First steps toward 2D time implicit hydrodynamical simulations of accretion process in very young low mass star objects.

Chris Geroux [1, @] , Isabelle Baraffe [1, @]

1 : College of Engineering , Mathematics and Physical Sciences [Exeter] - ***Website***

Prince of Wales Road Exeter, Devon EX4 4SB - United Kingdom

Recent calculations based on 1D stellar structure calculations have shown that episodic accretion can significantly affect the structure of very young low mass stars and impact their evolution even after a few Myr. Accretion effects can produce a spread in luminosity, as observed in young clusters and star formation regions, and explain various observational features (Baraffe et al. 2009, 2012). However, these conclusions depend on very simplified assumptions regarding the treatment of accretion in 1D stellar structure calculations, namely uniform redistribution of accreted mass and energy within the accreting object's interior. Seiss & Forestini (1996) and Siess et al. (1997) prescribe a more complex penetration function based on the Richardson criterion but it is unclear how much more correct these penetration functions are. We are now investigating the effects of accretion based on 2D time implicit simulations in order to better understand such effects on the structure on very young objects. One of the goals of such a study is to provide a better description of this process to be used in 1D stellar evolution code. Our simulations are based on a multi-dimensional fully compressible, time implicit hydrodynamical code (Viallet et al. 2011), using realistic stellar input physics (equation of state, opacities). I will present preliminary results of this exploration as applied to a young, one solar mass star which is almost fully convective, using as a first step a simple accretion outer boundary condition.

Subject :	:	oral
Topics	:	Astrophysics
Topics	:	Particle acceleration
Topics	:	Numerical simulations

