Accuracy of core mass estimates in simulated observations of dust emission

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We study the reliability of mass estimates obtained for molecular cloud cores using sub-mm and infrared dust emission. We use MHD-simulations and radiative transfer to produce synthetic observations with resolution and noise typical of Herschel surveys. We estimate dust colour temperatures using intensity pairs or all five Herschel wavelengths, calculate column densities and compare estimated and true masses. We study also the influence of embedded heating sources. The shape, but not the position, of mass spectrum is reliable against observational errors and analysis biases. This changes only if cores have optical depths higher than in basic hydrostatic equilibrium. Observations underestimate spectral index β when there are temperature variations along line of sight. A bias can be observed when true β varies with wavelength. Internal heating sources produce inverse correlation between colour temperature and β that may be difficult to separate from any intrinsic $\beta(T)$ relation of the dust grains.

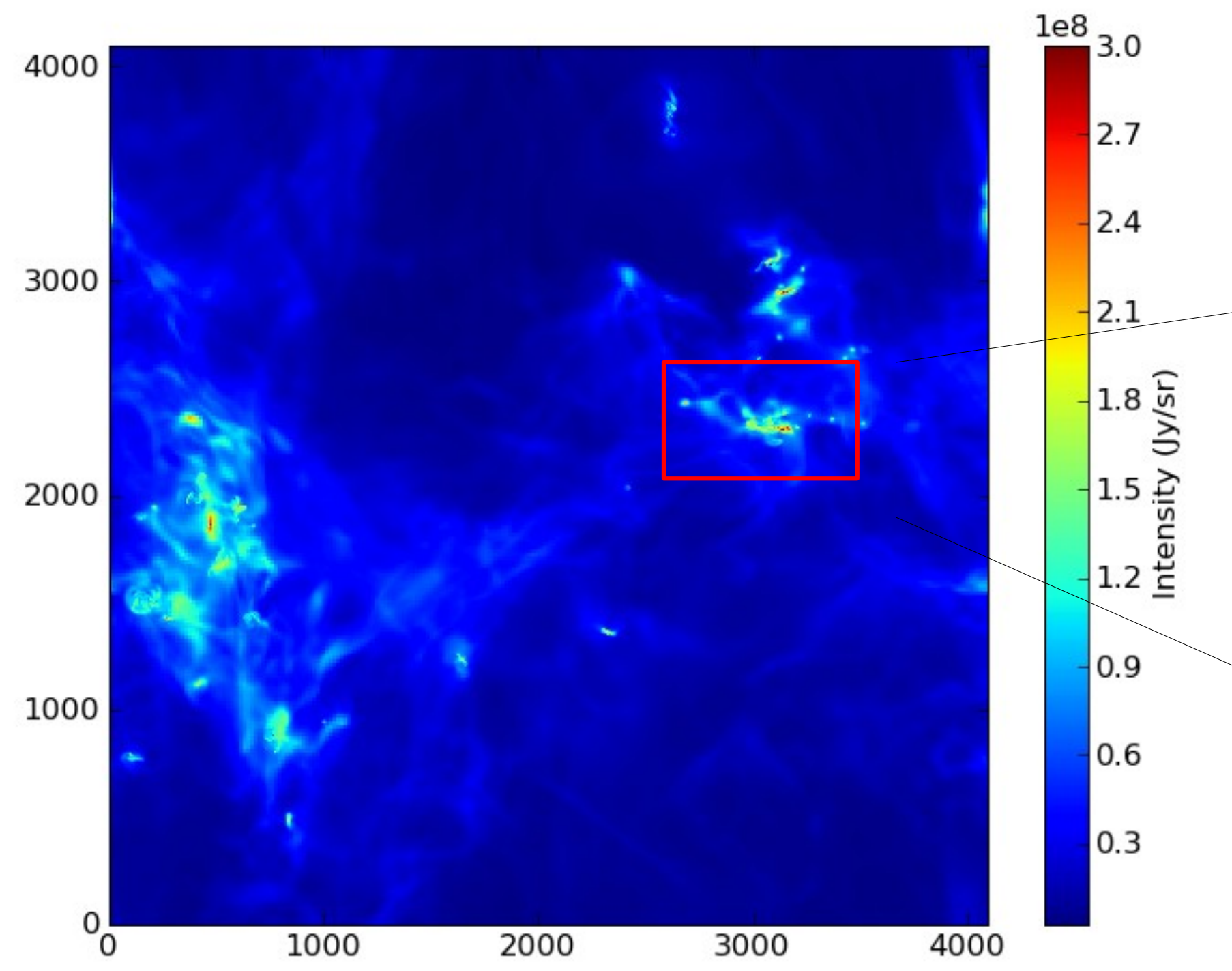


Figure 1. High opacity model: simulated 250 µm intensity map before adding noise.

