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CONTINUUM RADIATIVE TRANSFER MODELING OF SAGITTARIUS B2

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Abstract. We present results from radiative transfer modeling of the continuum emission towards Sagittarius B2 (hereafter Sgr B2). We have developed a radiative transfer framework – *Pandora* – that employs RADMC-3D (Dullemond 2012) for a self-consistent determination of the dust temperature. With this pipeline, we have set-up a single model that consistently reproduces the thermal dust and free-free continuum emission of Sgr B2 spanning four orders of magnitude in spatial scales (0.02–45 pc) and two orders of magnitude in frequency (20–4000 GHz).

1 Introduction

The giant molecular cloud complex Sgr B2 is located at a distance of 8.5 pc (Reid *et al.* 2014), close to the Galactic center. The entire complex contains a total gas mass of $10^7\,M_\odot$, distributed in a large envelope of $\sim$22 pc in radius (Lis & Goldsmith 1989). Despite the large mass reservoir, star formation seems to be mainly occuring in the two hot molecular cores Sgr B2(N) and Sgr B2(M). These two sites of active star formation are located at the center of the envelope occupying

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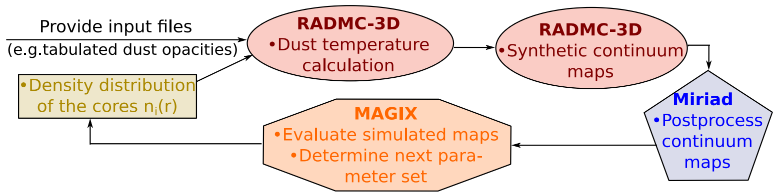

Fig. 1. Flowchart of the radiative transfer modeling framework Pandora.

an area of around 2 pc in radius. They contain more than 50 high-mass stars with spectral types ranging from O5 to B0, and constitute one of the best laboratories for the search of new chemical species in the Universe.

The modeling of the thermal dust and free-free continuum emission of Sgr B2 provides us with the three-dimensional model of the structure (*i.e.* density distribution) of this region. For this, multi-wavelength and multi-scale data is crucial to properly constrain the structure. In the next step this will enable us to model the line shapes (kinematics) and thus constrain molecular gas properties, such as the gas velocity field, molecular abundances, etc..

2 Pandora

Pandora follows the flowchart in Figure 1 for the continuum modeling. As part of the framework, we employ the 3-dimensional, publicly available radiative transfer program RADMC-3D (Dullemond 2012), Miriad for the post-processing, and MAGIX (Möller *et al.* 2013) for the optimization of the model input parameters. For a full description of *Pandora* see (Schmiedeke *et al.* 2016).

In short, we use the adaptive mesh refinement (AMR) technique to locally increase the spatial resolution on a cell-by-cell basis. We include stars as heating sources. For each known HII region, we place a corresponding star in the model. We then sprinkle low-mass stars according to Kroupa's initial mass function (IMF). The overall density structure is obtained by a superposition of the Plummer-like density profiles of all dust cores. We consider HII regions as Strömgren spheres, *i.e.* as fully ionized, spherical regions of uniform electron density with no dust. The dust temperature is calculated self-consistently by RADMC-3D. We use one dust species (dust without grain mantles and no coagulation from Ossenkopf & Henning 1994) and do not include scattering events.

In order to compare synthetic maps with real observations, telescope specific post-processing is necessary, *e.g.* performing uv-filtering in case of interferometric observations. Since three-dimensional modeling has intrinsically many free parameters, we focused on deriving the density field for a fixed dust setup. Exploring the complete parameter space of all free parameters is prohibitive in terms of computing time. Hence, we used a hybrid approach. First, we derive a good guess by varying parameters by hand and judging the quality visually (χ^2-by-eye). We then employ MAGIX (Möller *et al.* 2013) to iteratively search for the best solution.

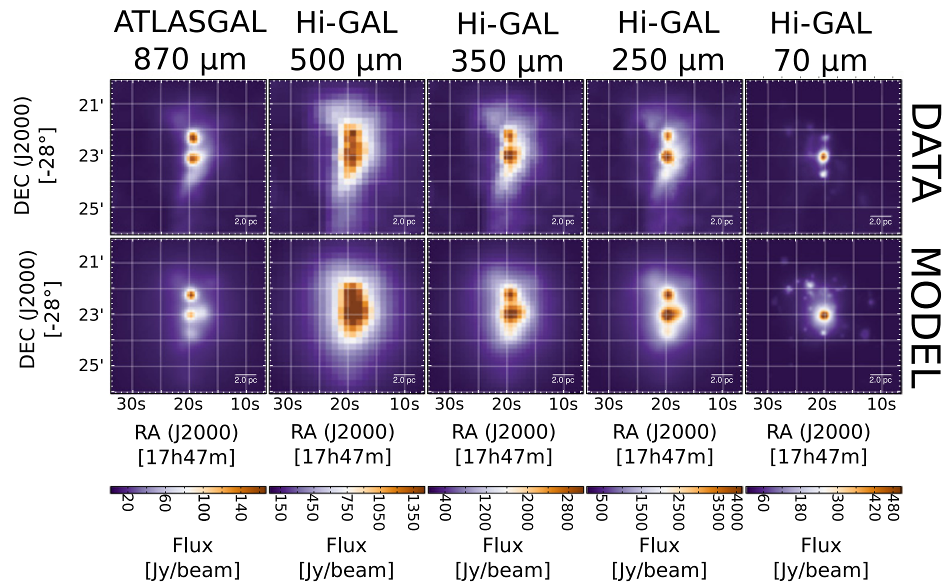

Fig. 2. Sgr B2, large scale continuum maps (see Schmiedeke *et al.* 2016).