Accretion onto Young Low Mass Stars

Chris Geroux & Isabelle Baraffe

TOFU Team: J. Pratt, T. Goffrey, M. Viallet, M. Popov, D. Folini, R. Walder

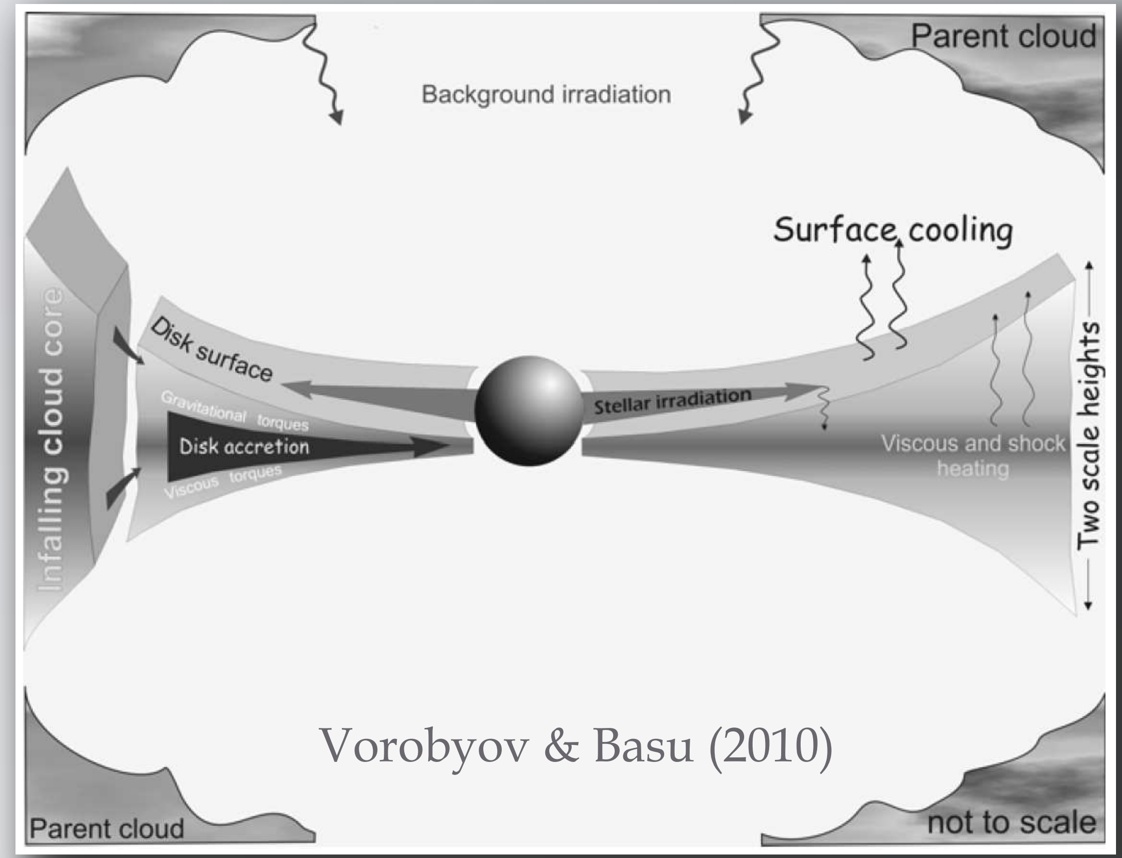
UNIVERSITY OF EXETER

European Research Council
Established by the European Commission

Science & Technology Facilities Council

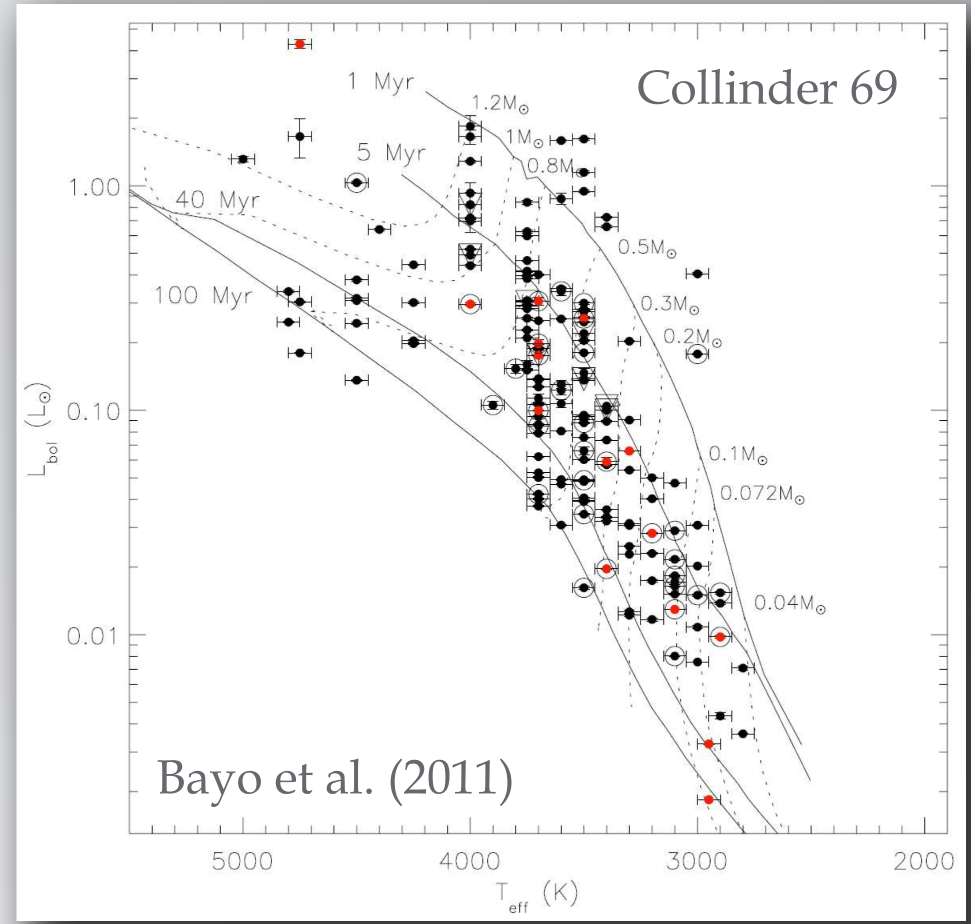
General Picture of Star Formation

- Matter falls on outer disk from cloud
- Transported to the inner disk by gravitational, viscous, and or magnetic torques
- Gravitational potential energy lost by in falling mater both heats the gas and is radiated away
- Disks fragment and lead to “bursts” of accreted material onto the central star
- Large bursts may lead to less energy being radiated away before material is accreted (Baraffe et al. 2012)
- Early evolution of stars can have a wide range of accretion histories



