Determining Protostar Masses: L1527 IRS in Taurus

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Abstract

We report on a pilot study to determine the mass of the L1527 protostar using CARMA interferometer data. The velocity channel maps are compared with a model that incorporates 1) LVG radiative transfer,
2) TSC collapse envelope and outflow cavity, and 3) a CARMA interferometer simulation. The model is first applied to C18O(2-1) observations.

Introduction

The masses of protostars and their mass infall rates have been difficult to determine. This is in part due to the complex structure of envelope and outflow.

High spectral resolution data are key to determining the gravity field, and thus the central mass of the protostar. Also, the typical spatial resolution of roughly 5′′ = 700AU (at 140 pc) of interferometers is well suited to studying the envelope structure 70′′ = 10, 000 AU for an envelope-dominated class 0 or I source. However the modeling of optically thick line emission detected by interferometers is nontrivial. In this investigation our goal is to produce realistic radiative transfer models that can be compared directly with interferometric velocity channel maps.

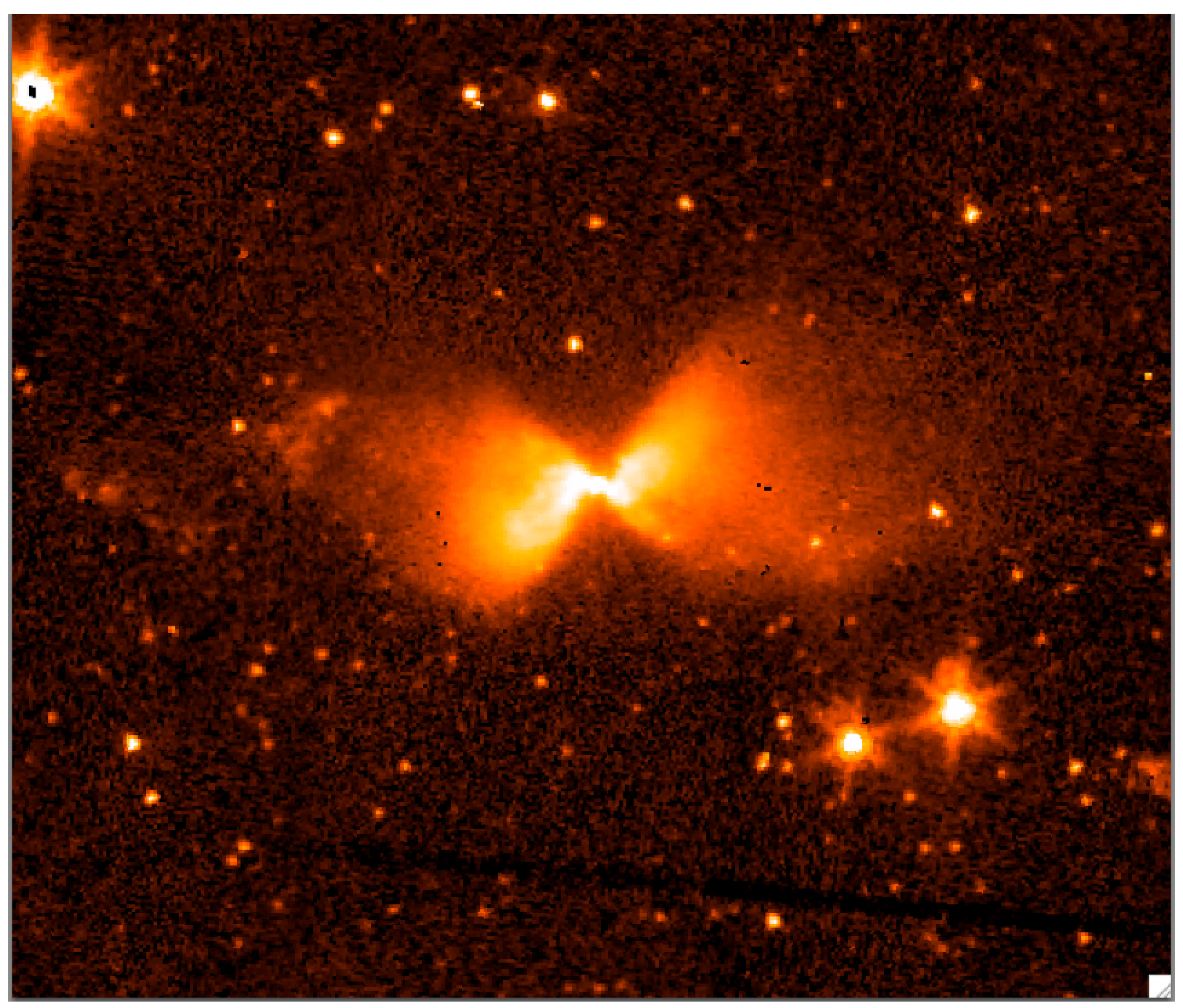


Figure 1. The embedded protostar L1527 IRS, hereafter L1527 (IRAS 04368 + 2557) is a well known class 0/I source that has been the focus of many studies. The approximately 2L⊙ source is located at 140 pc in the nearby Taurus star-forming region (Torres et al. 2007; Furlan et al. 2008; Tobin et al. 2008, 2012). Very Large Array (VLA) observations at 7 mm wavelength demonstrate the source is a binary with 0.17′′ projected separation (Loinard et al. 2002). L1527 exhibits an East-West bipolar outflow that is seen nearly edge-on. The Spitzer IRAC 4.5 µm image above shows reflection nebulosity that outlines the outflow cavity. The outflow lobe extends well outside the imaged region: knots of 8.0 µm shock emission extend out to 4′ from the source (Tobin et al. 2008, 2012).

