Fragmentation in Massive Star Forming Regions

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Abstract

With high spatial resolution PdBI dust continuum observations we disentangle the cluster-like structure of the young massive star-forming region IRAS 19410+2336. We detect about twenty-five continuum sources at 1.36 mm wavelength, distributed in two sub-regions. The "southern" sub-region has about 19 individual sources, clearly clustered within a radius of ~20,000 AU, while the remaining 6 detected individual sources are in the "northern" sub-region, also distributed in a cluster-like mode within ~30,000 AU.

We also observed H_2CO lines, a well known and reliable thermometer in star forming regions (Mangum & Wootten 1993, ApJS, 89,123), to derive a temperature structure for the region. However, the line observations suffered of a strong spatial filtering, and they will not be useful until we complement them with single-dish observations, already scheduled for November 2007 at the IRAM 30-meter Telescope.

Nevertheless, assuming an average dust temperature from previous single-dish observations we derive and discuss a cumulative Core Mass Function (CMF) for the region.

Motivation

One of the many open issues in Massive Star Formation (MSF) is the fragmentation of the gas clumps prior to the formation of the massive stars. Actually, there are two different models for that. One theory predicts that massive gas clumps fragment early on cores of different mass resembling the shape of the Initial Mass Function (IMF, e.g., Padoan & Nordlund 2002, A&A, 576, 870; Krumholz 2006, arXiv:astro-ph/0607429v1), while the other suggests that the fragmented cores are all of the order a Jeans mass (0.5 - 1 $M_{\odot}$), and that these cores competitively accrete form the surrounding gas envelope (e.g., Bonnell, Vine & Bate 2004, MNRAS, 349, 735; Clark & Bonnell 2006, MNRAS, 368, 1787). The first model implies that all gas available to accrete for the forming protostar is contained within the fragmented core, while the second model requires a globally -toward its gravitational center- collapsing gas clump, where the protostar at the gravitational center will accrete more gas than the other stars, hence forming the more massive final star. Studying the shape of the CMF of young massive star forming regions through high spatial resolution (sub)mm interferometric observations is the way to differentiate between those two theories, and toward that goal here we present our study on IRAS 19410+2336. This study is a follow-up to the previous work of Beuther & Schilke (2004) to overcome some of the given caveats there, like the assumption of a uniform dust temperature for all sub-sources.

