SOFIA FIFI-LS Observations of the PDR in Sgr B1

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In addition to the masive black hole and nuclear star cluster Sgr A, the Galactic Center (GC) contains additional massive clusters (Arches and Quintuplet), multiple luminous H II regions (Arched Filaments, Sickle, Sgr B, and Sgr C), and dense, cold molecular clouds that may or may not yet be currently forming stars. A layout of these regions is shown in Fig. 1. Sgr B itself is seen to contain at least two components but their relation is unclear: although they are found in a common envelope of molecular gas and far-infrared (FIR) emission, from which it has been assumed that the two sources are physically related, uncertainties arise because the ionized gas of Sgr B1 is much more extended and the stars of Sgr B1 have a significantly greater age than the newly-forming stars of Sgr B2.

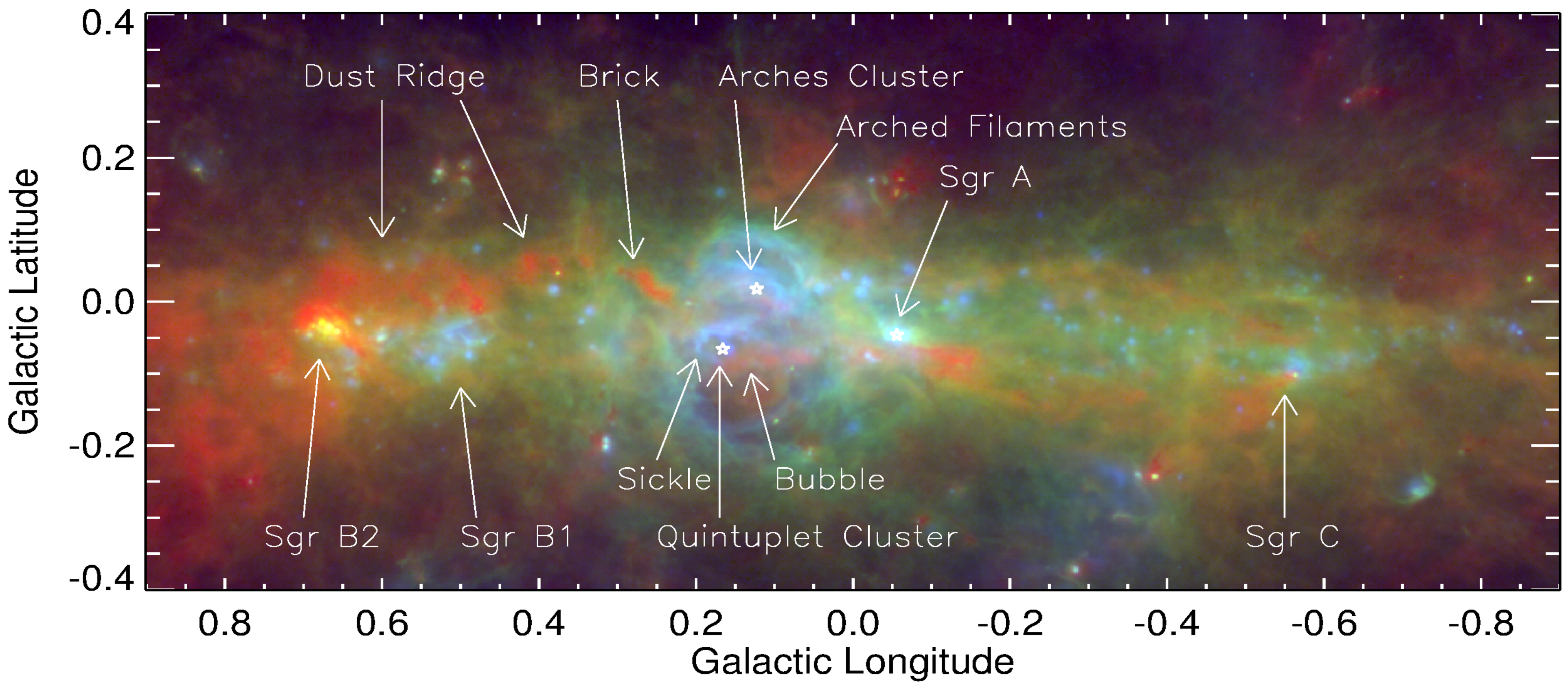

Figure 1a. Three-color image of the Galactic Center region, centered on the nuclear cluster Sgr A. H II regions and star forming regions are prominent in the blue (21 µm MSX Band E image from Price et al. 2001) and green (70 µm image from the Herschel Hi-GAL survey, Molinari et al. 2016) images, and the cold molecular clouds are conspicuous in the red image (500 µm image, also from the Hi-GAL survey).

Because Sgr B1 (Fig. 1b) is the least well understood of the GC H II regions, we are investigating it in detail with SOFIA (Young et al. 2012; Temi et al. 2014), both with FORCAST (Cotera & Simpson, Poster 256.10) and with FIFI-LS (Fischer et al. 2018). This poster describes the results of our FIFI-LS measurements of the FIR [O I] 146 and [C II] 158 µm lines in Cycles 4 and 5 (July, 2016 and 2017). During these cycles, we also mapped the Sgr B1 region in the [O III] 52 and 88 µm lines, which we published in Simpson et al. (2018).

Whereas H II regions (which produce the [O III] lines) are ionized by photons with energies E > 13.6 eV, the interface regions between the H II regions and molecular clouds can still be heated and ionized by the stars' far-ultraviolet (FUV) photons with 6 < E < 13.6 eV. Such regions, called photodissociation regions (PDRs; Tielens & Hollenbach, 1985; Wolfire et al. 1990; Kaufman et al. 1999, 2006), produce the [O I] and [C II] lines observed in this program.

Our observed regions of Sgr B1 are displayed in Fig. 2. Here, the [C II] 158 µm line was observed with high signal/noise (similar to the [O III] 88 µm line, Fig. 3); however, the [O I] 146 µm line is intrinsically weak and could not be detected at many positions. The data reduction is described in Simpson et al. (2018).

