Grain growth in Class I protostar Per-emb-50: A dust continuum analysis with NOEMA & SMA
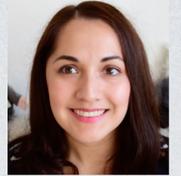
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Abstract

A good understanding of when dust grains grow from sub-micrometer to millimeter sizes occurs is crucial for models of planet formation. This provides the first step towards the production of pebbles and planetesimals in protoplanetary disks. Thanks to detailed studies of the spectral index in Class II disks, it is well stablished that Class II objects have already dust grains of millimetres sizes, however, it is not clear when in the star formation process this grain growth occurs. Here, we present data from NOEMA at 3mm and SMA at 1.3 mm of the Class I protostar, Per-emb-50, to determine the spectral index at mm-wavelengths of both the unresolved disk and the surrounding envelope. We find a spectral index in the (unresolved) disk 0.3 times smaller than that in the envelope, α_{env} = 2.18, comparable to values obtained toward Class 0 sources.

The source

Per-emb-50 is a protostar located in the active cluster forming region NGC1333, located in the Perseus cloud (Fig.1) at a distance of 235±18 pc [1]. It is the brightest (in bolometric luminosity) isolated Class I object [2]. Some relevant properties of Per-emb-50 are listed in Table 1.
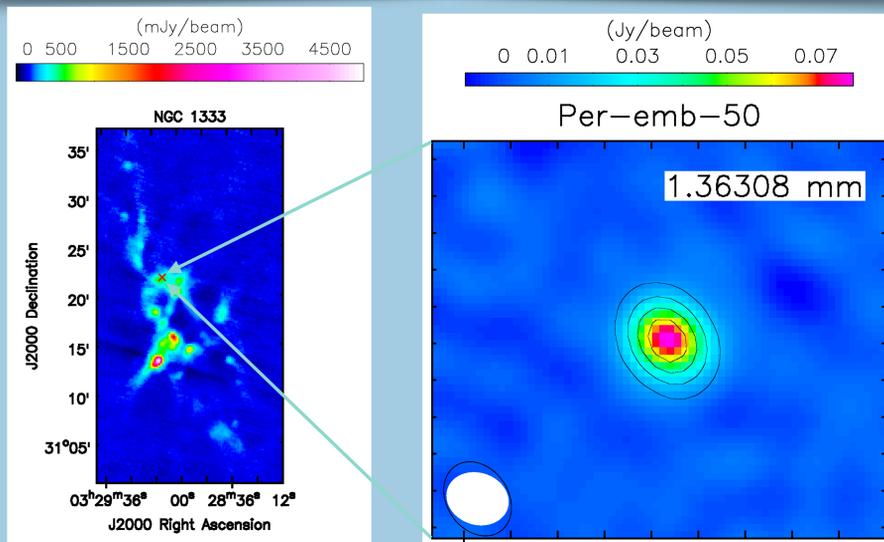
Figure 1. (Left figure) 1.1mm Bolocam map of the forming region NGC1333. In zoom (right figure) the continuum color image of Per-emb-50 at 1.3 mm with white beam size, and in black contours the 3mm NOEMA data.

α (J2000.0)	03:29:07.76
δ (J2000.0)	31:21:57.2
L_{bol} ($L_\odot$)	10.0 ± 3.0
T_{bol} (K)	254 ± 23
M_{env} ($M_\odot$)	1.62 ± 0.16
Disk P.A. (deg)[1]	170.0 ± 0.3
Disk inclination (deg)[1]	67 ± 10
Disk outer radius (AU)[1]	21.9 - 25.7

Table 1. Summary of properties Per-emb-50. [1] From Segura-Cox, et al., 2016 VANDAM

SMA and NOEMA data

The source, Per-emb-50, was observed in both: 1.3mm and 3mm. The 1.3mm from SMA was taken in sub-compact and extended configuration as part of the MASSES program, PIs: I.W. Stephens, M. Dunham. While the 3mm observations were carried out with the recently upgraded NOEMA in C configuration. Both set of data provide an angular resolution of about 2.0"x1.5" and are sensitive to scales down to 400au (see Fig. 2).

Analysis

At millimeter wavelengths, the emission is usually described by the spectral index of the SED α_{mm}, $F_\nu \sim \nu^{\alpha mm}$. In case of optically thin emission, the α_{mm} of the SED is related to dust emissivity spectral index β_{mm}, via $\alpha_{mm} = \beta_{mm} + 2$, and can be calculated from our NOEMA and SMA observations, with the following relation:

