Testing models of YSO envelopes with submillimeter continuum and line observations

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Theoretical models make definite predictions about the density and velocity structure of protostellar envelopes. Here we test a particularly popular model, the inside-out collapse model of Shu (1977: ApJ, 214, 488), by analyzing submillimeter-continuum observations obtained with SCUBA on JCMT of four embedded YSOs in Taurus, and making comparisons to molecular-line observations.

The images show centrally concentrated cores with radii of 2000–12,000 AU and masses of 0.02–2.0 $M_\odot$, in addition to more extended emission.

We fit two models to the density structure: **(a)** a power-law distribution, $\rho \propto r^{-p}$, and **(b)** the inside-out collapse model. For the dust emissivity we assume $\kappa = 0.1(\nu/10^{12}\ \mathrm{Hz})^\beta$ cm^2 g^{-1} (dust). Best-fit parameters from χ^2 minimization are:

Source	$R_{\rm out}$ (AU)	M ($M_\odot$)	p	a (km s^{-1})	t (yr)	β
L1489 IRS	2000	0.017	2.02	0.43	2×10^6	1.2–1.6
L1535 IRS	8000	0.1–0.2	1.74	0.29	8×10^5	1.0–1.7
L1527 IRS	8000	2.0	0.91	0.40	8×10^4	1.8
TMC 1	12,000	0.6	1.23	0.20	5×10^4	1.5

We test the parameters derived for the inside-out model by comparing molecular-line profiles as predicted by these *same* parameters to observations of ^{12}CO, ^{13}CO, C^{18}O, HCO$^+$, and H^{13}CO$^+$ from Hogerheijde et al. (1997: ApJ, 489, 293; 1998: ApJ, 502, 135). The model can explain the line observations of L1527 IRS and TMC 1, if $T_{\rm kin} \approx 0.67 \times T_{\rm dust}$ and CO is depleted by a factor of 10 when $T_{\rm kin} < 20$ K. An HCO$^+$ abundance of 2–7$\times10^{-9}$ is found. Alternatively, changing the dust emissivity or the gas:dust ratio may also aid the agreement between the two tracers, yielding different values of a but similar values for $r_{\rm CEW}$. The results for L1535 IRS are uncertain due to the low signal-to-noise of the continuum image.

The lines of L1489 IRS cannot be fit with the collapse model. Instead, its compact size of 2000 AU, its bright near-infrared emission, and interferometer results (Hogerheijde et al. 1998), suggest a different model for this source: a young star surrounded by a 2000 AU radius, 0.02 $M_\odot$ rotating disk, obscured at visible wavelengths by its near edge-on orientation. Possibly, L1489 IRS represents a transitional phase between a fully embedded Class I object and an optically revealed T Tauri star.

To summarize: we find that the collapse model of Shu (1977) can offer a satisfactory description of the envelopes around embedded YSOs. However, continuum or line observations *alone* do not give a unique solution. Ideally, the density, temperature, and velocity structure should be measured independently to allow a fiducial comparison to models.

In addition to the YSO envelopes, the observations reveal two cold cores within 10,000 AU of L1489 IRS and L1535 IRS. Their temperatures are 10–15 K, their masses range between 0.5 $M_\odot$ and 3.0 $M_\odot$, and their density follows a Gaussian rather than a power-law distribution. All this indicates that these cores have not (yet) formed stars. Apparently, even in Taurus star formation in truly isolated cores is rare.

Finally, we predict the spectral energy distribution of these four YSOs, and the two adjacent starless cores, at far-infrared wavelengths (30–300 μm). With its sensitivity and spatial resolution, SOFIA is expected to make important contributions in characterizing the continuum emission from the warm (> 25 K) regions of the envelope where the molecular emission originates.

For further information `http://astro.berkeley.edu/~michiel/pr/sofia/sofia.html`

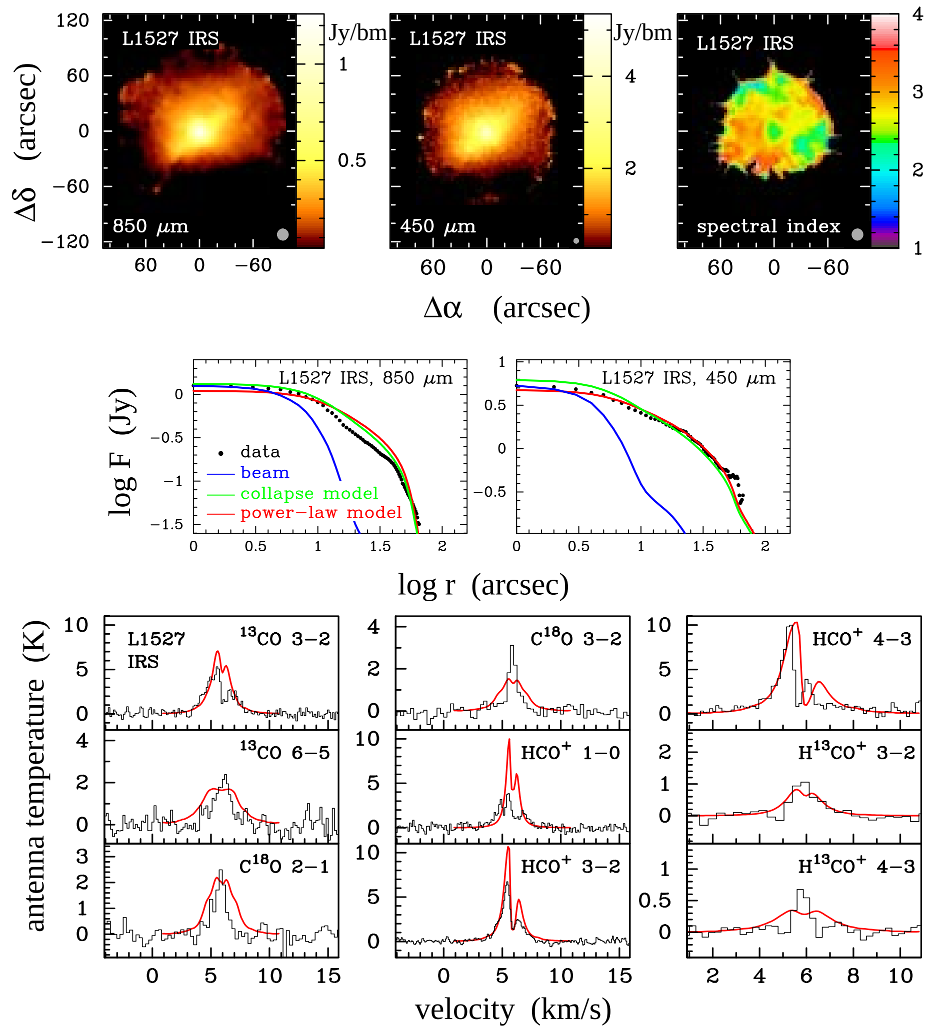

Illustration of the observations and analysis of L1527 IRS. The 850 and 450 μm are shown on top, together with the spectral index between these two wavelengths. The radial emission profiles are plotted in the middle with the best-fit models. At the bottom the observed spectra are compared with the line profiles predicted by the best-fit collapse model for the parameters derived from the continuum observations.