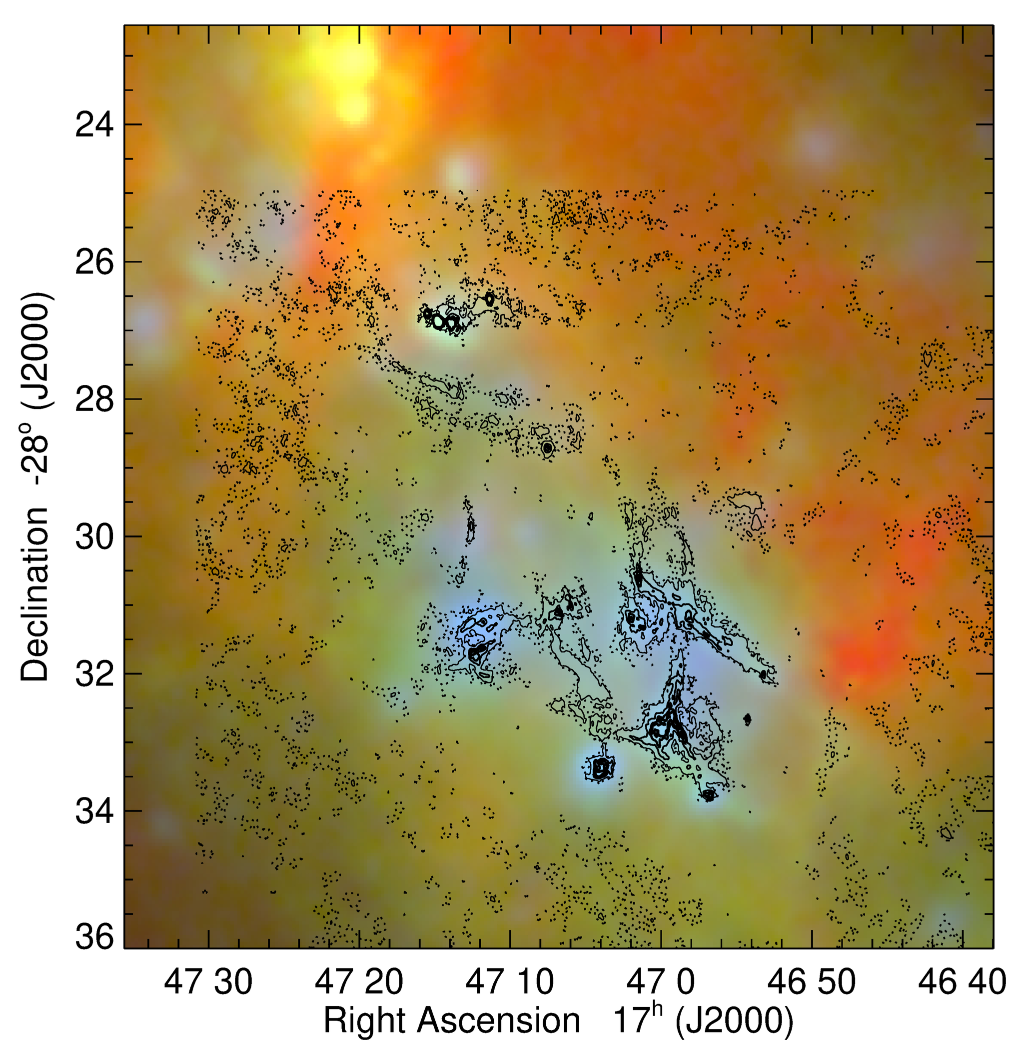

Figure 1b. The Sgr B1 region from Figure 1a, rotated to RA and Dec. The contours are the intensities of the 8.4 GHz VLA image of Mehringer et al. (1992) and are plotted at 0.005, 0.01, 0.03, 0.05, and 0.07 Jy/beam.

