky Way and its nearest neighbors, the Antennae galaxy (M31) and the Large Magellanic Cloud (LMC), are observed in the CO J=2-1 line of carbon monoxide (CO), the best tracer of interstellar molecular clouds. These clouds, the location of essentially all star formation, are composed almost entirely of molecules hydrogen and oxygen atoms, both nearly impossible to detect in the top map, the color, then dark blue (located in white foreground), represent the CO line velocity summed over all radial velocities, or measure of the total amount of molecular gas along the line of sight. The lowest velocity channel (top panel) is the center of the map is produced by the large number of molecular clouds in the inner spiral arms of the Galaxy, while clouds in the map individual nearby molecular clouds are prominent. Both the LMC and M31 are in view in CO that their structure has been imaged by 30cm of 3 and 10, respectively. A pixel size is 0.16 arcmin.

The bottom map shows the distribution of the CO-emitting molecular cloud in radial velocity-moment information lacking in conventional surveys. Here, the color represents CO line velocity summed across a 4° strip of Galactic latitude, centered on the Galactic plane. Molecular clouds at higher latitudes than the LMC and M31 are therefore excluded. The observed radial velocities would mainly from the differential rotation of the Galaxy, except near the Galactic center, where a poorly understood outflow of gas would be expected. A pixel size is 0.16 arcmin.

Neighbors at several times higher angular resolution—every beamwidth (3.7 arcmin) on half beamwidth—and at 2 to 10 times higher sensitivity per solid angle. These improvements have been achieved in this survey in the same Galactic plane over a 4° strip of latitude, as well as many local clouds at higher latitudes. The maps show radial velocity 20,000 m/s range, but beyond 10 m/s is used in some high-latitude regions (e.g., Dorado) where full-resolution observations do not exist.

Roughly half of the new data have already been published as separate surveys of particular clouds or regions (see list at right), and more COSE have formed the basis for CO SE 2, a scientific survey. The balance will be published in the next few years in new large-scale surveys of the first and second Galactic quadrants.

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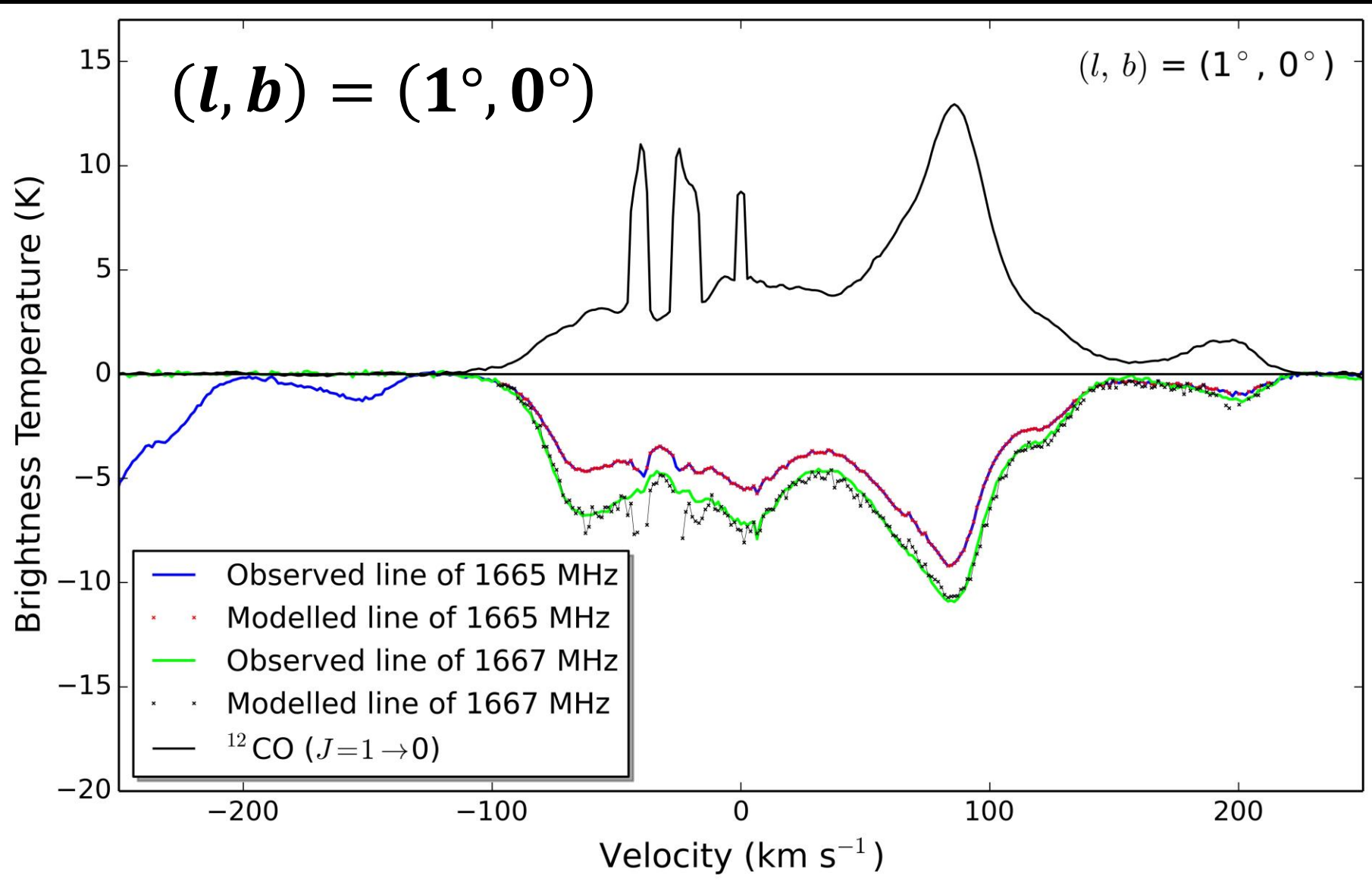
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Top map: $\log \int T_{mb} dv$ (K km s⁻¹)