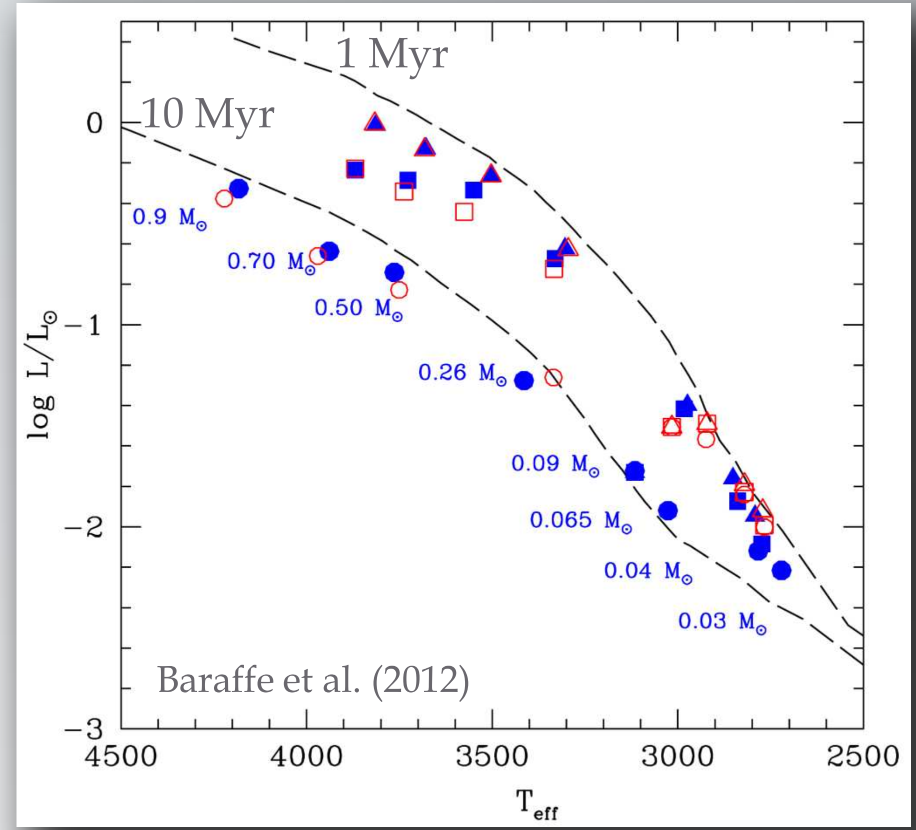
Observed HRD Spread In Young Clusters

- Young stars forming in clusters show a wide spread in HRD
- Due to an age spread?
  - An extended star formation period is in conflict with current picture of star formation and other observational constraints (Hartmann 2001; Ballesteros-Paredes & Hartmann 2007)
- Varying accretion histories can reproduce observed spread (Baraffe et al. 2009,2012)



