Far-infrared selected high-mass cores and protostars

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Overview

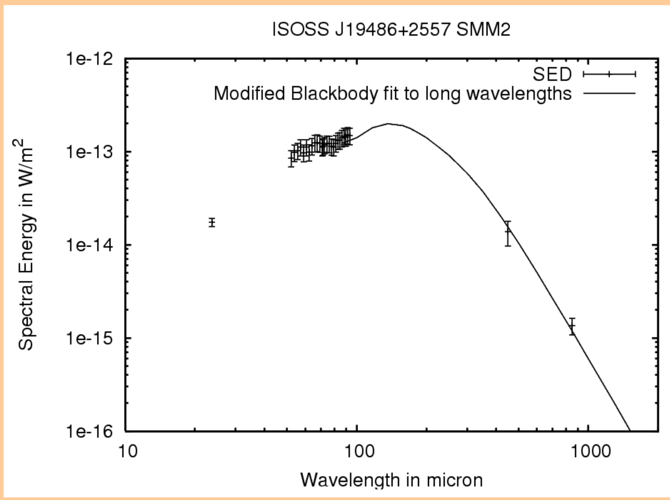
The far-infrared continuum is excellently suited to detect very young high-mass cores: Due to their very low temperatures such objects are expected to radiate most of their emission in the thermal dust continuum beyond 100μm. The 170μm ISO Serendipity Survey was the first large-scale sky survey beyond the IRAS limit and resulted in the detection of more than 50 cold and massive sources, presumably during the early stages of star formation.

Utilizing submillimeter mapping and Spitzer observations allows us to characterize the cores in detail: Cold dust temperatures of 20 K and less, masses of tens to hundreds of solar masses and we can distinguish between rather prestellar objects and deeply embedded protostars detected at 24μm. Additional molecular line observations reveal infall signatures of an early collapse as well as outflow activity.

Prime examples are submillimeter cores in the ISOSS J23053+5953 and ISOSS J18364-0221 regions which may represent the youngest high-mass protostellar cores observed so far. They feature infalling envelopes and molecular outflows confirmed by high-resolution interferometry. These observational findings support the scenario of accretion to build up high-mass stars.

Star formation properties in five ISOSS regions

These regions harbor one to four submillimeter condensations each. To derive the dust temperature of the cold dust component, which gives rise to the long-wavelength emission, we fit a Planck curve (Dust opacity κ_{1mm} = 1 cm²/g) to the submillimeter and far-infrared fluxes of each core. This results in a mass estimate for the cold gas (gas-to-dust mass ratio 100).