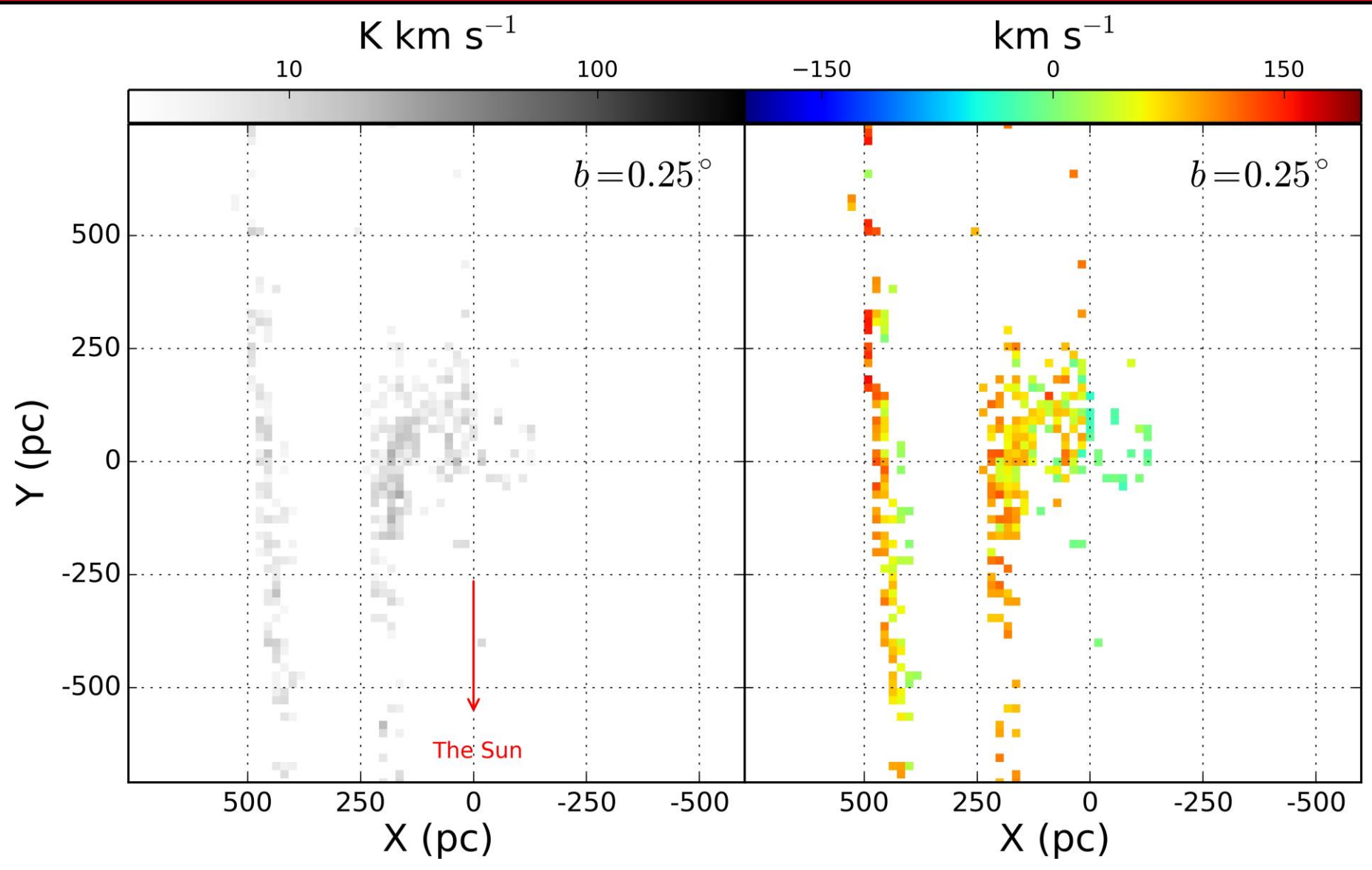
Bottom map: $\log \int T_{mb} dv$ (K arcmin)