Data

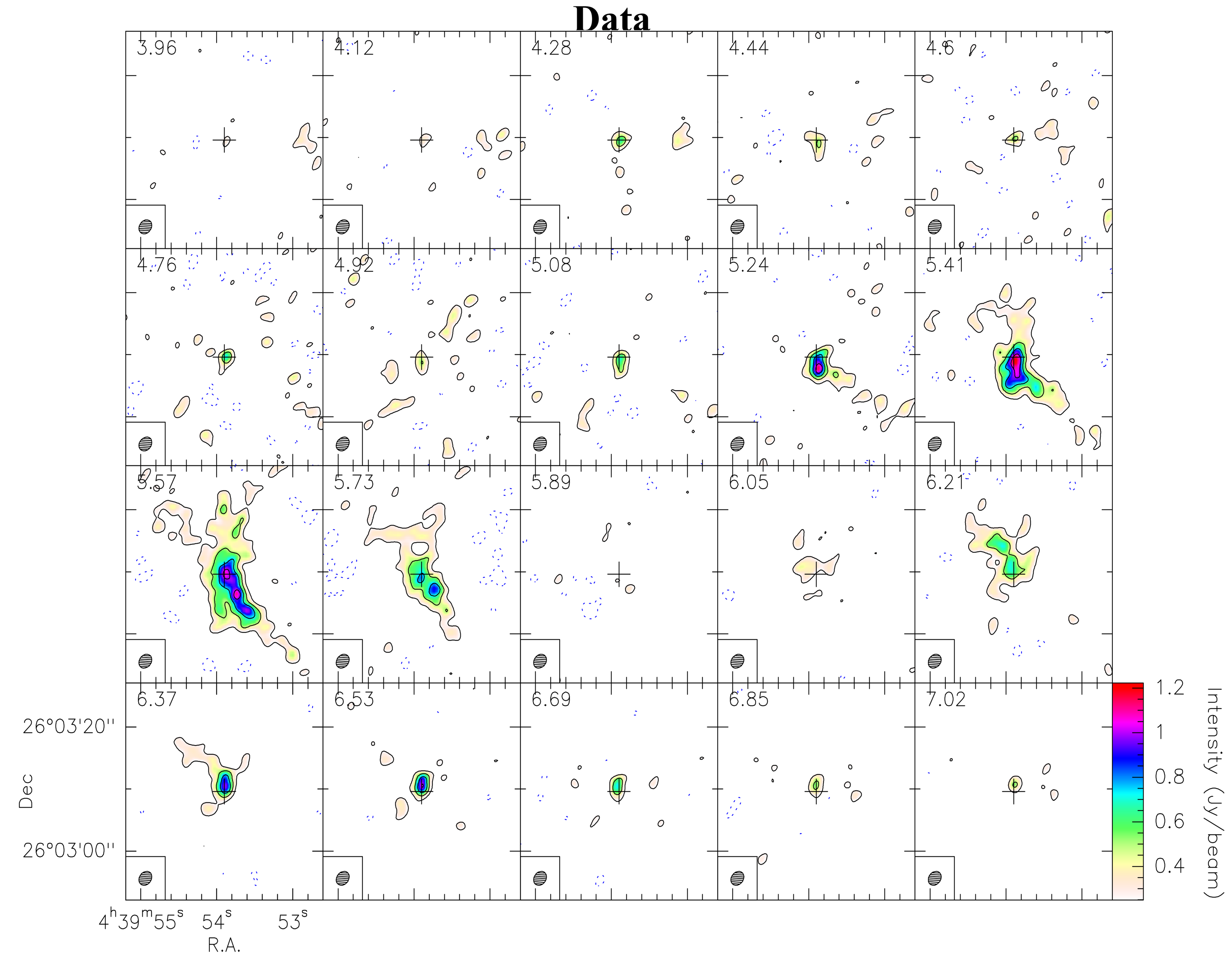


Figure 2. C18O velocity channel maps. YSO position indicated by + symbol. Channels near line center (v = 5.95km/s) appear blank, implying the emission is optically thick