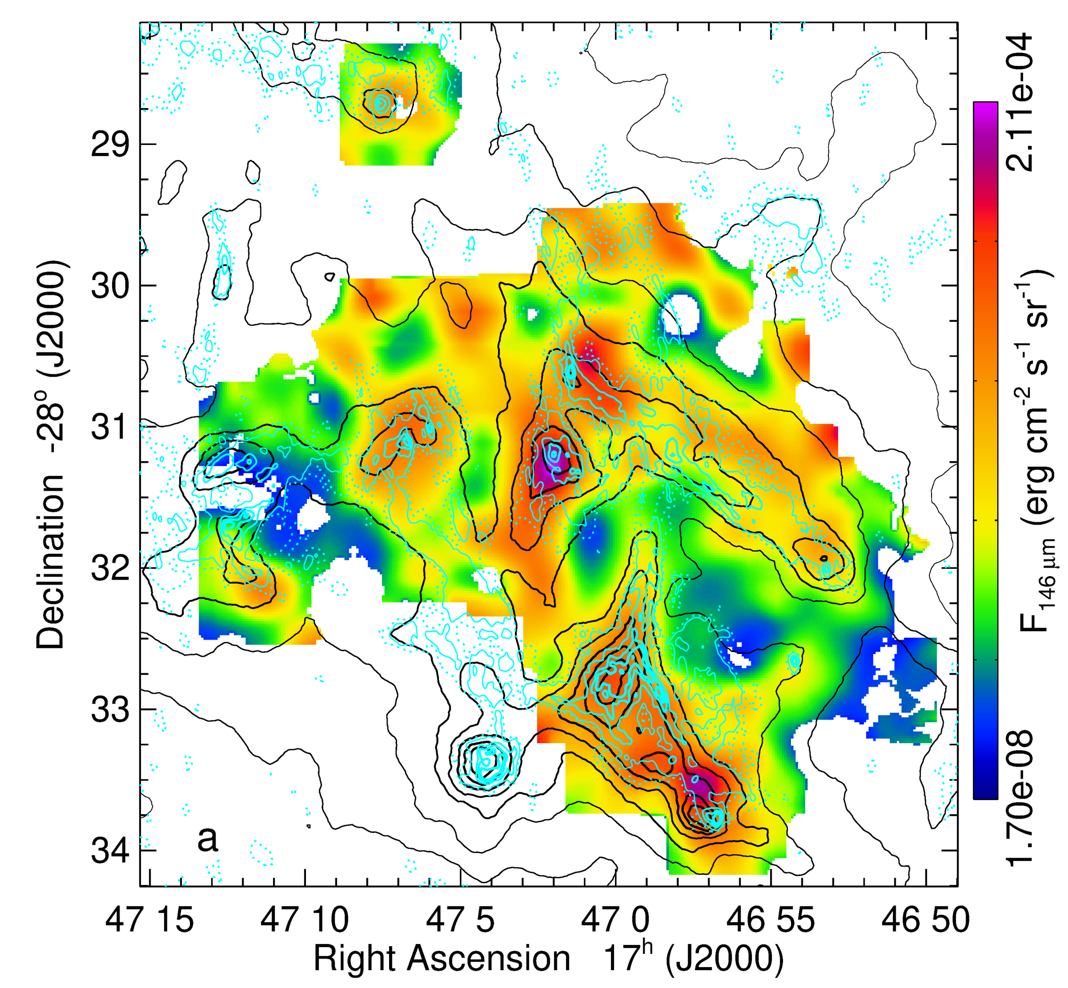

Figure 2a. The observed intensities of the [O I] 146 µm line. The black contours are the 70 µm Herschel PACS image (Molinari et al. 2016) and the cyan contours are the 8.4 GHz VLA image of Mehringer et al. (1992). The FIFI-LS pixel size is 12".