Harvard-Smithsonian Center for Astrophysics
T. M. Dame, Dap Hartmann, & P. Thaddeus

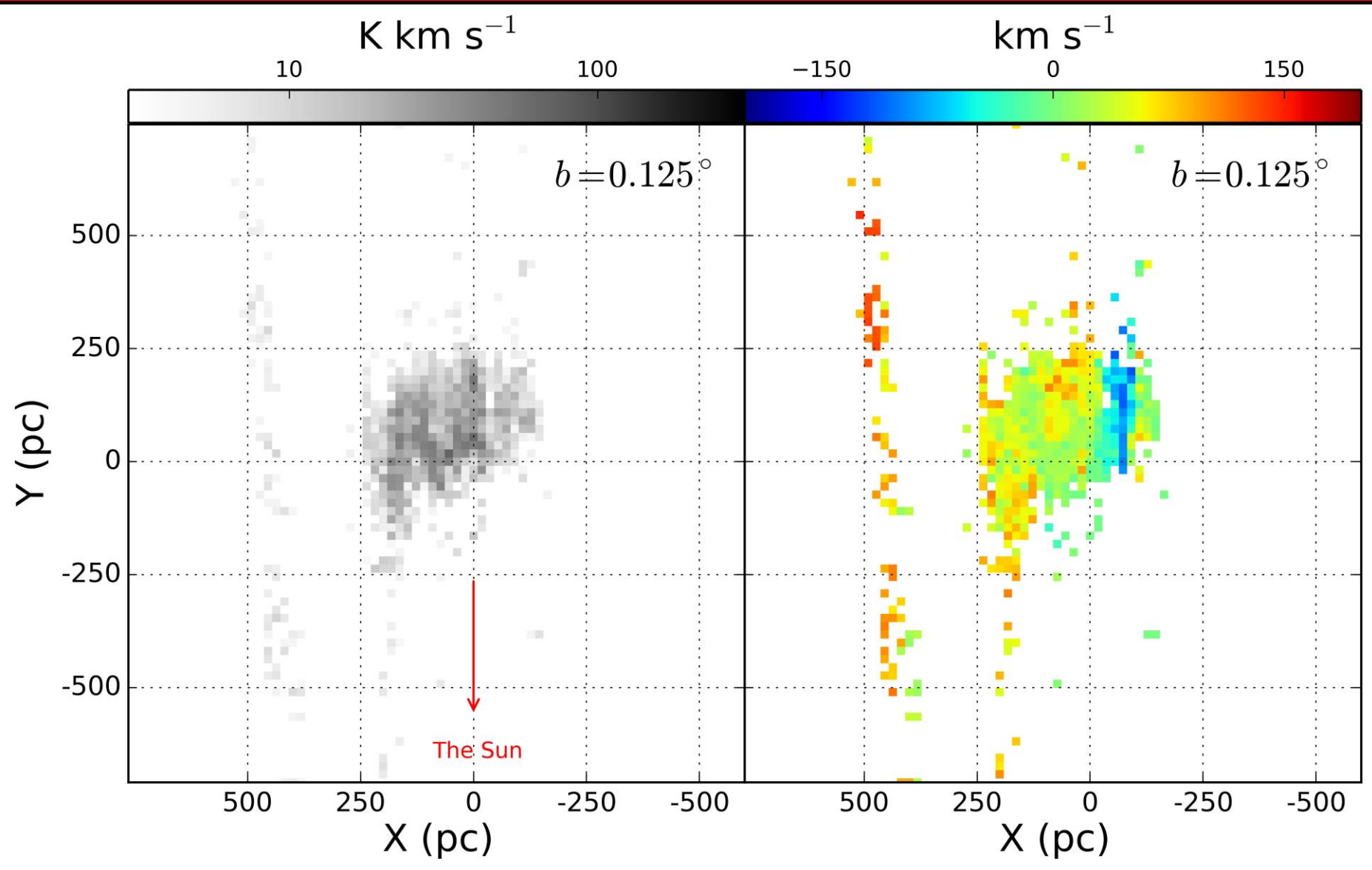