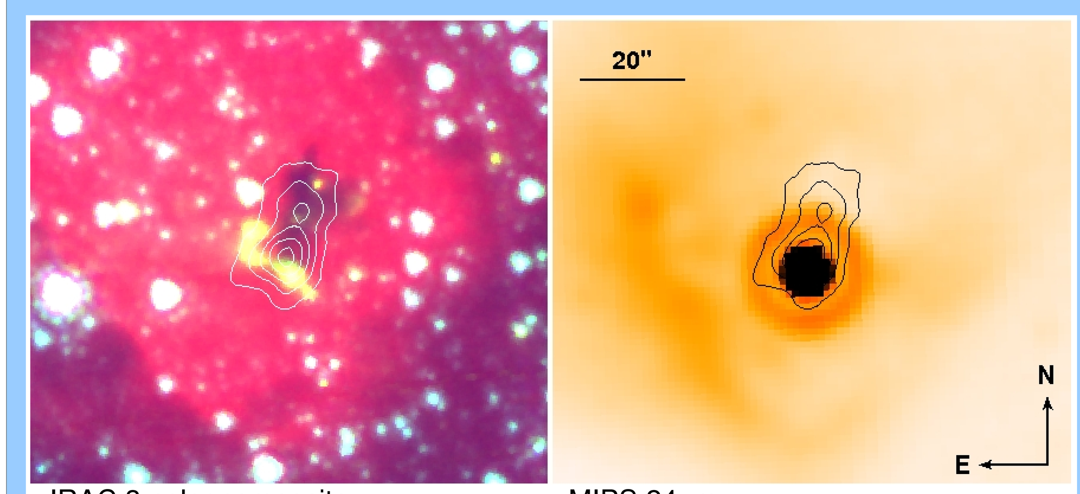


Region ISOSS...	Distance (kpc)	Core	Fluxes (Jy) 70μm	450μm	850μm	T_D (cold component)	M_{gas}	Projected Diameter (pc)
J19357+1950	4.0	SMM1 North	3.3	2.1	0.6	16 K	210 M_{sun}	0.6
		SMM1 South	0.6	1.2	0.2	15.5 K	110 M_{sun}	0.6
		SMM1 South-West	0.2	1.8	0.4	14 K	230 M_{sun}	0.6
J19486+2557	2.9	SMM1	<0.15	2.1	0.6	11.5 K	250 M_{sun}	0.4
		SMM2	2.7	2.1	0.4	16 K	90 M_{sun}	0.25
		SMM3	7.4	4.0	1.0	16 K	200 M_{sun}	0.45
J20153+3453	2.0	SMM1	12.7	12.7	3.5	15 K	390 M_{sun}	0.5
J20298+3559	1.8	SMM1	1.7	1.3	0.2	17 K	18 M_{sun}	0.2
		SMM2	1.1	0.3	0.1	19 K	9 M_{sun}	0.2
		SMM4	0.4	3.3	1.0	12 K	130 M_{sun}	0.4
J22478+6357	4.1	SMM1 East	0.8	1.7	0.8	14 K	330 M_{sun}	0.5
		SMM1 West	0.7	2.3	0.4	15 K	220 M_{sun}	0.5

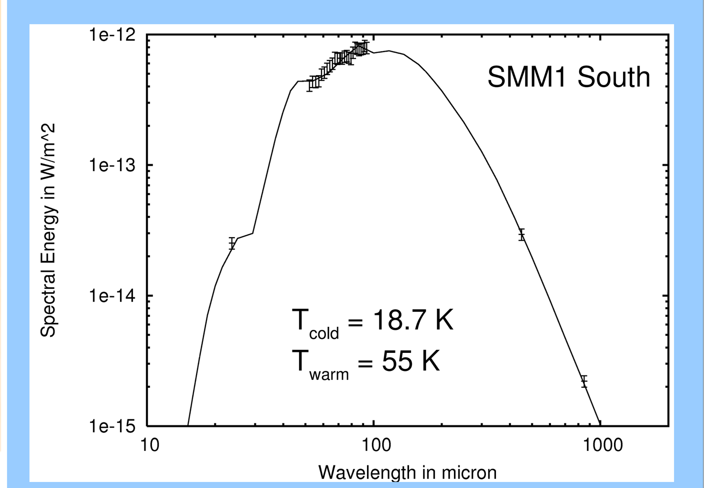
Towards a number of these cores, we detect 24μm sources coinciding with the submillimeter emission. Those unseen in the optical are best candidates for young protostars embedded in their parental molecular cloud core.

ISOSS J18364-0221

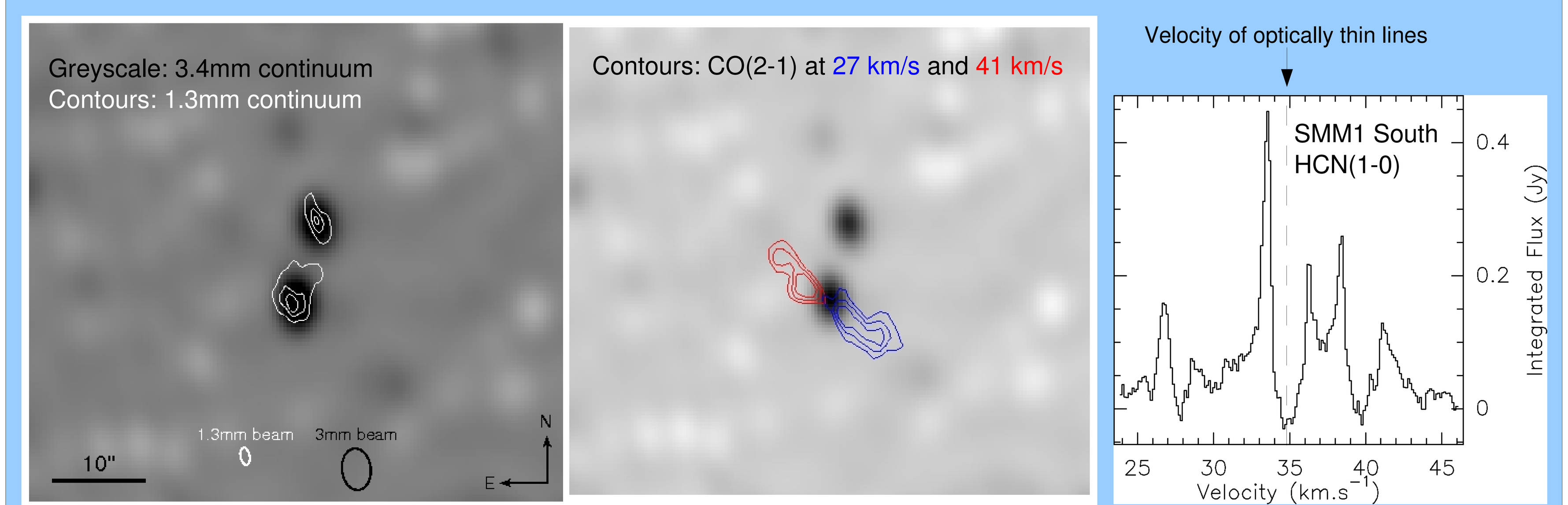
This source is located at a distance of ~2.2kpc. It harbors a submillimeter core SMM1 which is resolved in two components separated by 9". The submillimeter emission is coinciding with absorption at 8μm in the IRAC image. Outflows are traced by the 4.5μm IRAC band excess. A far-infrared point source is associated with the southern component, the northern shows no counterpart.