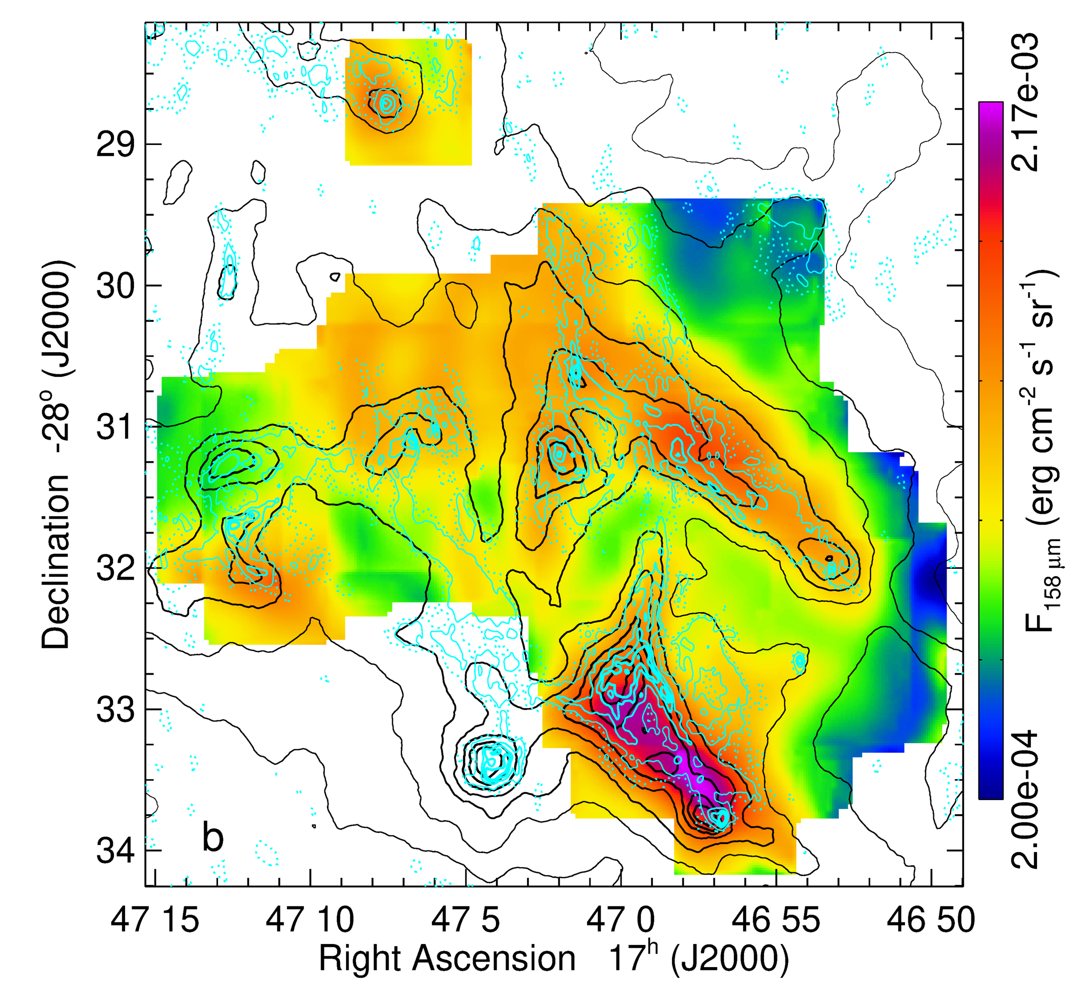

Figure 2b. The observed intensities of the [C II] 158 µm line. Contours are the same as in Fig. 2a.

Along with the FIR continuum estimated from the Herschel 70 and 160 µm images, the [O I] and [C II] line intensities were analysed using the PDR Toolbox (Pound & Wolfire 2008; Kaufman et al. 2006; http://dustem.astro.umd.edu/pdrt), thereby producing estimates of the proton density, n, and the incident FUV intensity, G0, as shown in Fig. 4.