3 Results

We show the best-fit model for the large-scale envelope and the small-scale structure around Sgr B2(M) in Figures 2 and 3, respectively. In these figures, the top row shows the observational data while the bottom row shows the synthetic maps. For the extended envelope, we find a superposition of dust density structures that are elongated along the line-of-sight necessary to match the observations. To reconstruct the spectral energy distribution, we locate Sgr B2(N) along the line-of-sight behind the plane containing Sgr B2(M). In both, the observed and the synthetic maps, the intensity of Sgr B2(M) is stronger than Sgr B2(N) except at 870 μm. Furthermore the observed maps show a clear asymmetry, *i.e.* the continuum emission shows a faint extension to the west and a sharp edge to the east. So while incapable of reproducing the absolute intensities, this model reproduces the general behaviour. A detailed study of the envelope structure will likely lead to a more clumpy distribution of the dust density and provide an improved fit.

In addition, we show in Figure 3 the physical structure as three different density-isocontours, $10^{-17.5}$, 10^{-18}, and 10^{-19} g cm^{-3}, coloured with the dust temperature. The surface of the many HII regions in Sgr B2(M) gets heated by the embedded protostellar objects up to temperatures of more than 600 K. Assuming a gas-to-dust ratio of 100 (Hildebrand 1983), we convert dust mass into gas mass and together with the stellar mass distribution we derive an average star formation efficiency of 50% for Sgr B2(M) and 5% for Sgr B2(N), indicating that Sgr B2(M) has already dispersed a lot of gas.

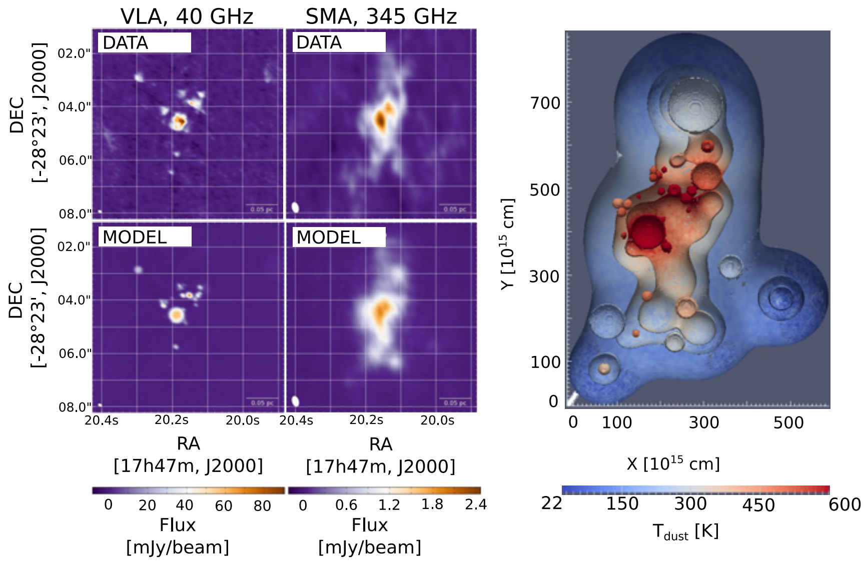

Fig. 3. *Left* and *middle*: interferometric continuum maps from the VLA (*left*) and the SMA (*middle*) of Sgr B2(M). The observed maps are located in the top row, the synthetic maps in the bottom row. Observed and synthetic map share the same colorscale. *Right*: impression of the 3d view of the dust density distribution in Sgr B2(M). The model is cut open at the model center to allow a view inside (see Schmiedeke *et al.* 2016).

4 Conclusions

We successfully reconstruct a possible three dimensional density distribution of Sgr B2, recovering the continuum structures covering a wide frequency range (20–4000 GHz) on scales from 100 au to 45 pc. We derive a total dust mass of $10^5\,M_\odot$ for Sgr B2 and find stellar masses of $20700\,M_\odot$ and $2400\,M_\odot$, as well as luminosities of $1.2 \times 10^7\,L_\odot$ and $1.8 \times 10^6\,L_\odot$ for Sgr B2(M) and Sgr B2(N), respectively. The average star formation efficiency is low (5%) for Sgr B2(N) and comparatively high (50%) for Sgr B2(M), indicating that Sgr B2(M) has already dispersed a lot of gas.

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