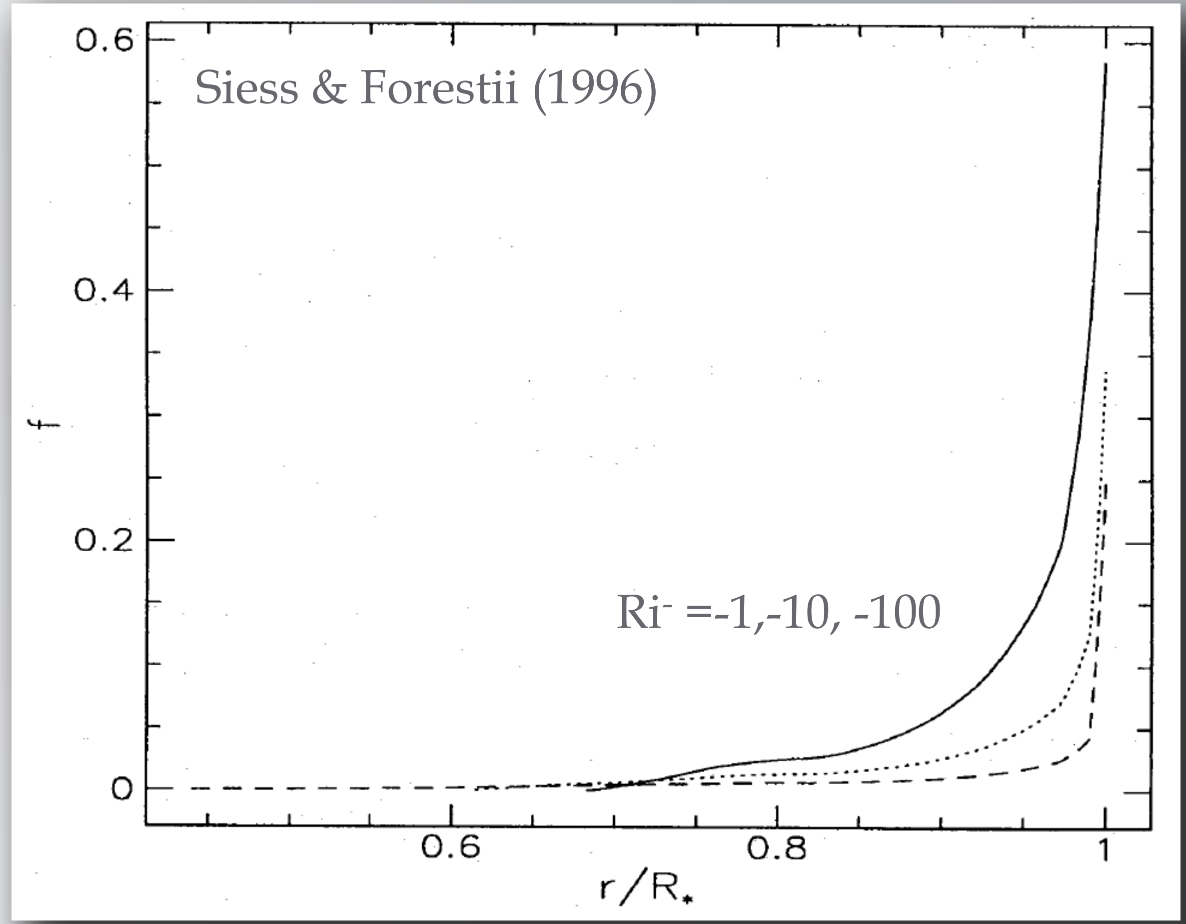
Varying Accretion Histories Lead to Differing Evolution of Young Stars

- Using simplistic accretion model with inputs guided by multi-D hydrodynamic simulations
  - Assumes instantaneous redistribution of accreted material and energy
  - Variable accretion rates from simulations
- α is the fraction of energy absorbed from the accretion material
  - Likely depends on the accretion rate
  - Likely that large accretion bursts lead to larger α
- Cold accretion (α=0)
  - More compact
  - Low accretion rates $\dot{M} < 10^{-5} M_{sun} yr^{-1}$
- Hot accretion(α>0)
  - If α large enough could cause the star to expand



A More Sophisticated 1D Accretion Model

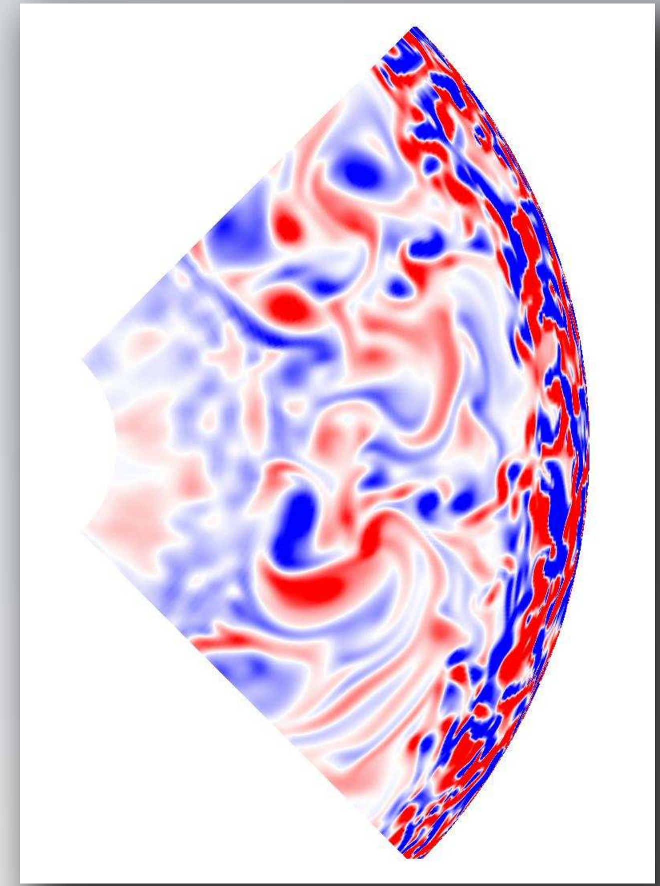
- Defines a penetration function $f(r) \equiv \frac{dm_{acc}(r)}{dm_{star}(r)}$
- Determined from the solution of a differential equation
- Kippenhahn & Thomas (1977) derived a differential equation describing f to explore accretion onto white dwarfs (SN Ia)
- Later Kutter & Sparks (1987) refined the differential equation by relaxing some previous assumptions
- Finally Siess & Forestini (1996; 1997; 1999) derive a differential equation considering gradients in mean molecular weights and applied it to young forming stars
- Depends on a number of free parameters:
  - ε^a is related to the time scale over which the accreted matter is thermalized
  - ξ is the fraction of the Keplerian angular momentum the accreting material has at the surface of the star
  - Ri^- is a kind of Richardson number for convection (small → inefficient convection, large → efficient convection)
- $M_{acc} = \int_0^{R_*} f dm_* = \dot{M}\Delta t$
- What are good values of the free parameters? How do they vary?