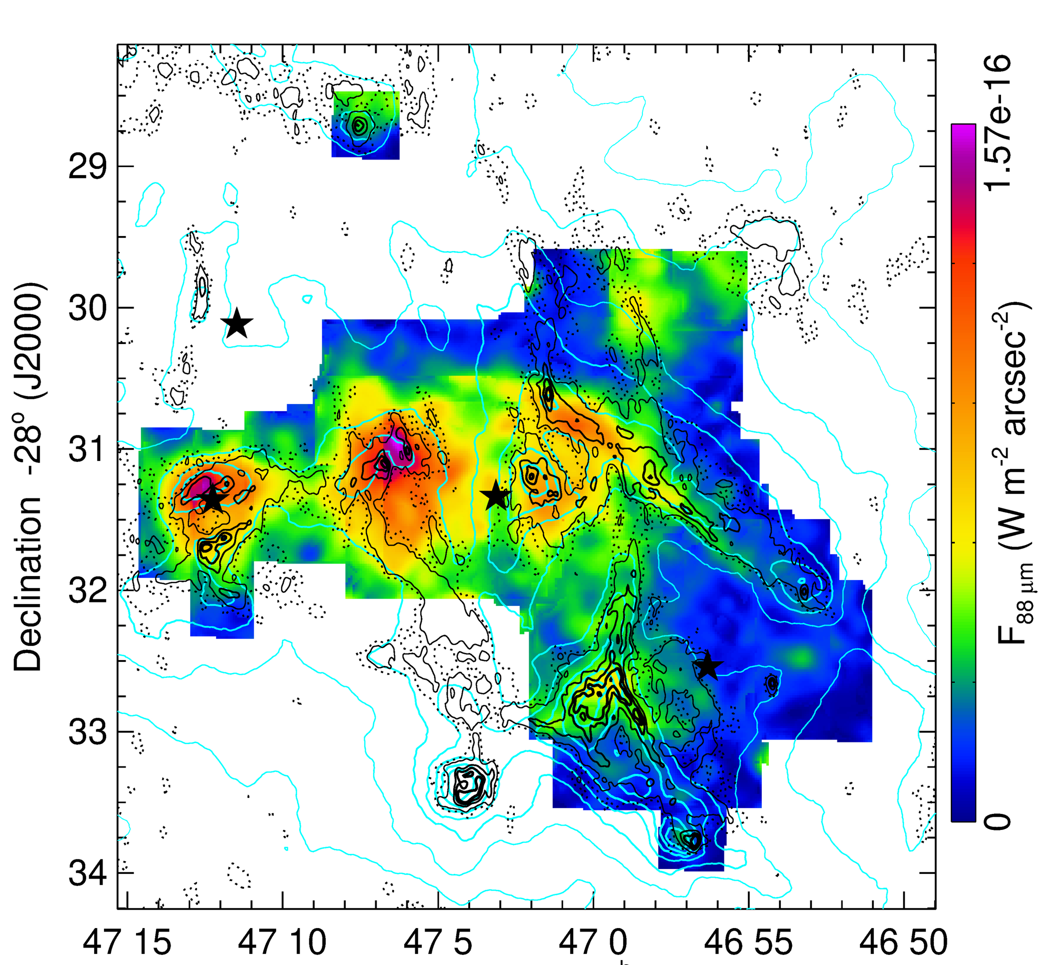

Figure 3. The observed intensities of the [O III] 88 µm line from Simpson et al. (2018; pixel size 6"). Contours are the same as in Fig. 2. The black stars are the Wolf-Rayet and O supergiant stars observed by Mauerhan et al. (2010).