IRAC 3-color composite
Contours: 450μm continuum
MIPS 24μm
Contours: 450μm continuum



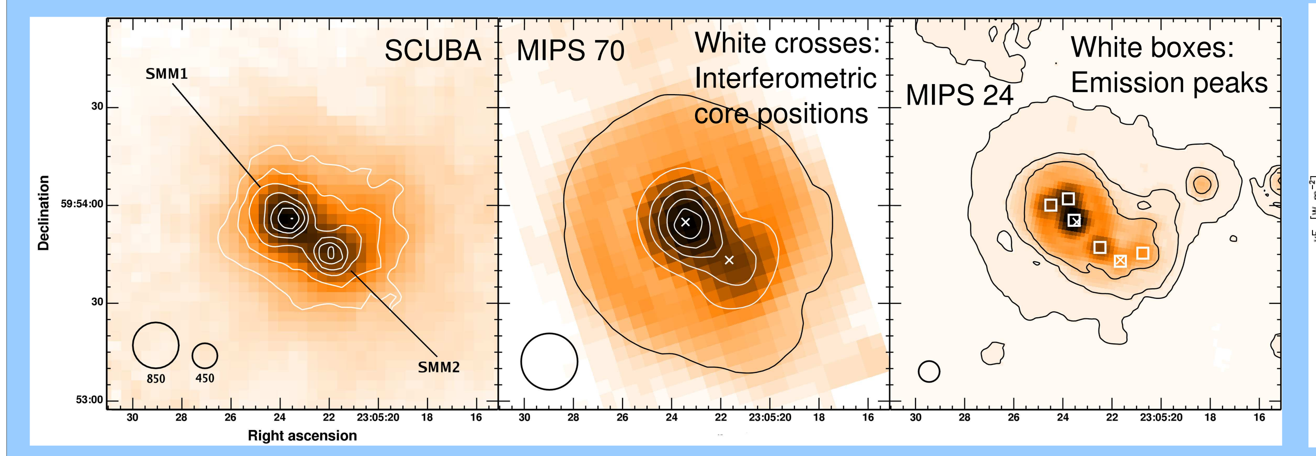
Thermal dust emission: The southern component can be fitted with M ≈ 70 M_{sun} and M_{cold} > 99% (Dust opacity κ_{1mm} = 1 cm²/g, gas-to-dust mass ratio 100). Using T_{cold} = 18.7 K also for the northern component provides M ≈ 50 M_{sun}.

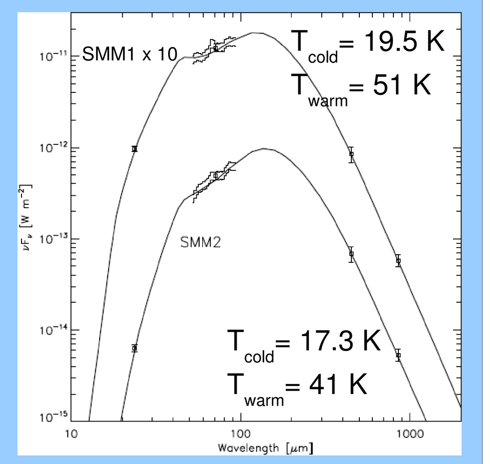


PdBI Interferometry confirms the presence of two dense cores at SMM1. At 1.3mm the core sizes are 10000 x 7400 AU (south) and 11400 x 3400 AU (north). The southern component features an outflow traced in CO(2-1). Infall motion is suggested by red-shifted self-absorption in the HCN(1-0) spectrum. Assuming T_{cold} = 18.7 K for both components, the central regions have masses of 25 M_{sun} (south) and 15 M_{sun}(north).