Introduction The conditions in cold molecular cloud cores determine many fundamental aspects of star formation: stellar mass distribution, formation efficiencies, evolution timescales etc. In order to understand the early phases of star formation, we must study the cold cloud cores. The initial mass function (IMF) appears to be directly linked to the core mass function (CMF) of pre-stellar cores (Motte et al. 1998, 2001; Johnstone et al. 2000; Enoch et al. 2008). However, large temperature gradients and changes in dust emissivity could distort core mass estimates and even affect the shape of the derived core mass spectra. Also internal heating caused by protostars could affect the estimated mass spectra. We investigate these errors by combining magnetohydrodynamic (MHD) simulations and radiative transfer modeling of dust emission.

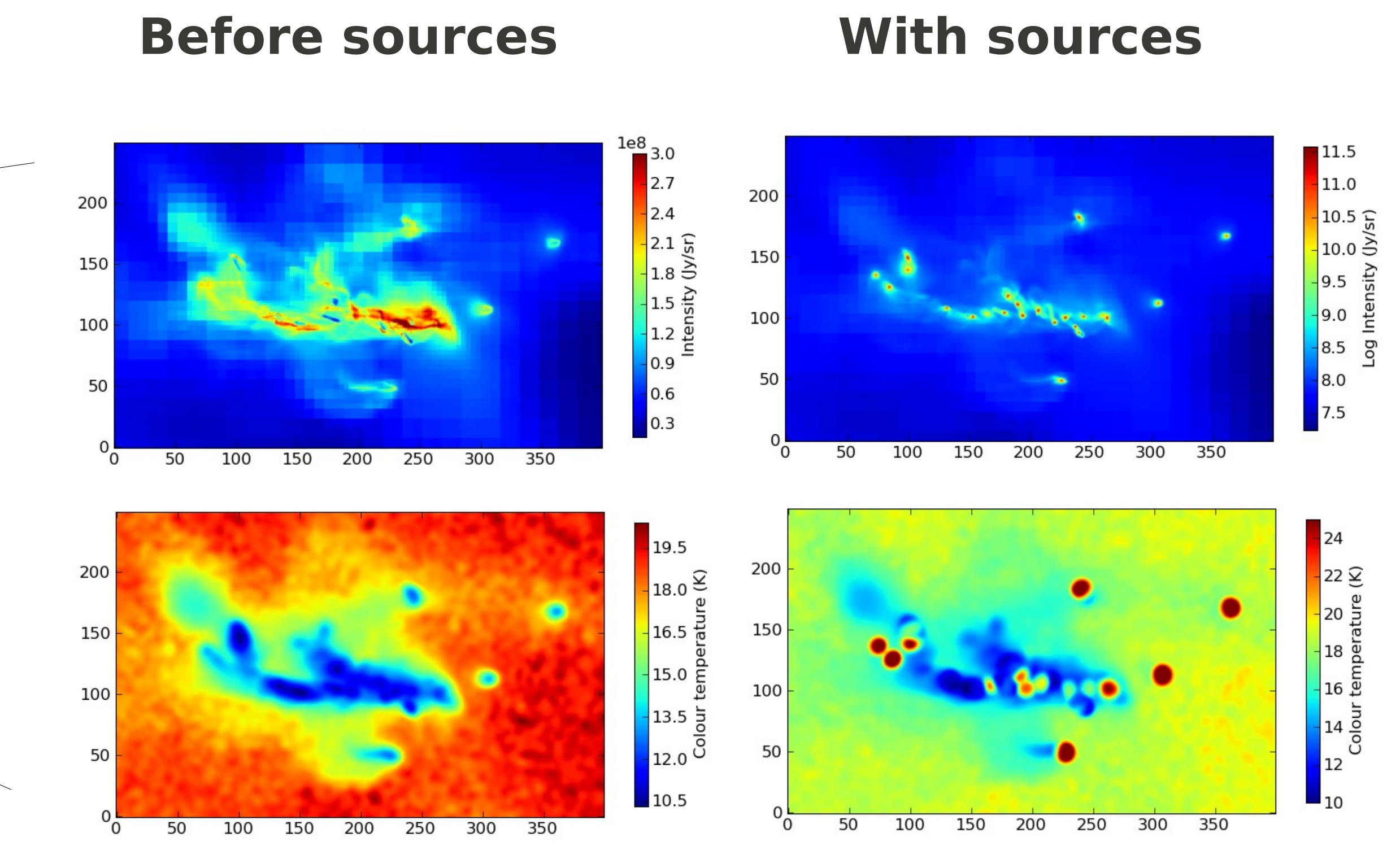
We present the results from a study using cloud models derived from MHD runs performed on hierarchical grids. With automatic mesh refinement (AMR) one can follow the evolution of individual cores much further (see Collins 2010) and, because of the stronger density and temperature variations, also the errors in the derived core masses may be larger. Our main interest is not in the shape of the CMF but in the changes caused by observational biases. The results obtained in this study are more thoroughly presented in Malinen et al. (2011). The present study is relevant to many Galactic studies that are being conducted with Herschel satellite and will be continued with the future high-resolution ALMA observations.