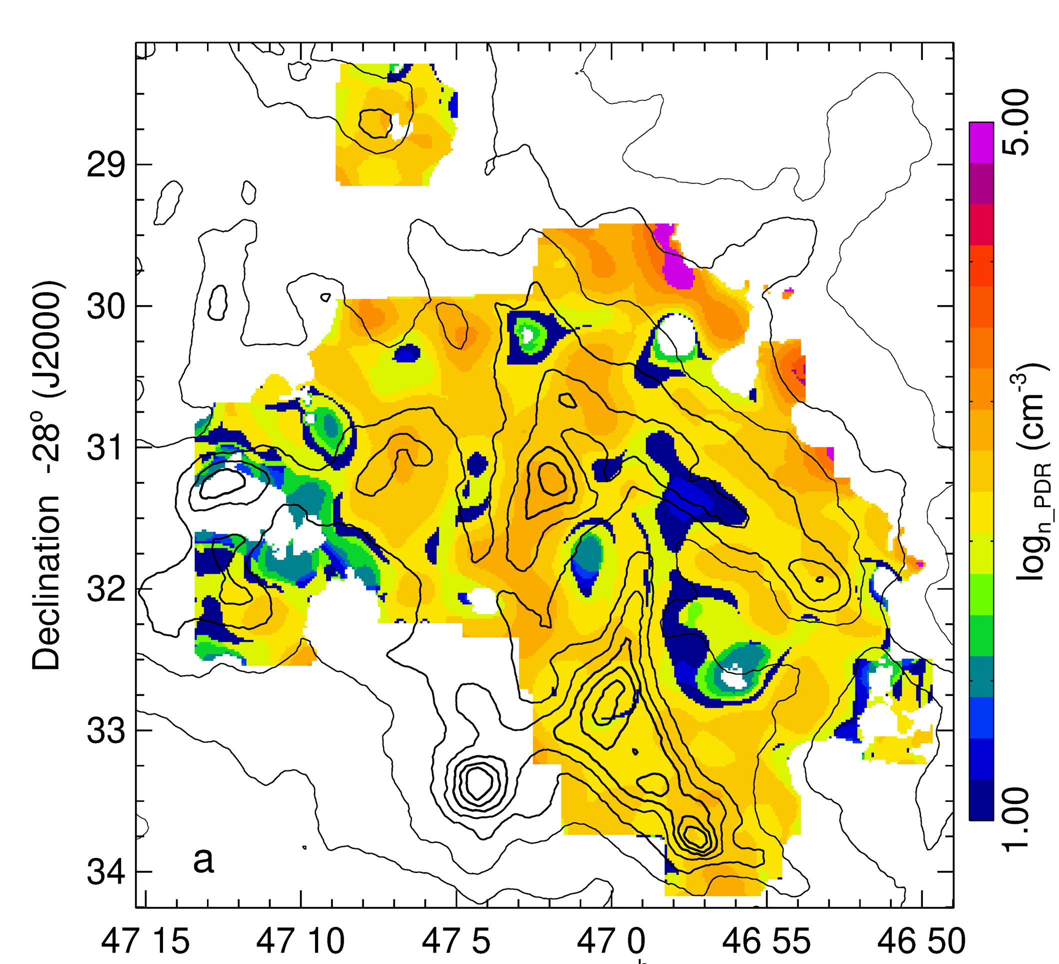

Figure 4a. Proton density, n. The black contours are the 70 µm Herschel PACS image (Molinari et al. 2016).

