TRACING PROTOSTELLAR EVOLUTION USING GAS KINEMATICS

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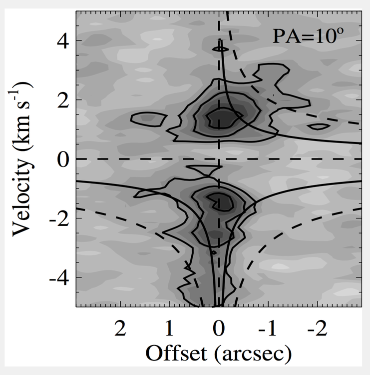
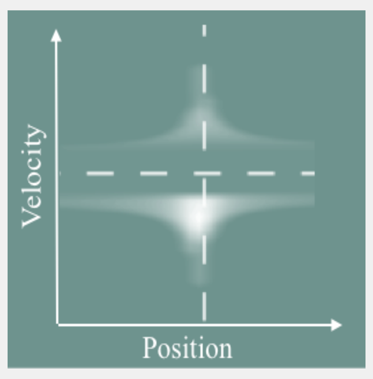
Introduction

This poster presents a method to determine the evolutionary stage of a protostar based on the topology of the velocity field in the gas that surrounds it. By comparing the velocity field of an observed protostellar environment to the velocity fields of an ensemble of simulated protostars, it is possible to determine the age of the observed protostar. Because the simulation contains so many stars, it is possible to statistically look at the evolution in different mass bins, in different types of environment or at stars with different multiplicity.

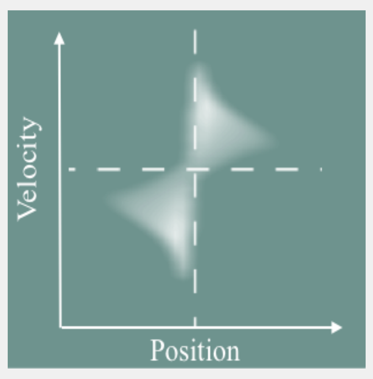
Infall vs rotation

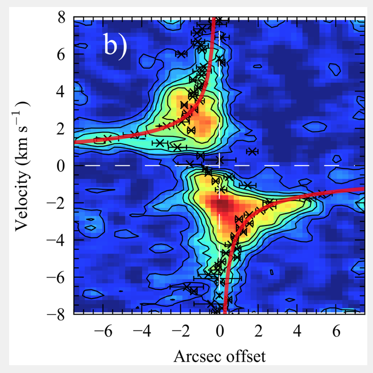
The basic assumption of our method is that protostars experience an initial collapse phase where gas moves predominantly along radial trajectories and ends up with a fully Keplerian disk with rotational motions only and no infall. The motion of the gas is reflected in the spectral profiles and the two distinct regimes, infall and rotation, show characteristic patterns in the PV - diagrams. When the gas is infalling, the PV-diagram is symmetric around the x-axis and shows a slight asymmetry around the y-axis, whereas in the case of pure rotation, the PV-diagram shows the well known butterfly pattern. We use a model, introduced in [1] which parametrizes the velocity field as the ratio of infall to rotation. We can fit this model to the PV-diagram.





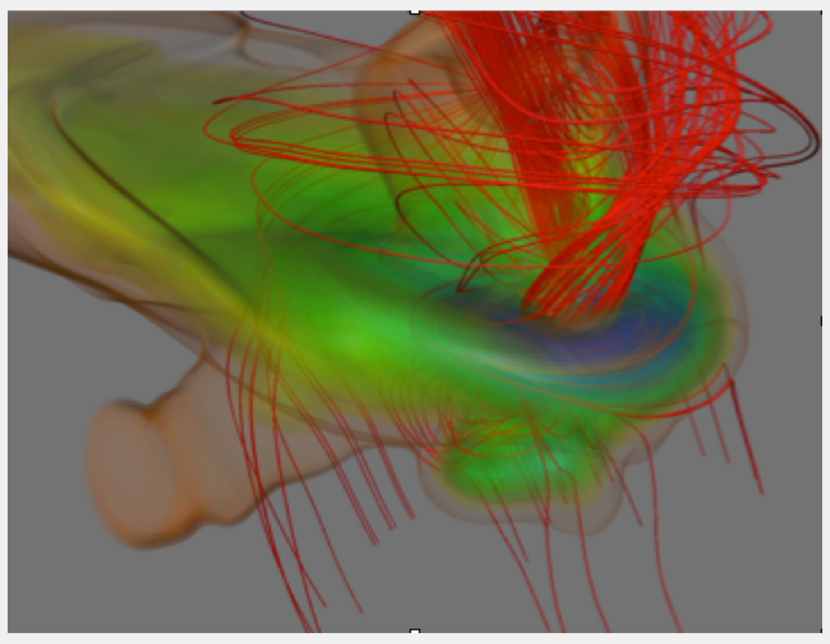
Example PV-diagrams.
Left: typical infall signature [2].
Right: typical rotation signature