Calculations We use two MHD model clouds, another with cores of moderate opacity (maximum column density 10^{25} $1/\mathrm{cm}^2$) and another with cores of high opacity (maximum column density 10^{26} $1/\mathrm{cm}^2$). The size of both clouds is 10 pc. The dust properties were kept constant throughout the volume although the mass is strongly concentrated in the densest regions. We calculated surface brightness maps of dust emission with our 3D radiative transfer programs (Juvela & Padoan 2003; Lunttila et al. 2011) and added to the maps noise typical of current Herschel observations.

Dust colour temperatures were estimated from surface brightness maps at two wavelengths and the core masses were estimated using correct dust absorption cross section (κ) and spectral index (β) for the dust model. We used the automatic clump finding method Clumpfind (Williams et al. 1994) to locate clumps in column density maps and derived the core mass spectra, i.e. number of cores vs. core mass. We compared these results to the case when all five Herschel wavelengths are used.

We investigated the effect of internal heating by adding protostellar sources in the range of ~0.3-120 solar luminosities to the most prominent cores and derived the mass spectra again. We also compared the core masses in the surroundings of the source positions before and after adding the sources in order to have an objective definition for the core.

Results One of the simulated intensity maps is shown in Figure 1. Closeups of the intensity map and colour temperature map before and after adding the sources are shown in Figure 2. The mass spectra and relation of true vs. observed mass within a constant radius in moderate opacity model are shown in Figure 3. We get more accurate mass estimates using 250/500 µm pair than with a fit to 5 wavelengths, if shorter wavelengths (~100 µm) are included. The core mass spectra with and without sources in high opacity model are shown in Figure 4. Without the sources the core masses are strongly underestimated. With the sources the observed mass spectra comes closer to the true mass spectra. The correlation between simultaneously fitted T and β in moderate opacity model is shown in Figure 5. Without internal sources T and β are correlated, in opposite to the inverse T-β relation detected in interstellar clouds (Dupac et al. 2003). Internal heating sources produce an inverse correlation, because β is underestimated towards warm cores.


Before sources

With sources

Figure 2. High opacity model: closeup of the area marked with a rectangle in Figure 1 of intensity and colour temperature maps before (left frame) and after (right frame) adding the heating sources.