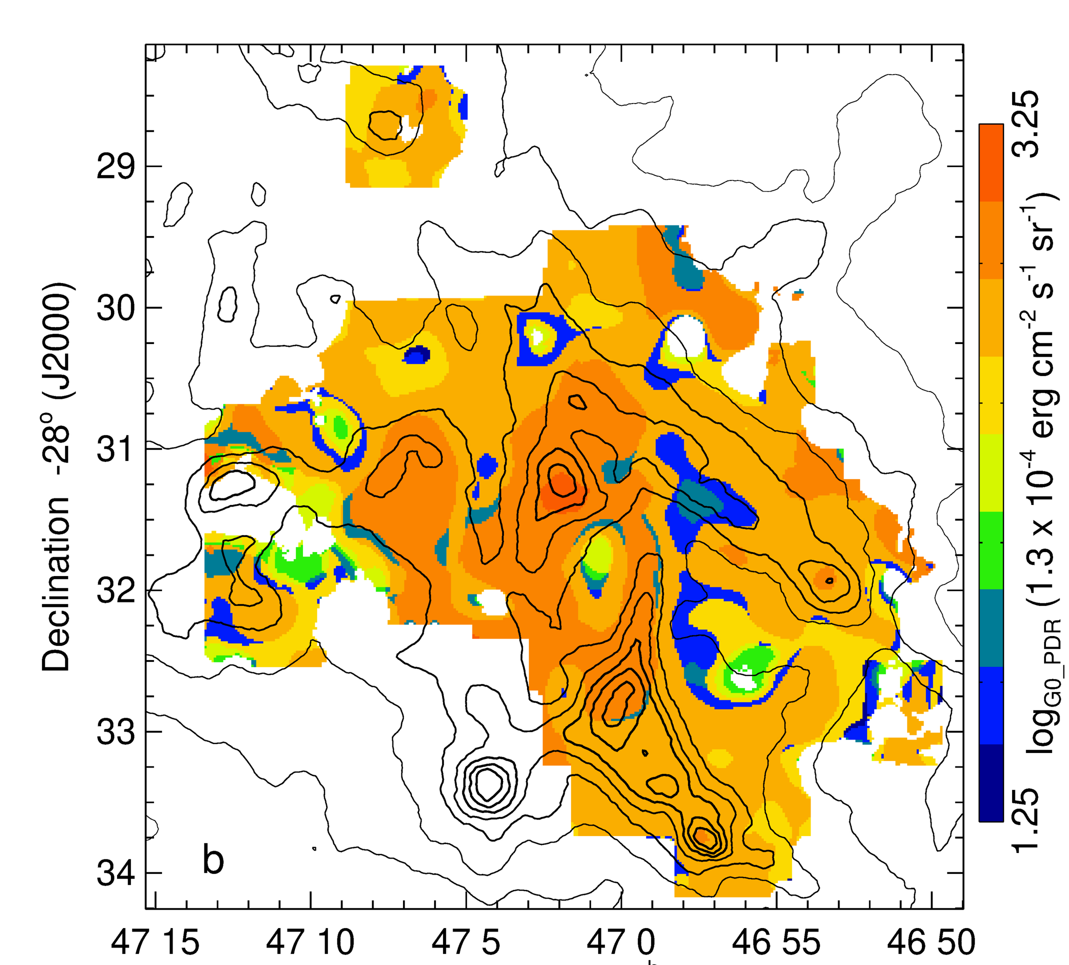

Figure 4b. Estimates of the incident FUV intensity, G0, in units of the local interstellar FUV intensity (e.g., Tielens & Hollenbach, 1985; Wolfire et al. 1990; Kaufman et al. 1999, 2006).

References

Fischer, C., et al. 2018, J. Astron. Instrum., 7, 1840003
Kaufman, M. J., et al. 1999, ApJ, 527, 795
Kaufman, M. J., et al. 2006, ApJ, 644, 283
Mauerhan, J. C., et al. 2010, ApJ, 710, 706
Mehringer, D. M., et al. 1992, ApJ, 401, 168
Molinari, S., et al. 2016, A&A, 591, A149
Pound, M. W., & Wolfire, M. G. 2008, ADASS XVII, 394, 654
Price, S. D., et al. 2001, AJ, 121, 2819
Simpson, J. P. 2018, ApJ, 857, 59; Erratum, ApJ, in press
Simpson, J. P., et al. 2018, ApJ, 867, L13
Temi, P., et al. 2014, ApJS, 212, 24
Tielens, A. G. G. M., & Hollenbach, D. 1985, ApJ, 291, 722
Young, E. T., et al. 2012, ApJ, 749, L17
Wolfire, M. G., et al. 1990, ApJ, 358, 116

Results and Conclusions

•Typical densities (Fig. 4a) are of order a few hundred to about 1000 cm^{-3}, not very much higher than the electron densities measured by Simpson et al. (2018).