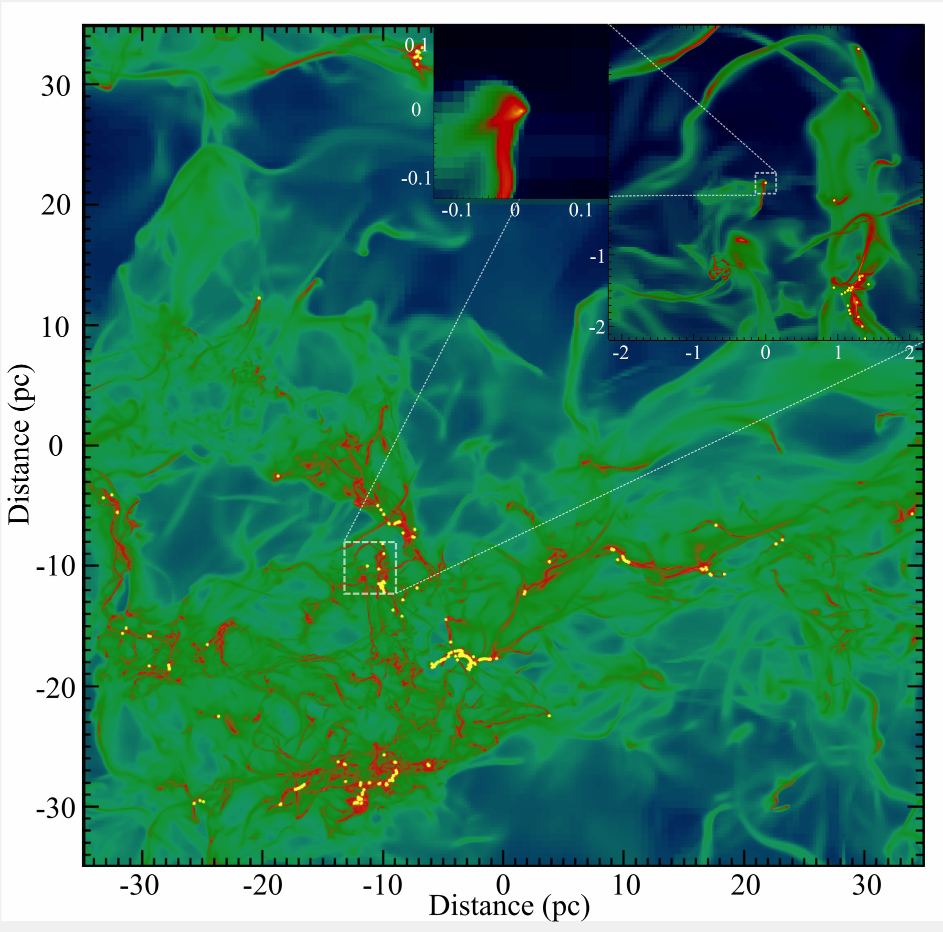


Numerical modeling

A large scale dynamical star formation simulation done with the RAMSES code is used to create a library of simulated protostars. The simulation spans up to a hundred parsec and several hundred thousand years in time. It produces several tens of thousands protostars. Using AMR techniques each protostellar object is resolved down to a scale of ten AU.
For more information on this simulation, see posters by Frimann (1H009), Haugbølle (1H004), Küffmeier (1H003), and Nordlund (1H002).



Left: a rendering of density iso-surfaces around a protostar from the RAMSES simulation. The red lines are gas stream lines. This is a relatively evolved object with an age of a few hundred thousand years.