and resolved out by the interferometer. Structure of extended emission suggests a flattened envelope in north-south direction.

Model

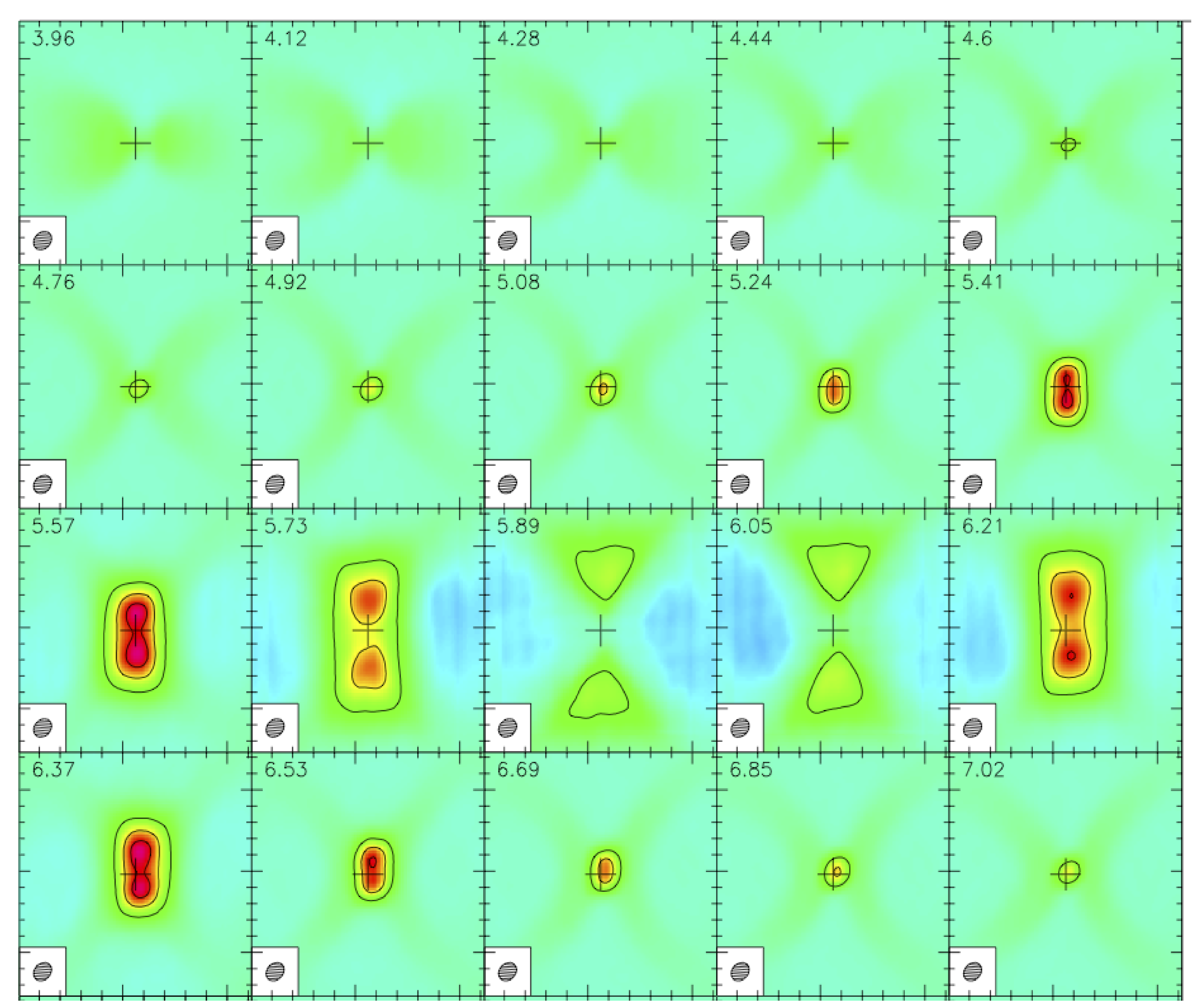
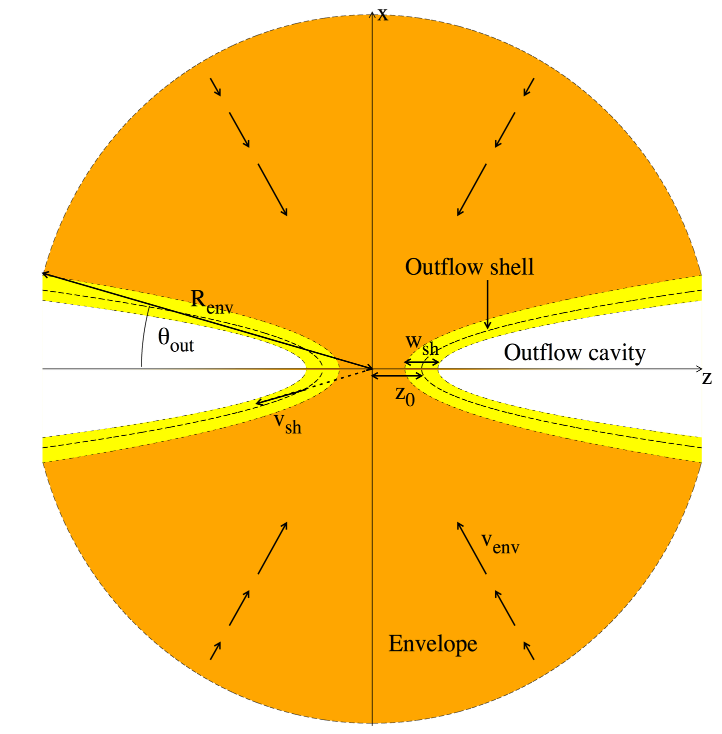