Testing the method



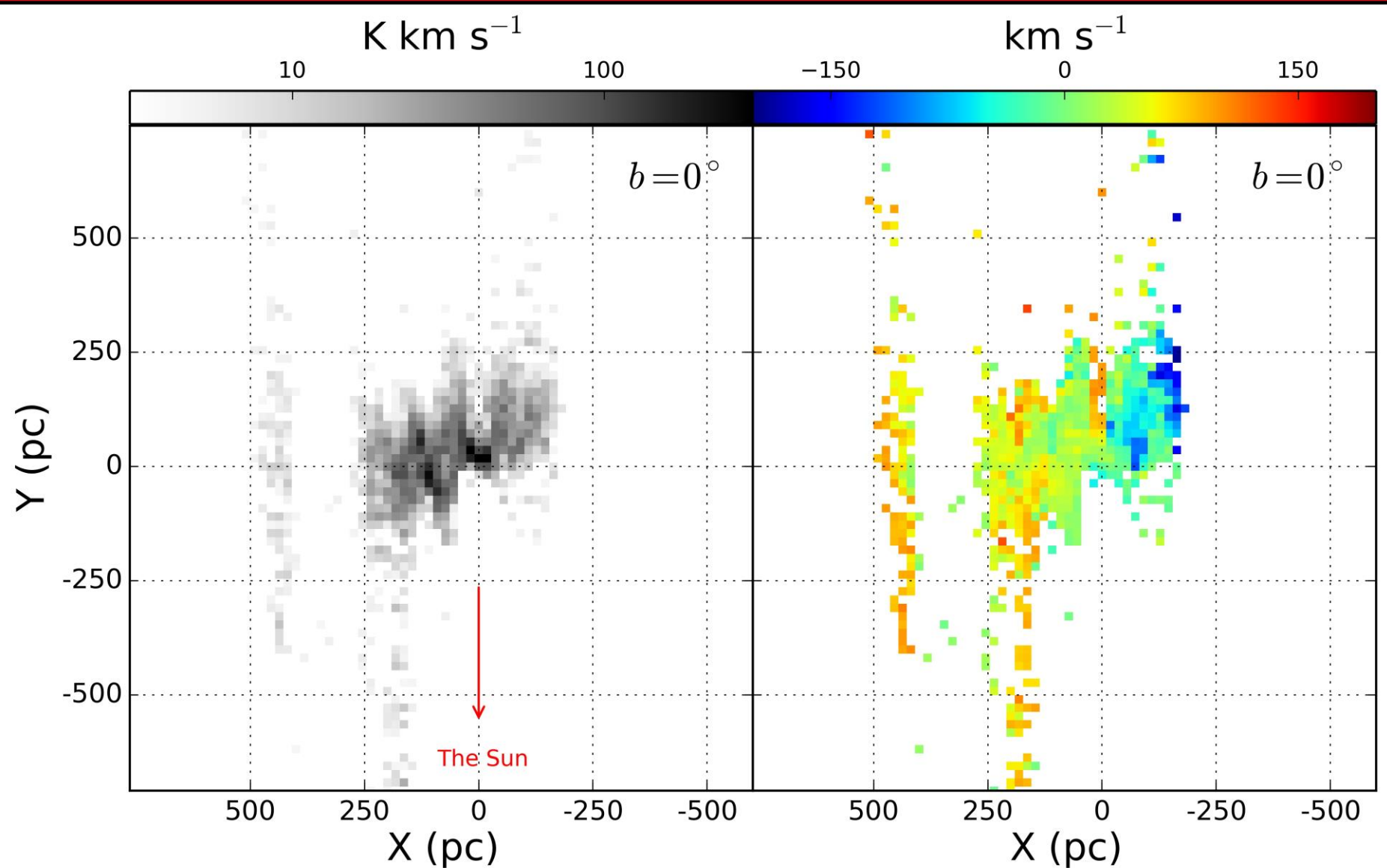
Face-On View ($b = 0.25^\circ$)