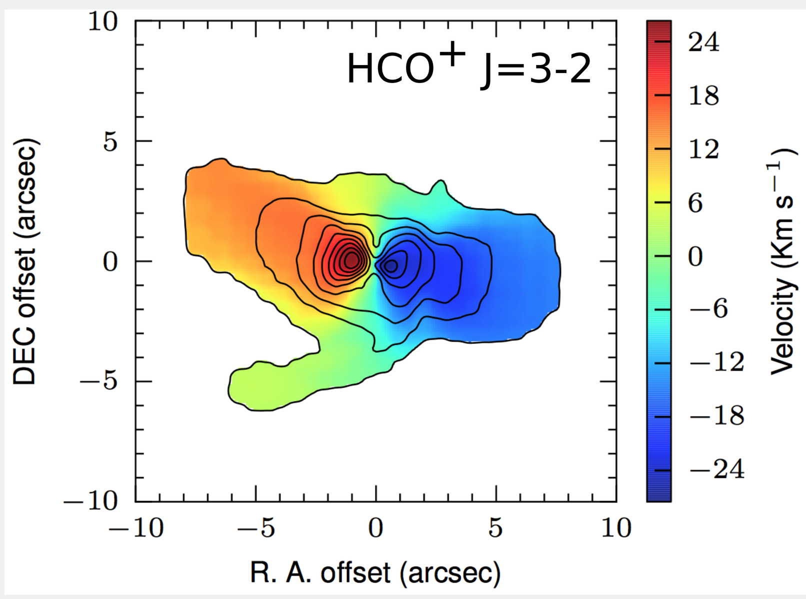


Left: an illustration of the dynamical range in the RAMSES simulations, with a zoom-in from GMC scales to a single solar mass star.

Below: a moment map of the same object after radiative transfer calculations using the LIME code. The image below is in a typical ALMA resolution at 100 pc.

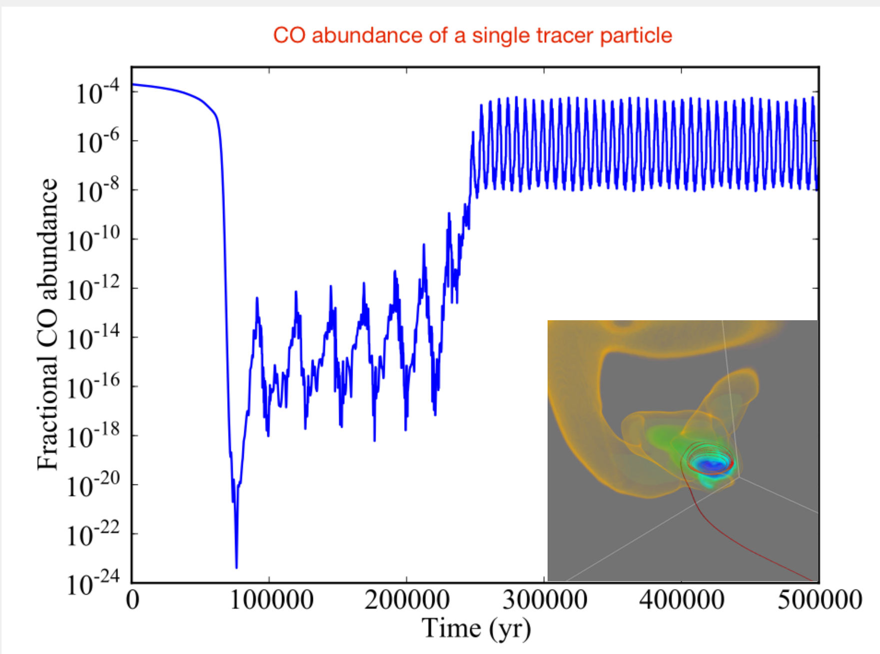
Mock observations

Individual protostars are selected from the simulation and post-processed using radiative transfer tools to create simulated observations. First, the temperature profile is calculated using RADMC-3D [4] and then molecular excitation and line radiative transfer is done using the LIME code [5]. The velocity model (described in the box above) can be fitted to the resulting data cube, just as if it was observations of a real protostar. Contrary to real protostars however, the simulated objects can be followed in time and "observed" from different directions. A huge database of velocity fields in time can be made this way.