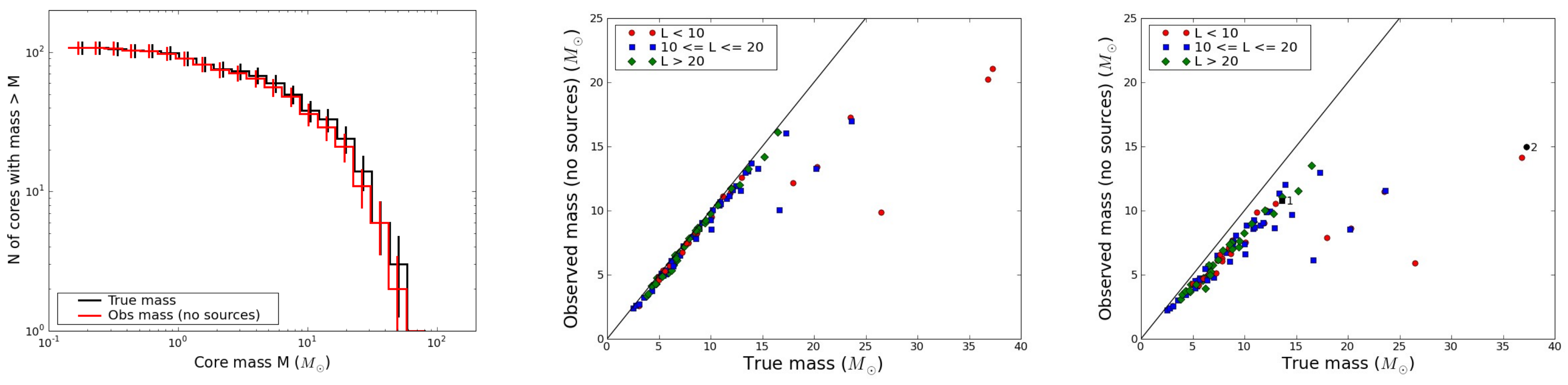


Figure 3. Moderate opacity model (without added sources): (Left) Cumulative core mass spectra. Colour temperature is calculated using 250 and 500 µm maps. (Center) Relation of true mass vs. observed mass (within 20 pixel radius) using 250/500 µm maps before adding the source (L means the luminosity of the source to be added in the clump and is related to the mass of the clump). (Right) True mass vs. observed mass using all Herschel wavelengths (100, 160, 250, 350, 500 µm).