Siess & Forestii (1996)
Ri⁻ =-1,-10, -100
0.6
0.4
0.2
0
f
0.6
0.8
1
r/R*

Improving Models of Accretion onto Stars

- Turn to Multi-D simulations for more insight
- Difficulties
  - Long time scales to accrete a non-negligible amount of mass
  - Vastly different pressure scale heights at surface and interior
    - Characterize convection cell sizes and thus turn over time scales
    - Convection at surface limits time step
  - Relaxation of initial model from 1D structure
    - Differences in discretization
    - Differences in Convective Model (MLT for 1D)

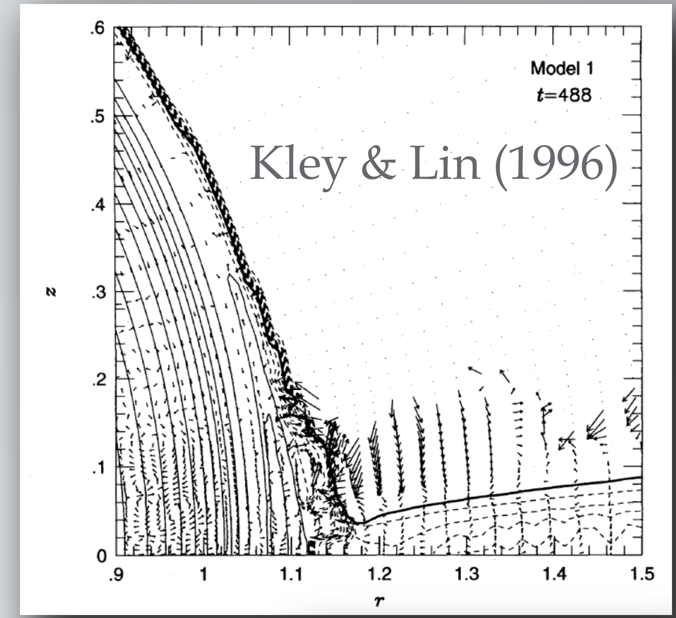


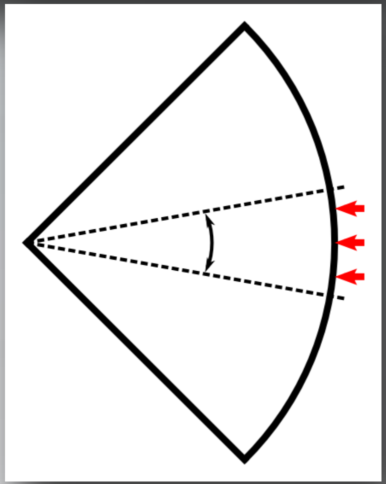
MUSIC: MULTI-DIMENSIONAL STELLAR IMPLICIT CODE

- Fully implicit
  - Solves a system of equations for the new state which depend on both the old and new state
  - CFL condition is no longer a stability constraint
  - Time step limited by flow speed and not sound speed
- Compressible
- Radiation Diffusion Approximation
- Includes realistic opacities (Iglesias et al. 1996; Ferguson et al. 2005)
- Parallelized using MPI using domain decomposition
- For more details see Viallet, Baraffe & Walder (2011;2013)