Figure 3. Best-fit C18O model reproduces main features of the data using M_*=0.24 Mo. The emission is spatially extended north-south over roughly 20 arcseconds at velocities within 1 km/sec of line center. Panels are 30" across.

Model description



Density distribution:

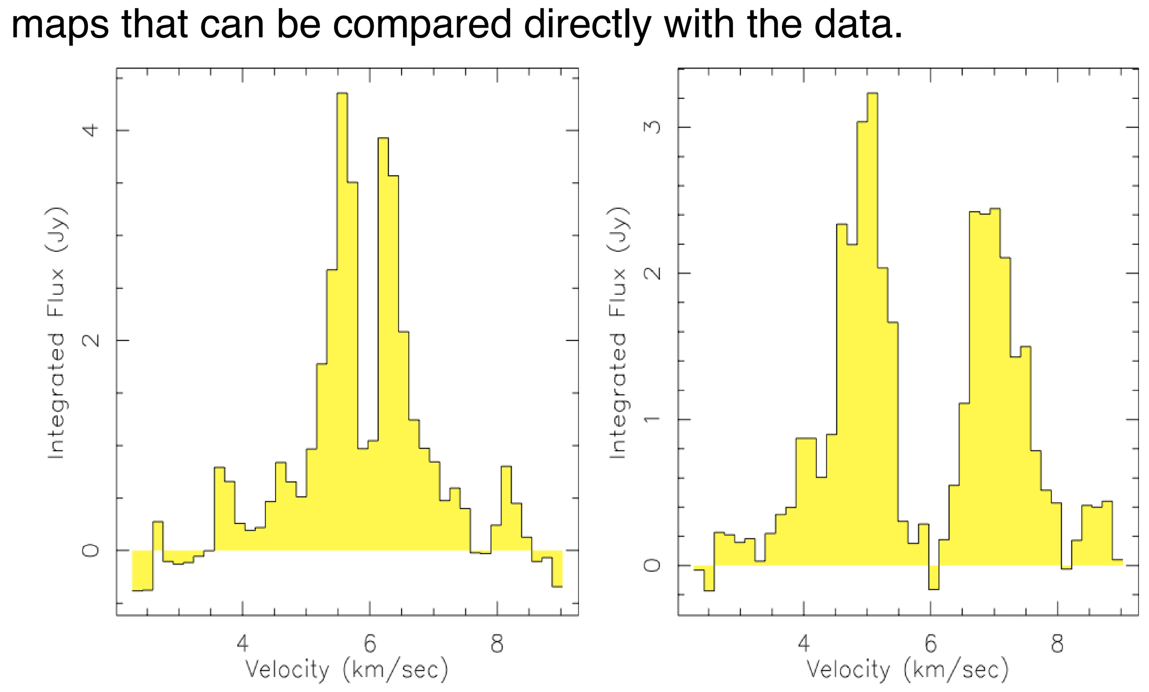
Is the TSC collapse model, also called the infall envelope (Terebey, Shu, and Cassen 1984). Bipolar outflow is modeled as an empty cavity with emission from a thin shell offset from the star, and having constant velocity in the outward radial direction. There is no disk component in this version of the model.