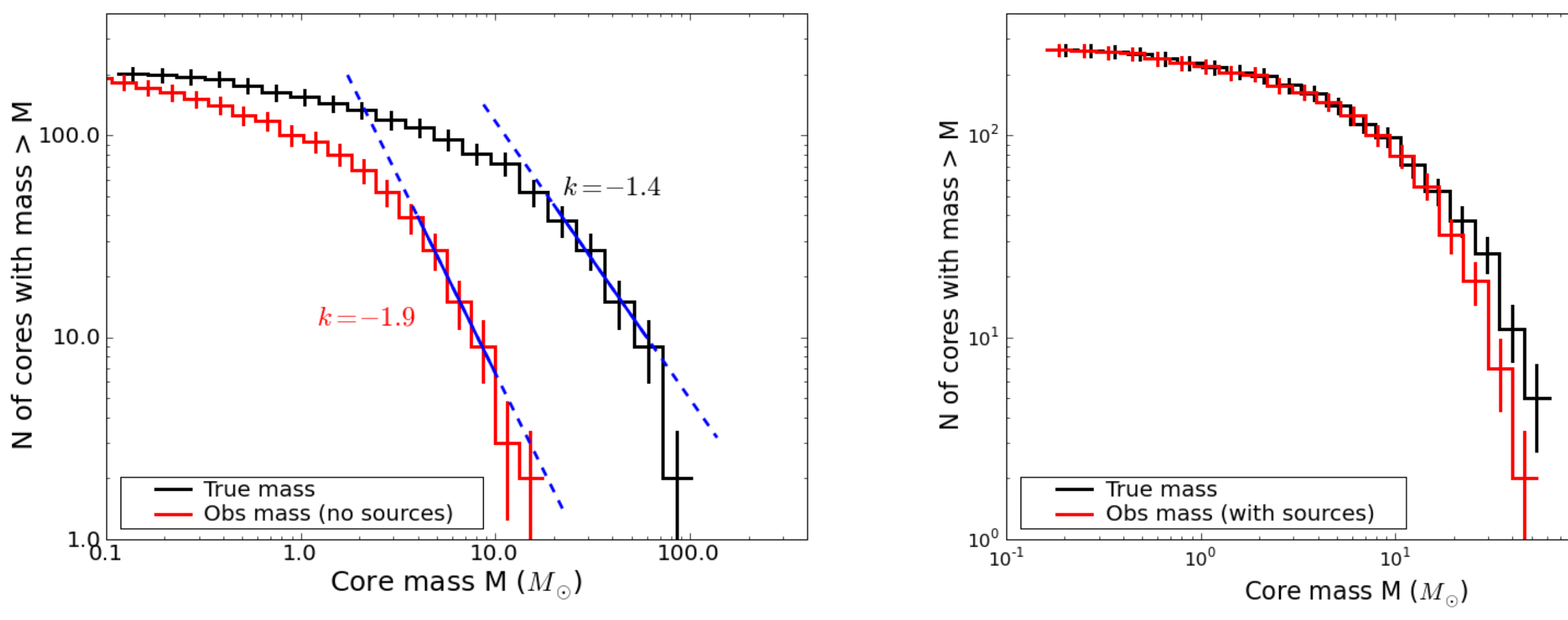


Figure 4. High opacity model (250/500 µm): cumulative core mass spectra before adding the heating sources (left frame) and after it (right frame). True mass spectrum is derived from true column density map using observed clumps.

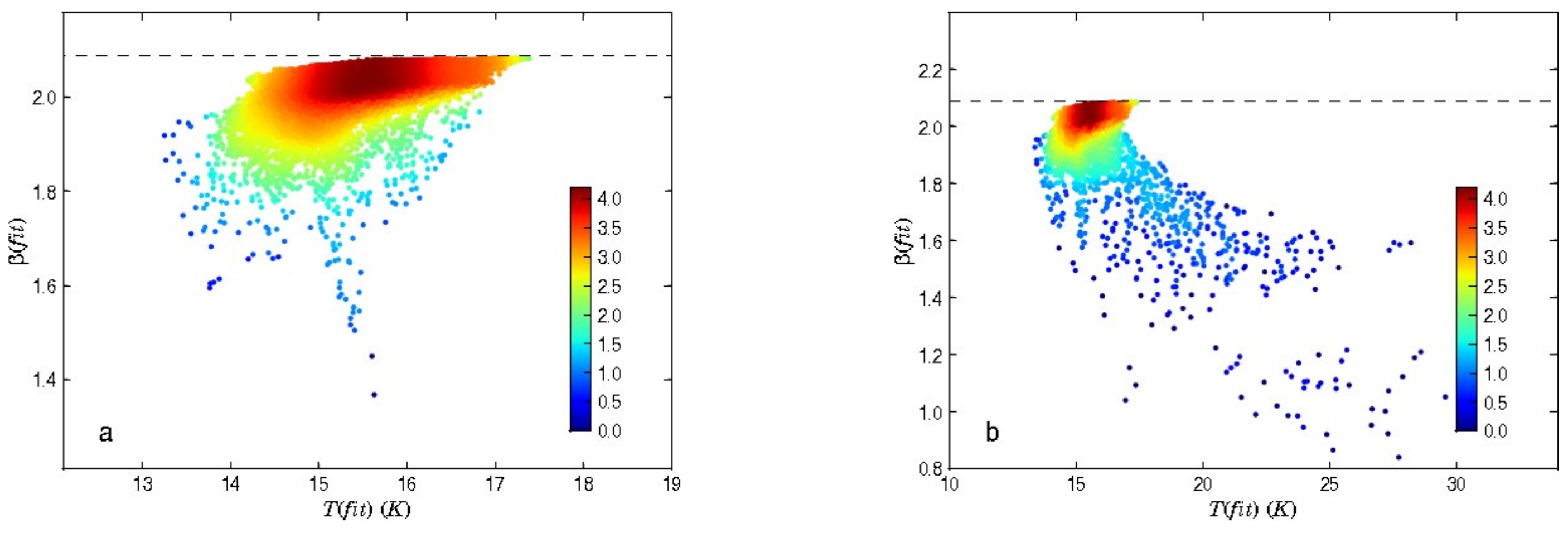


Figure 5. Moderate opacity model: correlation between dust colour temperature T and emissivity spectral index β. The colour scale indicates logarithmic density of points and the dashed line marks the average β. (Left) Without added sources. (Right) With added heating sources.

References Collins, D. et al. 2010, ApJS 186, 308; Dupac et al. 2003, A&A, 404, L11; Enoch et al. 2008, ApJ 684, 1240; Johnstone et al. 2000, ApJ 545, 327; Juvela & Padoan 2003, A&A 397, 201; Lunttila et al. 2011, in preparation; Malinen et al. 2011, A&A 530, 101; Motte et al. 1998, A&A 336, 150; Motte et al. 2001, A&A 372, 41; Williams et al. 1994, ApJ 428, 693