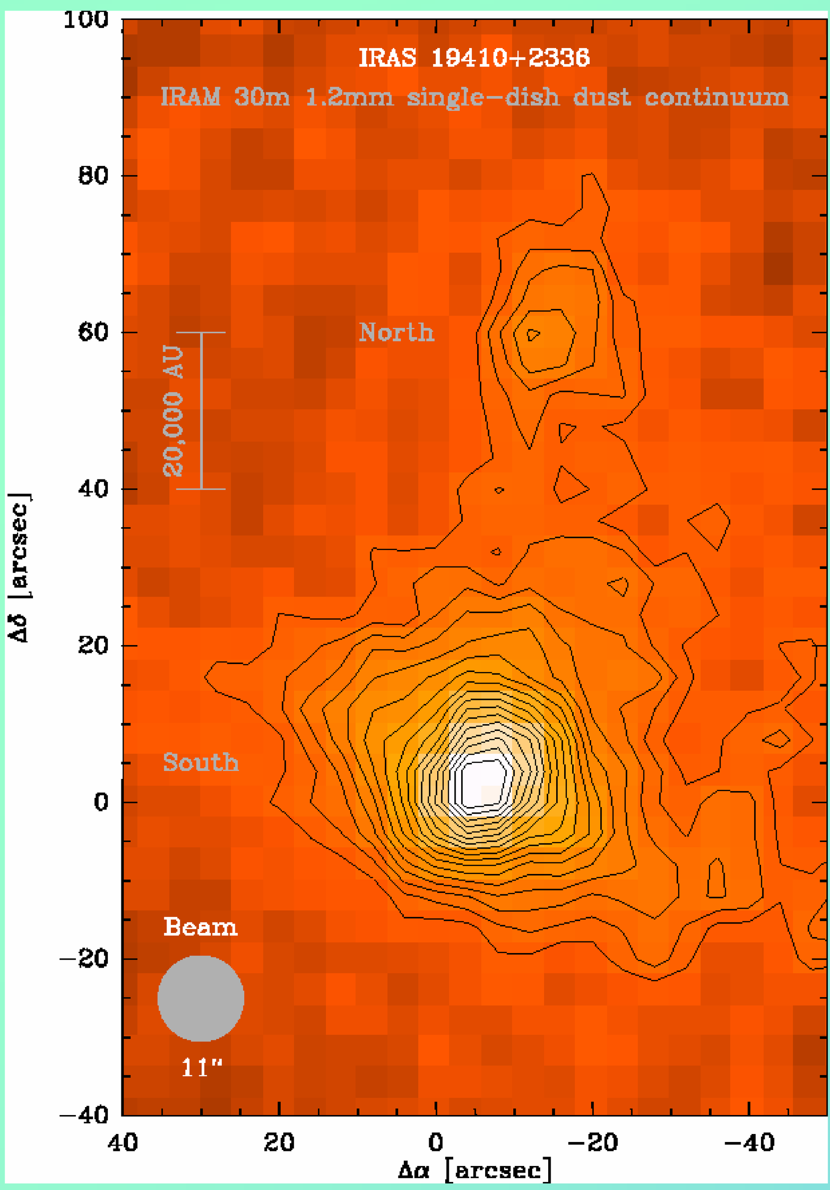

Figure 4: 1.2 mm single-dish dust continuum map of IRAS 19410+2336, obtained with the IRAM 30 m telescope by Beuther & Schilke 2004. The contours start at 15% of the peak flux increasing in 5% steps.