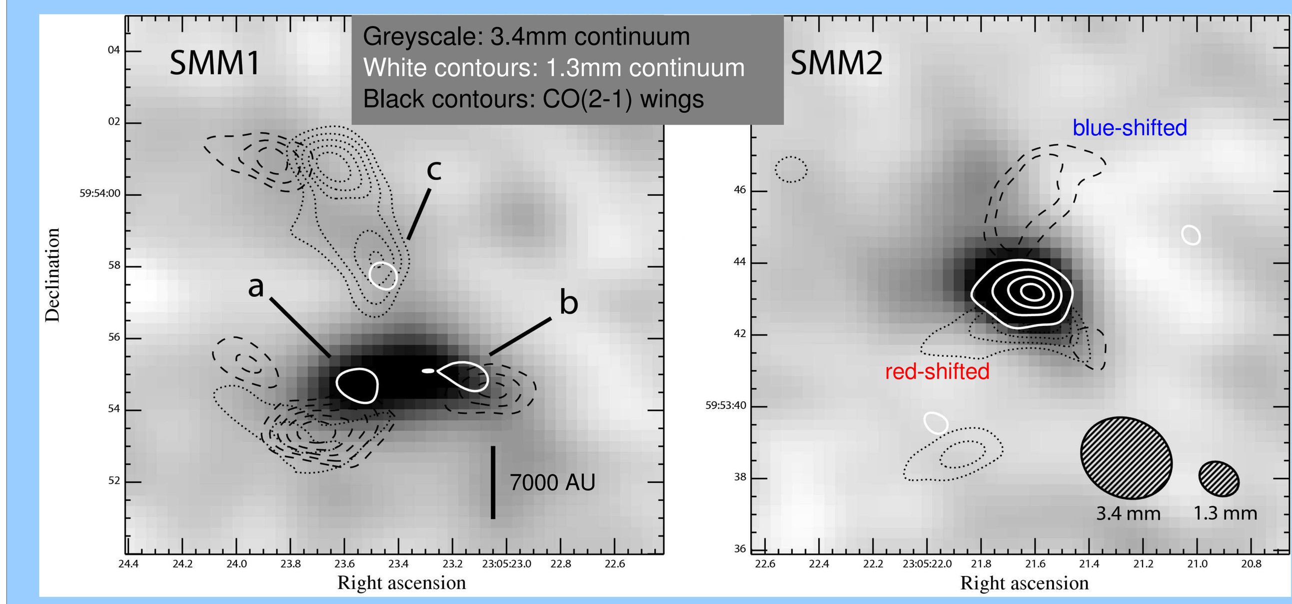
ISOSS J23053+5953

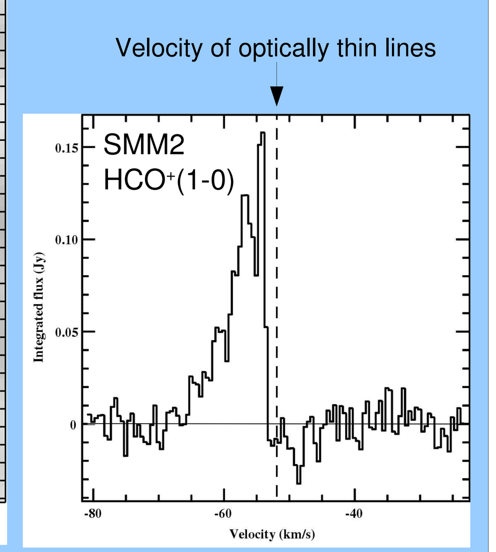
This source coincides with IRAS 23032+5937. It is located at a distance of ~3.5kpc towards the Cepheus molecular cloud complex. The total gas mass from $C^{18}O(2-1)$ emission is M_{H_2} ≈ 1000 ± 200 M_{sun}. We find two submillimeter cores separated by 17". Six emission peaks at 24μm trace protostellar objects.