$\alpha_{mm} = (\ln F_1 - \ln F_2) / (\ln \nu_1 - \ln \nu_2)$, (see Fig 3).
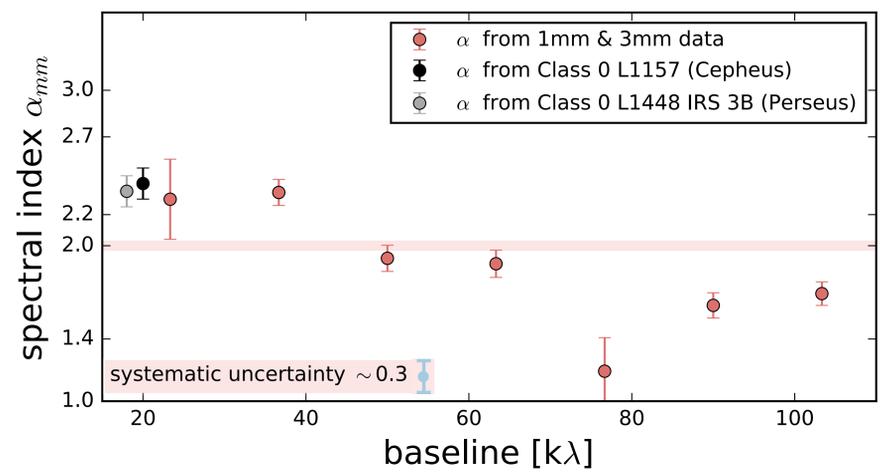
Figure 3. Spectral index α_{mm} of Per-emb-50 as a function of u–v distance. The error bars show the statistical errors, while the systematic error due to the typical absolute calibration uncertainty is ~0.3. As comparison we include the results from previous studies of the spectral index in envelopes around Class 0 from [4].

We assume that Per-emb-50 consists of two components, an envelope and a disk. Since it is possible that envelope and disk emission are better described with different spectral indices α, we decide to model the emission with two components with different α. On the one hand a model of the unresolved disk contribution with no changes at long baselines, on the other hand, the envelope emission modelled as a gaussian (see Fig. 2).

We separate the unresolved flux at both wavelengths to determine the spectral index of the unresolved disk emission. The excess emission is modelled as a gaussian, and the derived spectral index is: 2.18 ± 0.12, while the spectral index relative to the disk is 1.61±0.11 (see Fig. 3). Thus, the spectral indices in the disk and envelope are significantly different, with a ratio of $\alpha_{env}/\alpha_{disk}$ =1.36±0.16.
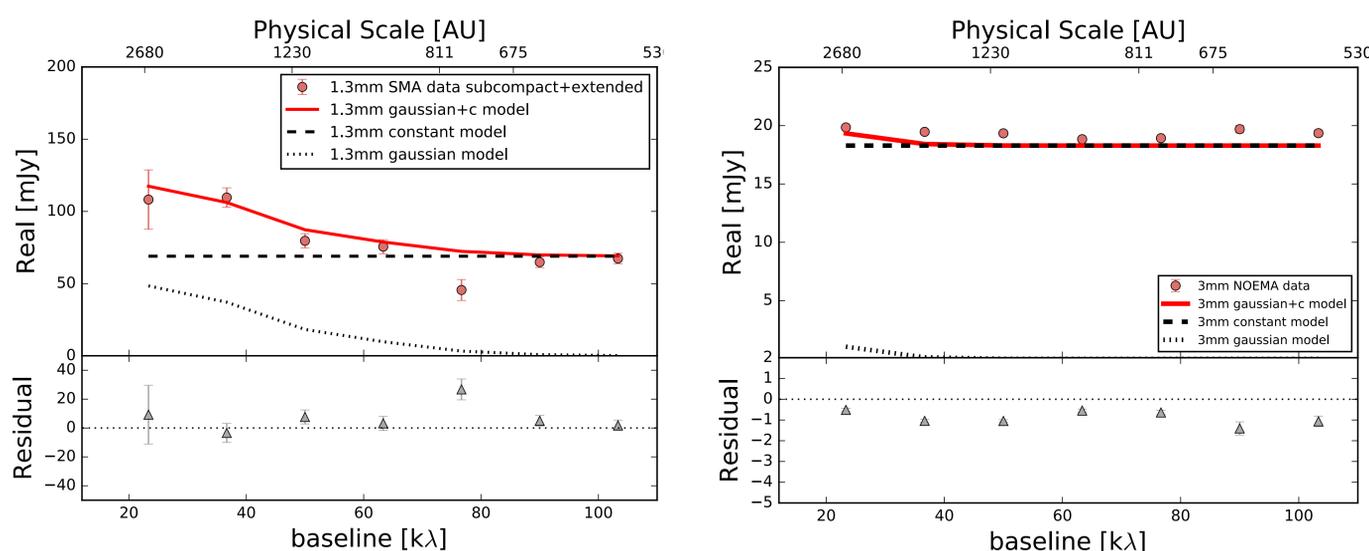
Figure 2. Real amplitude of 1.3 mm and 3mm data and the model fit (solid lines). The simple model fit includes two components: a power-law envelope (dotted lines) and an unresolved disk (broken lines). While modelling is done with non-averaged visibilities, binned visibilities of 10kl are shown as a function of u–v distance.

Conclusion and future work

* This observations show for the first time a differentiation of the spectral index along uv distance between the envelope and disk for a Class I protostar.

* Our spectral index in the envelope is smaller than the typical ISM values, α = 3.7, and consistent with previos studies in Class I [5] and Class 0 protostars [4].

* We will model the disk and envelope emission using RADMC-3D [6], to robustly determine the dust properties in the envelope and disk.

References

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