Chemical abundances

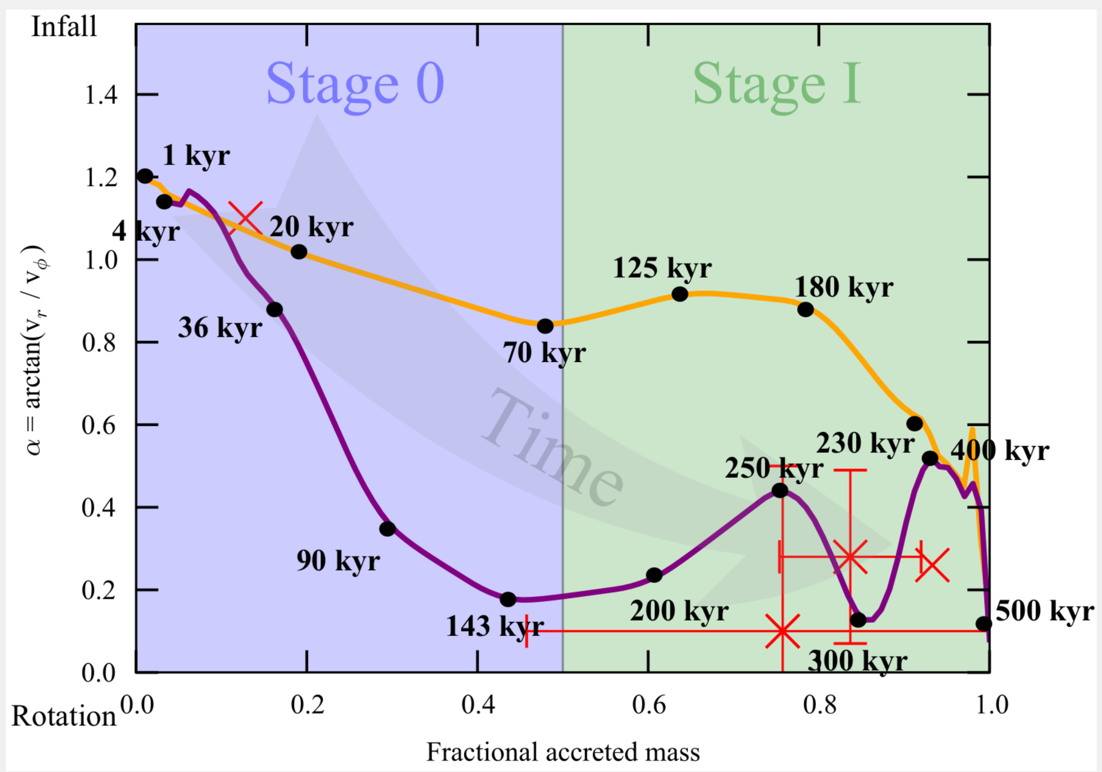
Using tracer particles in the RAMSES code, chemical depletion can be tracked by solving freeze-out and desorption rate equations in time as the tracer particles moves with the gas flow through changing density and temperature conditions. Accurate chemical abundances are needed by the LIME code in order to predict the spectral signature. This scheme can be expanded to include gas-phase reactions between species as well.



Left: the abundance history of a single tracer particle as it falls into the disk. The trajectory is shown by the red curve in the inserted rendering.

Protostellar evolution

The fitted velocity field parameter can be plotted as function of fractional accreted mass. In this diagram, protostars are assume to emerge in the top left corner, with pure infall and no stellar mass and enter the T Tauri stage at the bottom right corner in pure rotation and all the mass in the star.
In the plot to the right is shown four real protostars (red crosses) and two different simulated protostars drawn from the RAMSES simulation. The two protostars differs only by one evolving inside a filament (orange) and the other being relatively isolated (purple).
By populating this diagram with data points from observed protostars, it is possible to compare their distribution to the distribution of tracks from the simulation and thereby derive reliable ages.



Above: this diagram shows the evolution in time of the velocity field of two simulated protostars. Also shown are four observed protostars (red crosses).

References

[1] Brinch, Hogerheijde, Richling, 2008, A&A, 489, 607
[2] Brinch, Jørgensen, Hogerheijde, 2009, A&A, 502, 199
[3] Brinch and Jørgensen, 2013, submitted
[4] http://www.ita.uni-heidelberg.de/~dullemond/software/radmc-3d/
[5] Brinch and Hogerheijde, 2010, A&A, 523, 25

Scan the QR code for a copy of this poster

Need a new radiative transfer code?

LIME

The LIME code is a full 3D molecular excitation and line radiative transfer code with support for dust polarization, line blending and arbitrary geometry input models. It handles a large dynamic range in spatial scales which makes it well suited for ALMA modeling.

Copies of LIME can be downloaded from http://brinch.eu/limeforum or by scanning the QR code to the right.