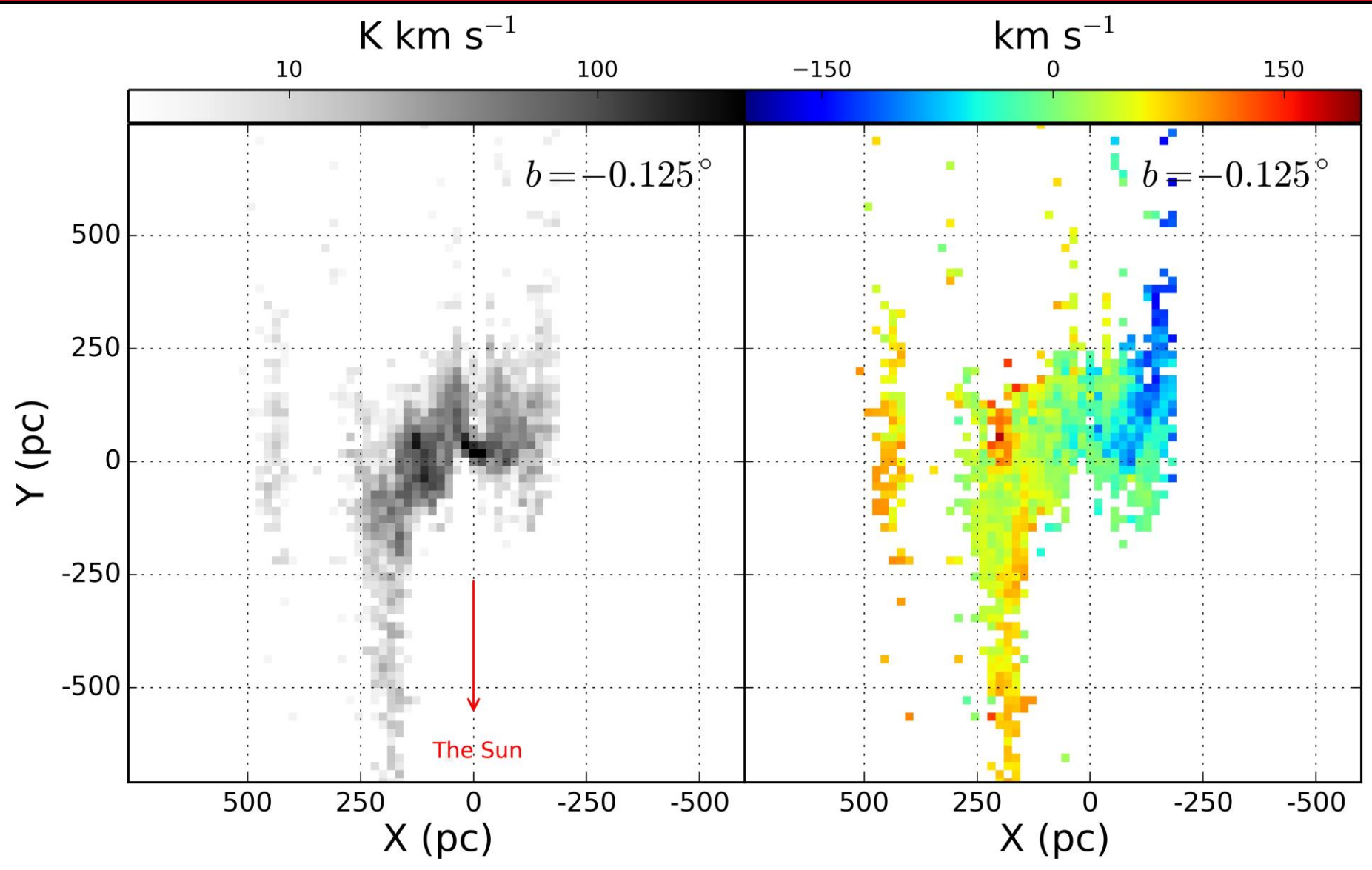
Face-On View ($b = 0.125^\circ$)