•The maximum G0 (Fig. 4b, dark orange, $10^{3.25} \times 1.3 \times 10^{-4}$ erg cm^{-2} s^{-1} sr^{-1}), corresponds well with the G0 estimates of models that fit the ionized lines of Sgr B1 (Simpson 2018, Simpson et al. 2018). These H II region models have stellar effective temperatures < 35,000 K, inner radii of ~1 pc and filling factor ~0.1.
•Significant variations are seen. For example, the region at 17:47:12 -28:31:15 has doubly-ionized gas, a W-R star, warm dust, but very little neutral gas. The region 45" farther south has more gas, both ionized and neutral, but less warm dust.
•The widely dispersed regions of high G0 indicate that the exciting stars are also widely dispersed throughout Sgr B1, just as is seen in the ionizing stars of the Sgr B1 H II region (Fig. 3; Simpson et al. 2018). The dark blue regions of Fig. 4 probably contain multiple components along the line of sight.

Based on observations made with the NASA/DLR Stratospheric Observatory for Infrared Astronomy (SOFIA). SOFIA is jointly operated by the Universities Space Research Association, Inc. (USRA), under NASA contract NAS2-97001, and the Deutsches SOFIA Institut (DSI) under DLR contract 50 OK 0901 to the University of Stuttgart. Financial support for this work was provided by NASA through awards 04_0113 and 05_0082 issued by USRA.