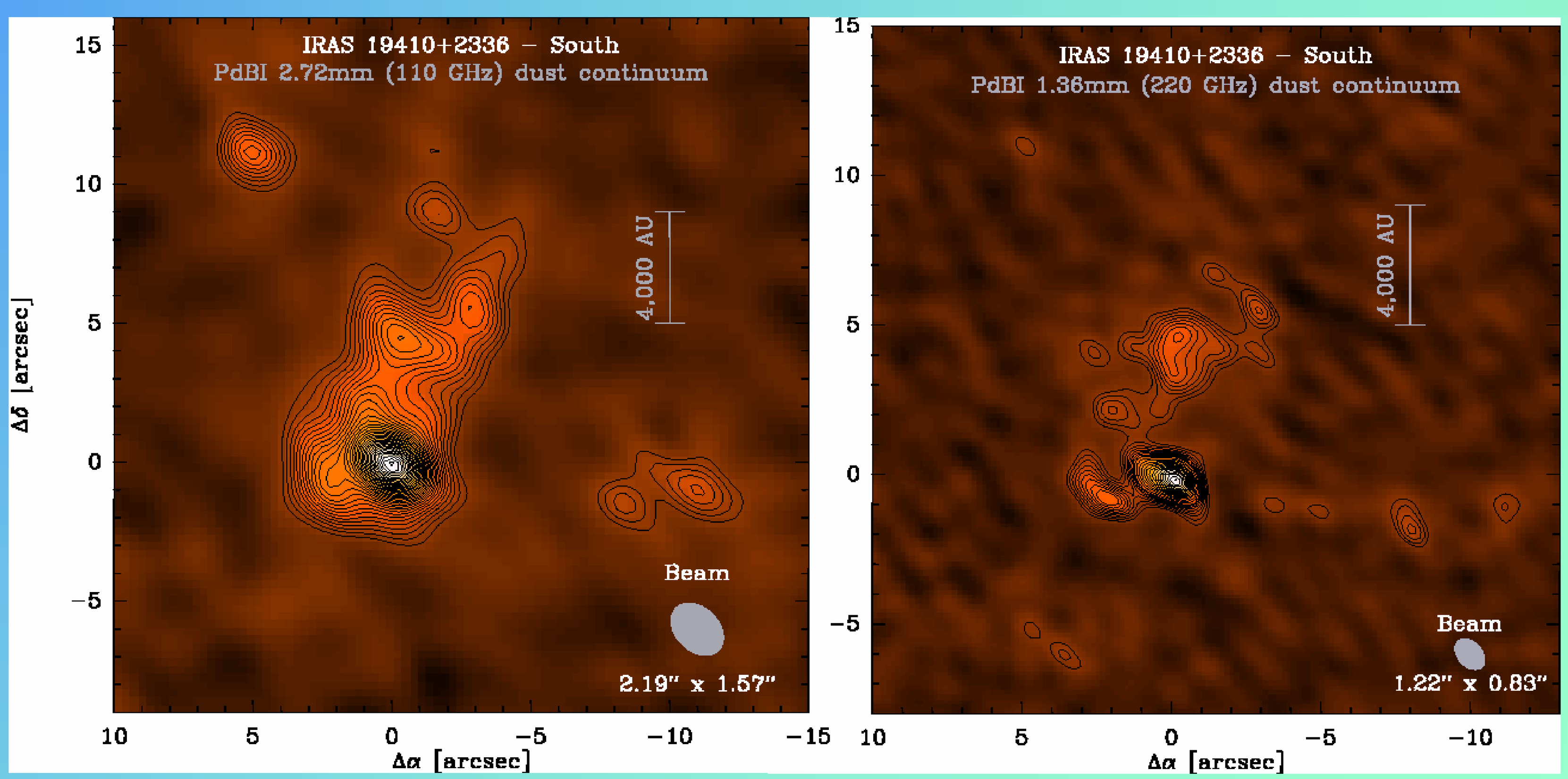

Figure 2: PdBI dust continuum maps of IRAS 19410+2336. Left: 3 mm map of the south sub-region, the contours start at the 4σ level of 1.7 mJy/beam with 1σ steps of 0.4 mJy/beam. Right: southern sub-region mapped at 1 mm., the contours range from the 4σ level of 4 mJy/beam and 12 mJy with 1σ steps of 1 mJy/beam, and at 2σ steps above that.

Continuum Observations

IRAS 19410+2336 is in an early stage of high-mass star formation (Kurtz et al. 2000, Protostars and Planets IV), is at a distance of ~2 kpc and has an integrated bolometric luminosity of about 10^4 $L_{\odot}$. We observed this region with the Plateau de Bure Interferometer at 1.3 and 3 mm, imaging the dust continuum with a synthesized beam of ~1.2" × 0.8" at 1.3 mm and ~2.2" × 1.6" at 3mm (Figures 1 & 2). Previous single-dish observations (with a beam size of ~11"), show two massive gas cores aligned in a north-south direction (Figure 4), considering a 4σ level sensitivity, we resolve those cores into 25 individual sources, 19 in the "southern" sub-region and 6 in the "northern" sub-region (Figures 1 & 2), and in both cases we see a cluster-like structure, with a dominating central massive source surrounded by a cluster of less massive sources.

Assuming that the dust is optically thin and an uniform temperature of 46 K (Beuther & Schilke 2004), the overall gas mass we detect in the 1.3 mm continuum is 24 $M_{\odot}$ in the south and 6 $M_{\odot}$ in north, representing about 6% of the masses detected in the single-dish data: 420 $M_{\odot}$ and 95 $M_{\odot}$ for the south and north respectively. The "missing" mass is contained in larger scale structures, which are filtered out by the interferometer, tracing only the most compact sources. However, although a large amount of flux is filtered out, this should not affect the relative fluxes and masses of the sources.