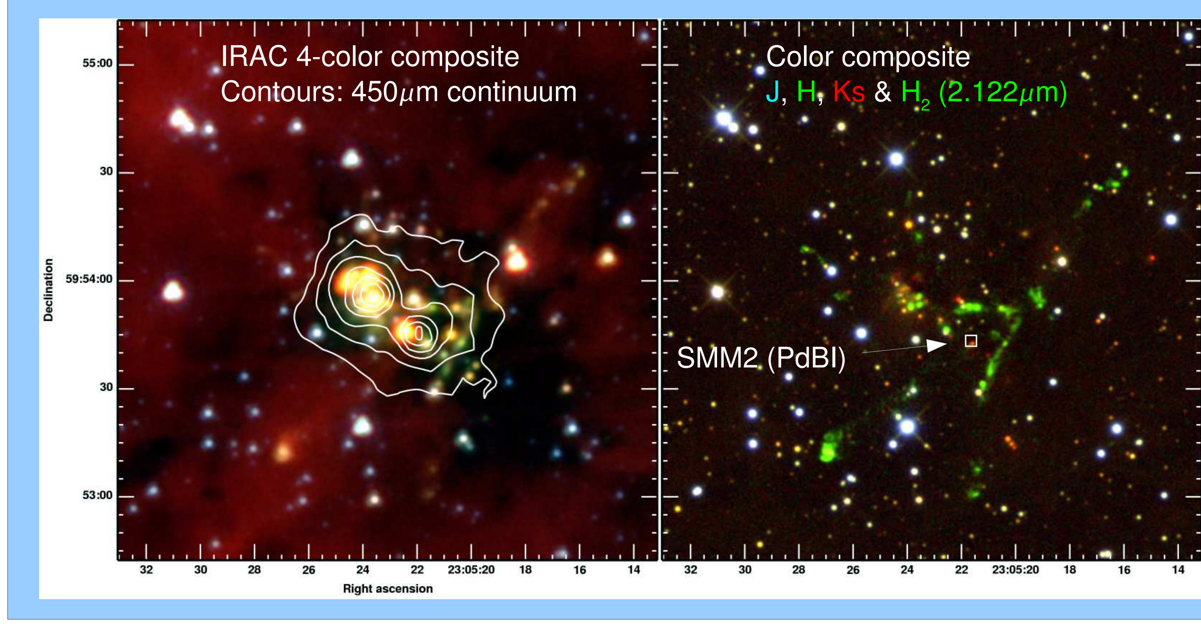


Thermal dust emission: Two Planck components fitted to each core gives M ≈ 200 M_{sun} and M_{cold} > 99% (Dust opacity κ_{1mm} = 1 cm²/g, gas-to-dust mass ratio 100).





PdBI Interferometric observations reveal 2-3 components of SMM1 and partly resolve SMM2: 8750 x 5600 AU. SMM2 features a possible outflow. HCO⁺(1-0) shows red-shifted self-absorption which suggests infall motion. Assuming T_{cold} the central core region of SMM2 has a mass of 26 M_{sun}.



Near- to mid-infrared view: Several young stellar objects and outflows are detected. The source close to SMM2 is not consistent with being a stellar or T Tauri counterpart and is rather not embedded centrally.

Conclusions and Summary

From the analysis of the long-wavelength SEDs of the submillimeter cores found in several ISOSS star-forming regions we can confirm the cold dust temperatures below 20 K first derived from the ISO and IRAS measurements. The masses of the cold gas and dust components range from several to hundreds of solar masses and the core sizes are up to 0.6 pc which implies that a number of them should be able to form high-mass stars and accompanying clusters.

The mid-infrared sources found towards submillimeter cores suggest that the affected cores are actively producing a multiplicity of stellar objects. But we also find a number of cores that seem to be in a very early stage of evolution.

Using observations with high spatial resolution we can confirm this for cores in ISOSS J18364-0221 and J23053+5953. In both regions we find promising candidates for cores that form massive stars. Especially the northern component of SMM1 in ISOSS J18364-0221 without infrared counterpart can be interpreted as prestellar object, while the southern component and SMM2 in ISOSS J23053+5953 represent two of the first examples for very young protostellar cores whose emission is dominated by massive infalling envelopes. The presence of outflows suggests that accretion plays an important role in the assembly of high-mass stars.

Our results show that the initial search for early stages of high-mass star formation in the far-infrared is successful when combined with multi-wavelength follow-up observations. This lead to the discovery of very promising candidate objects, and far-infrared missions like Akari and Herschel provide excellent possibilities to extend our strategy in the near future.

References

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