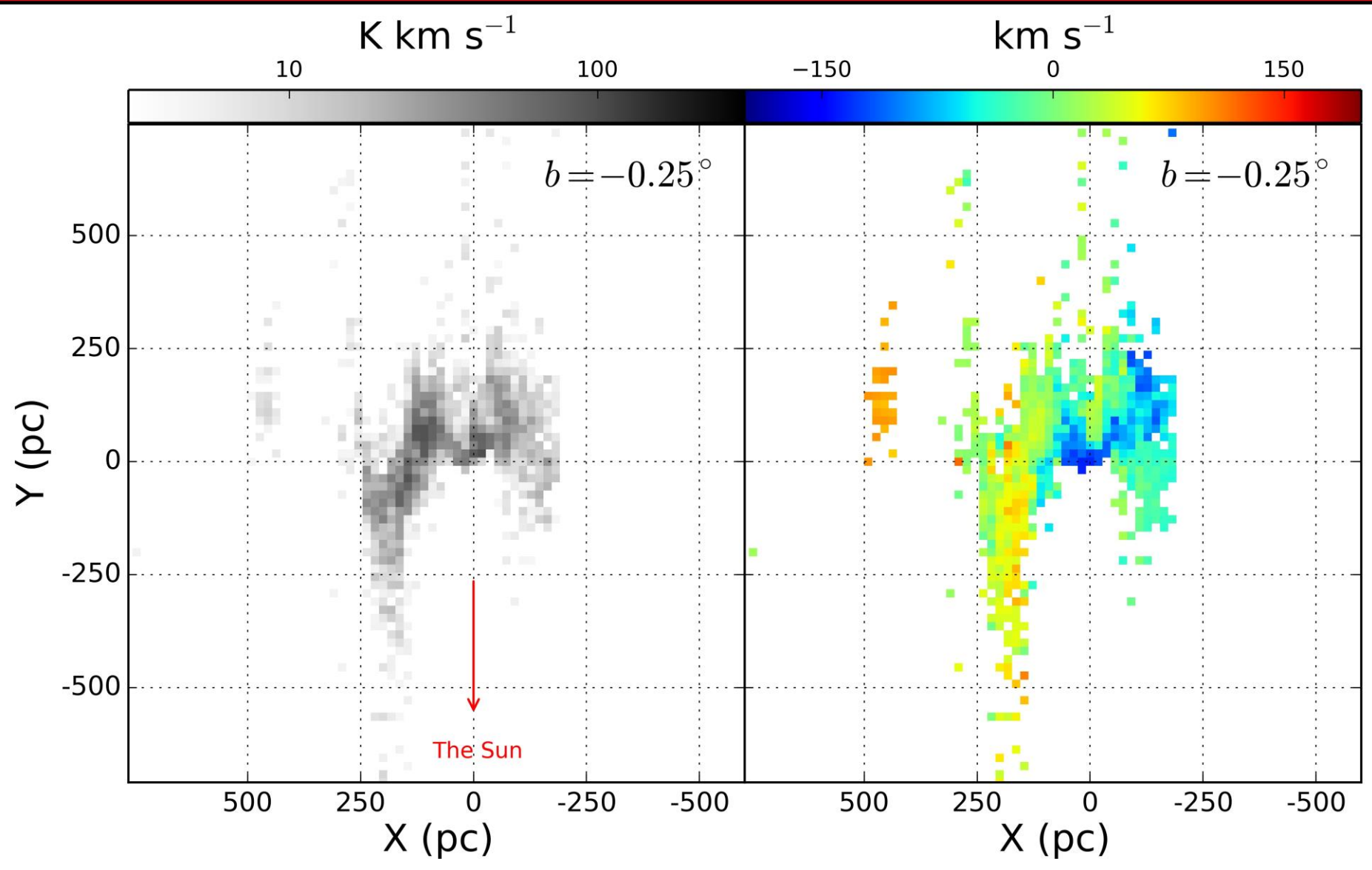
Face-On View ($b = 0^\circ$)