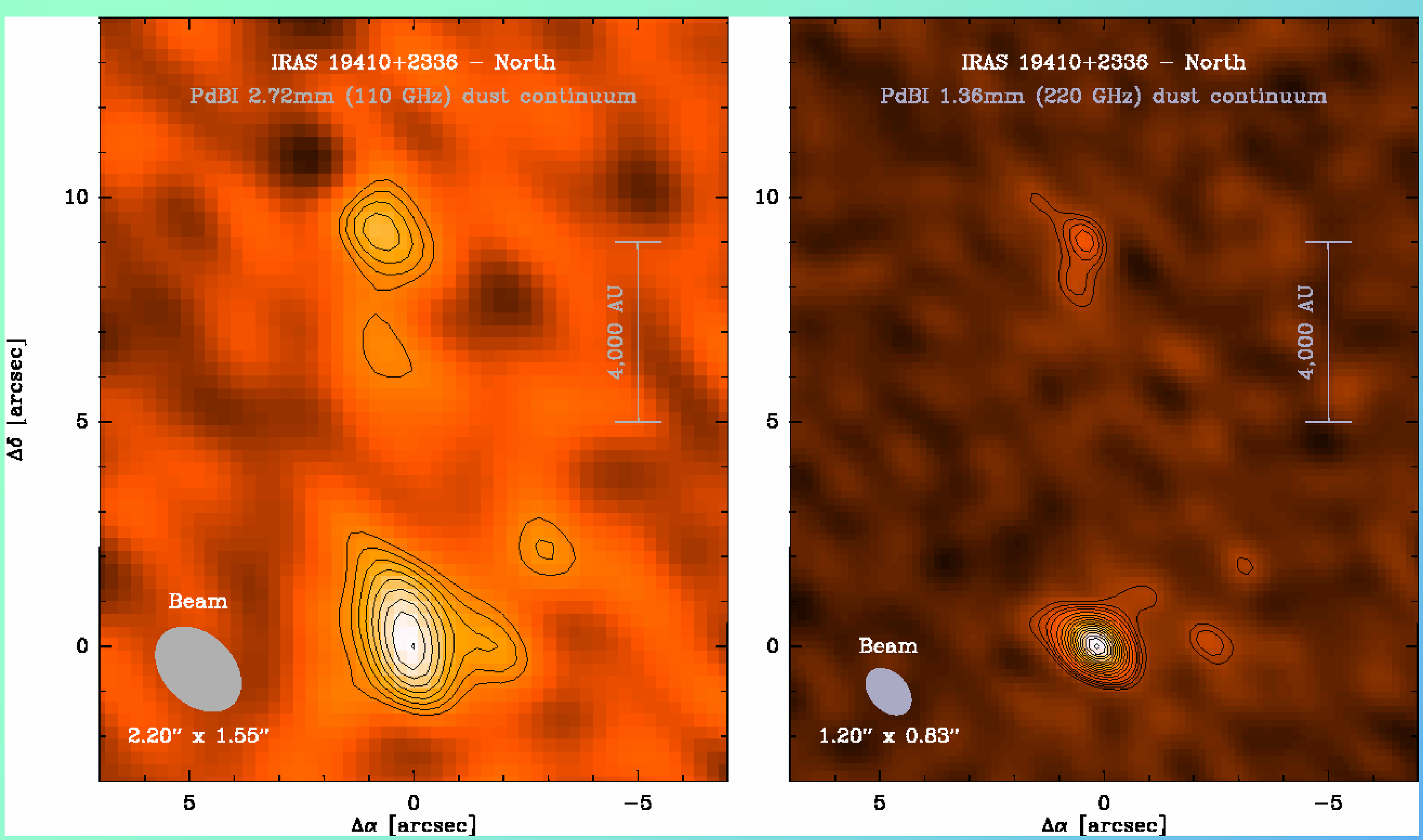

Figure 1: PdBI dust continuum maps of IRAS 19410+2336. Left: 3 mm maps of the north sub-region, the contours start at the 4σ level of 1.7 mJy/beam with 1σ steps of 0.4 mJy/beam. Right: northern sub-region mapped at 1 mm, contoured at 1σ steps of 0.8 mJy/beam between the 4σ level of 3.2 and 6.4 mJy/beam, and at 2σ steps above that.

Temperature Structure and the Core Mass Function

In the 3 mm band the dense-gas tracer ^{13}CO, as well as the CH_3CN lines series between 110.3 GHz and 110.4 GHz were observed. In the 1.3 mm band, we observed the H_2CO (3-2) lines between 218.2 GHz and 218.8 GHz, to derive a temperature structure for the region. These three lines are a well known and reliable thermometer in star forming regions (Mangum & Wootten 1993). With these lines we want to determine a temperature structure for the cluster, to build a more accurate CMF for it. However, we can see in Figure 5 how the line observations suffered of a strong spatial filtering, rendering them useless until we complement them with single-dish observations, already scheduled for November 2007 at the IRAM 30-meter Telescope.

Nevertheless, we assumed a uniform temperature for the cluster and calculated preliminary masses for the individual sources to build a power-law CMF. Because of the spatial filtering and the low number of sources detected, we could not calculate a differential CMF ($dN/dM \sim M^{\alpha}$) but a cumulative CMF ($N(>M)/N(Total) \sim M^{\alpha+1}$; Li et al. 2006, ApJ, 655, 351), shown in Figure 3. The line is the best fit to the cumulative CMF, giving a value of α = -2.5, in contrast with the value of α = -2.35 derived from Salpeter for the IMF.

We see how the massive end of the cumulative CMF flattens. This behavior is likely due to the uncertainty on the assumed uniform temperature for the more massive cores, we expect for it to become steeper once we have determined a more accurate temperature distribution. For that reason, the massive "tail" was not used for the fit of the cumulative CMF. Although this is a preliminary result, the value obtained is not expected to vary too much, thus remaining rather steep.