Radiative transfer:

Constant excitation temperature is assumed for the outflow shell (Tex ~ 50K) and infall envelope (Tex ~ 10-25K). Level populations are solved for assuming the LVG approximation, for a variety of linear molecules. The C18O(2-1) transition is presented here.

CARMA simulation:

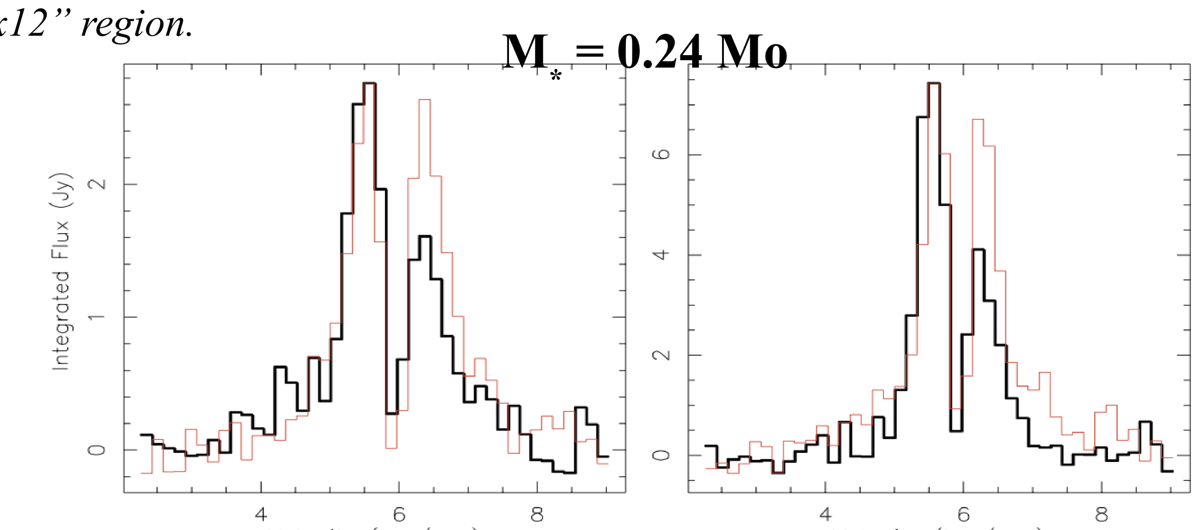
The model emission cube of T_{R^*} versus velocity is "observed" by the CARMA simulator. A primary beam correction is applied, UV sampling from the observed data is applied, and noise is added to produce simulated channel maps that can be compared directly with the data.



M_* = 0.1Mo **M_* = 0.6Mo**

Figure 4. Model C18O spectra ***above*** *illustrate that the models are sensitive indicators of central mass. The model line width depends only on the interior mass. Models with M_* = 0.1 Mo and M_* = 0.6 Mo are ruled out by the C18O data.* ***Below****, data (black) and best-fit model (red) with M_* =0.24 Mo are shown. Left panel shows emission integrated over 4"x6" region. Right panel shows larger 8"x12" region.*

M_* = 0.24 Mo



Summary

The models are able to reproduce observed C18O channel maps well, and are sensitive to the gravity field of the **infalling** gas. **The best-fit mass is 0.24 +/- 0.04 Msun for the L1527 protostar plus disk**. This compares favorably with the 0.22 Msun found by Tobin et al 2012 in their analysis of the disk emission. Investigation of model parameters indicates that line-width is a sensitive and robust indicator of mass. We conclude that comparing millimeter interferometer data with infall models incorporating radiative transfer shows promise for determining a fundamental but poorly known quantity, the protostar mass.