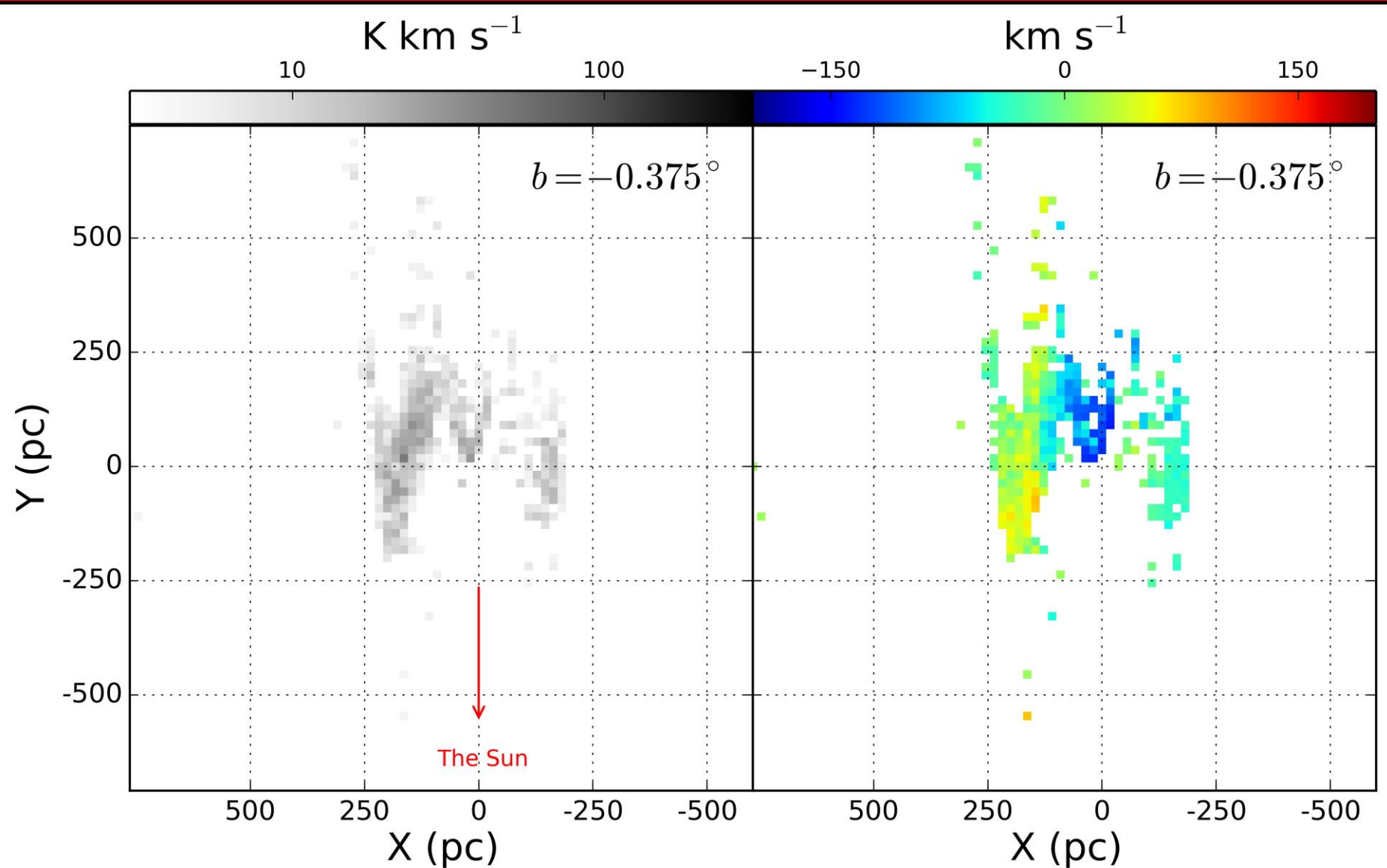
Face-On View ($b = -0.125^\circ$)



Face-On View ($b = -0.25^\circ$)



Face-On View ($b = -0.375^\circ$)





Future studies

- **We have observed the OH spectral lines towards the CMZ with VLA.**

- **The data reduction of CO (Mopra) is ongoing.**



Summary

- **We found a new method of calculating OH column densities.**
- **We have derived a three-dimensional structure of the molecular clouds in the Galactic Centre.**