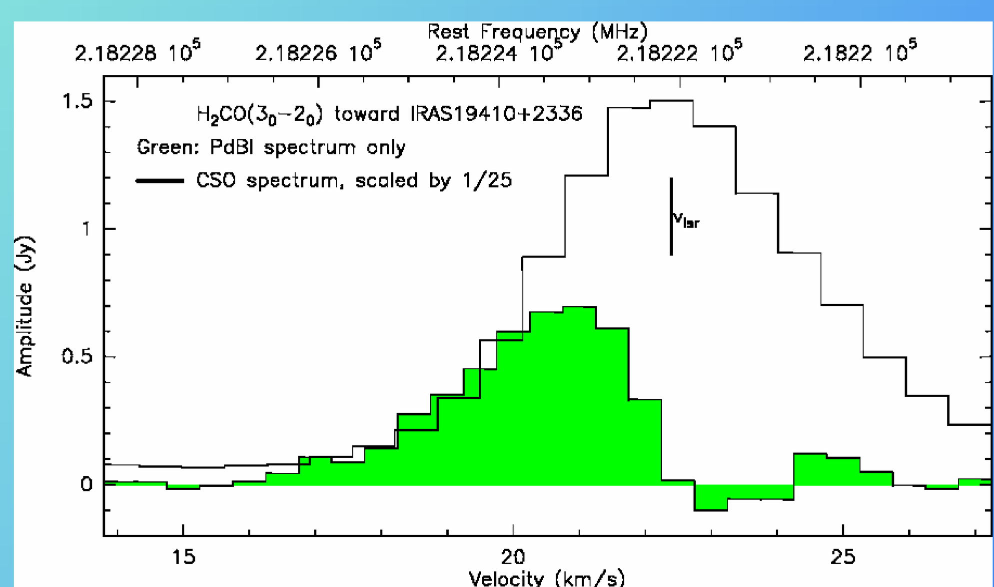

Figure 5: comparison of the spectrum of H_2CO (3_0 – 2_0) toward IRAS 19410+2336 taken with the CSO telescope (solid line) and the PdBI (green), showing the missing flux around the velocity of rest. This is due to the spatial filtering of the flux caused by the interferometers.

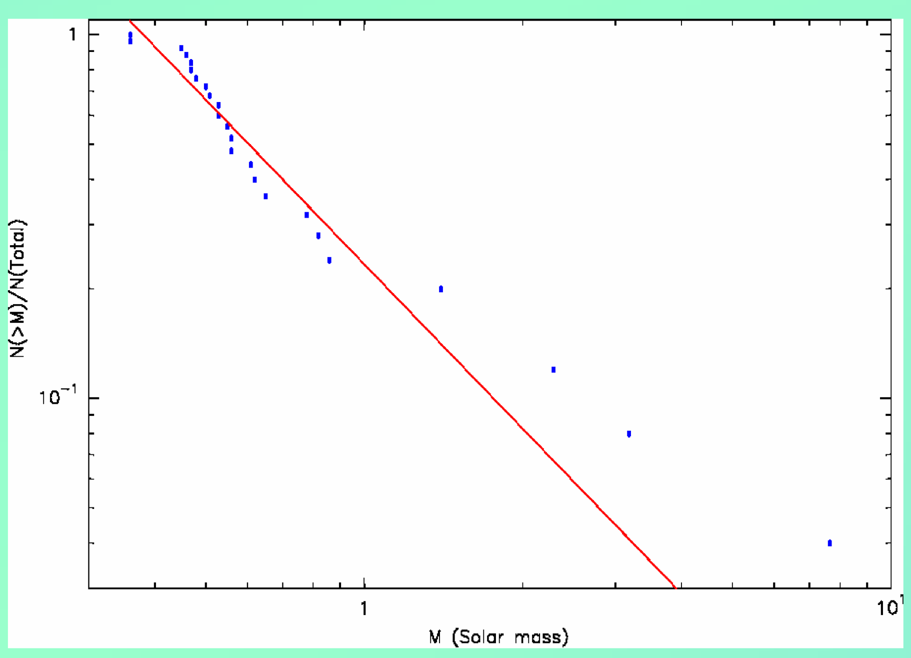

Figure 3: Cumulative core mass function (CMF) with the fitted power law for M < 1 $M_{\odot}$. The fit corresponds to N(>M)/N(Total) ~ $M^{\alpha+1}$ with α = -2.5 ± 0.2

Open Questions

The preliminary results shown leave some questions to be answered.

- The cumulative CMF shows a steep slope, while its massive-end flattens. That CMF was made assuming an uniform temperature for the cluster, thus introducing an uncertainty on the slope. Then, is the actual shape of the cumulative CMF real, indicating the presence of just a few very massive objects and several less massive? Or is it just a product of the temperature estimate and after a more accurate temperature structure is calculated it will flatten on the lower-mass end and steepen in the high mass end?
- We see that more than 90% of the dust mass emission, contained in large-scale structures, has been filtered out by the interferometer. We suspect that some of this large-scale structure will be accreted to form the final stars but, does each core have its own mass "reservoir"? Or the mass "reservoir" is shared among all the sub-sources, being determined to which will be accreted by competitive mechanisms?

These are just some questions that will be answered after we obtain the single-dish H_2CO observations scheduled for November 2007, and further analyze the remaining available data.