Accretion Setup

- Using work of Kley & Lin (1996;1999)
  - Opening angle of accretion boundary
  - Inflow velocity
- Mass accretion rate of 1e-6 M_{sun}/yr
- Two entropies of accreted material
  - Entropy 30% higher than mean
  - Entropy 30% lower than mean
  - Entropy nearly flat in convective region
- Onto a 1Msun model
  - Largely convective
- Simulated 5e6 s or 0.16 yrs
  - after fully relaxed and convection is well established
- Accreted 3.16e26 g of material



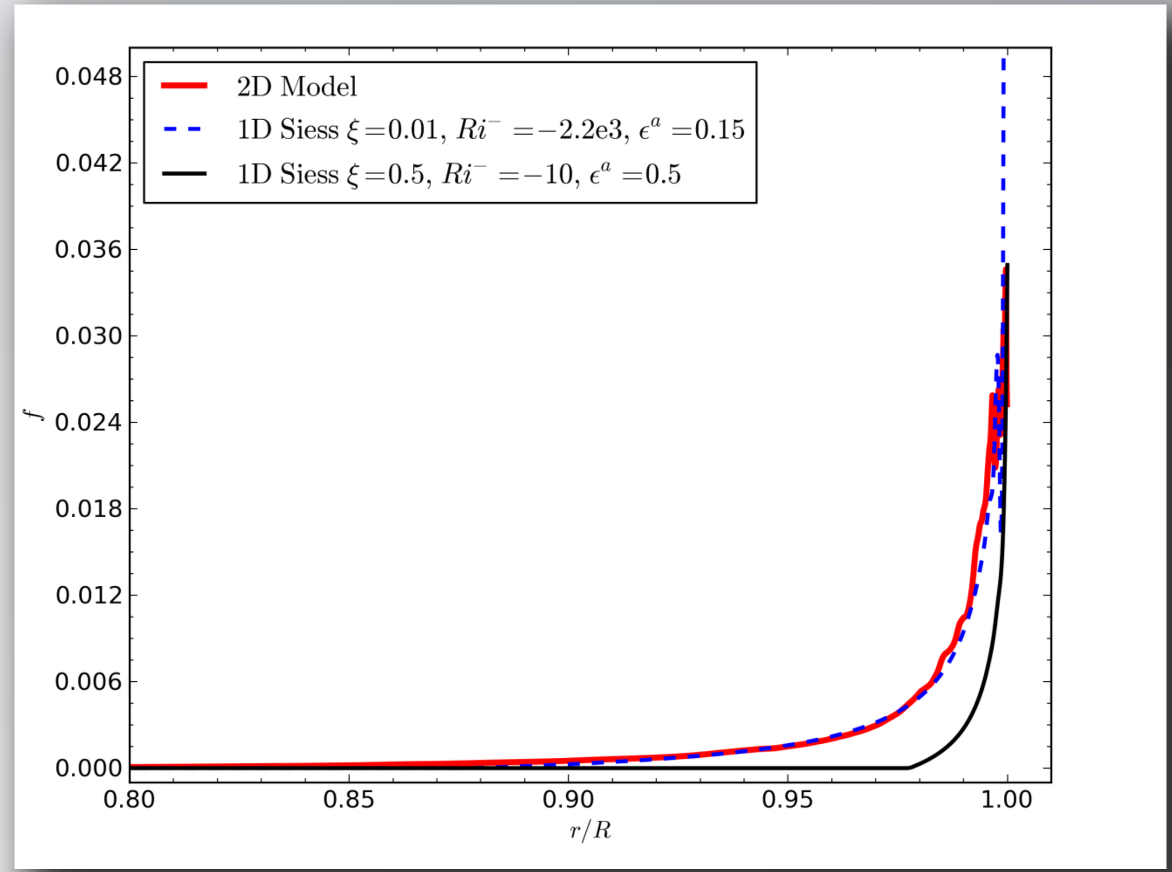


Questions to Answer

- Does a 1D penetration function make sense
  - If so what are good parameters to describe it?
  - How universal are they?
- Is the energy of the accreted material redistributed in the same way as the mass
  - If not can it be described by an analytic function?
- Better parameterize the accretion process for 1D models
  - 1D required for longer time scales

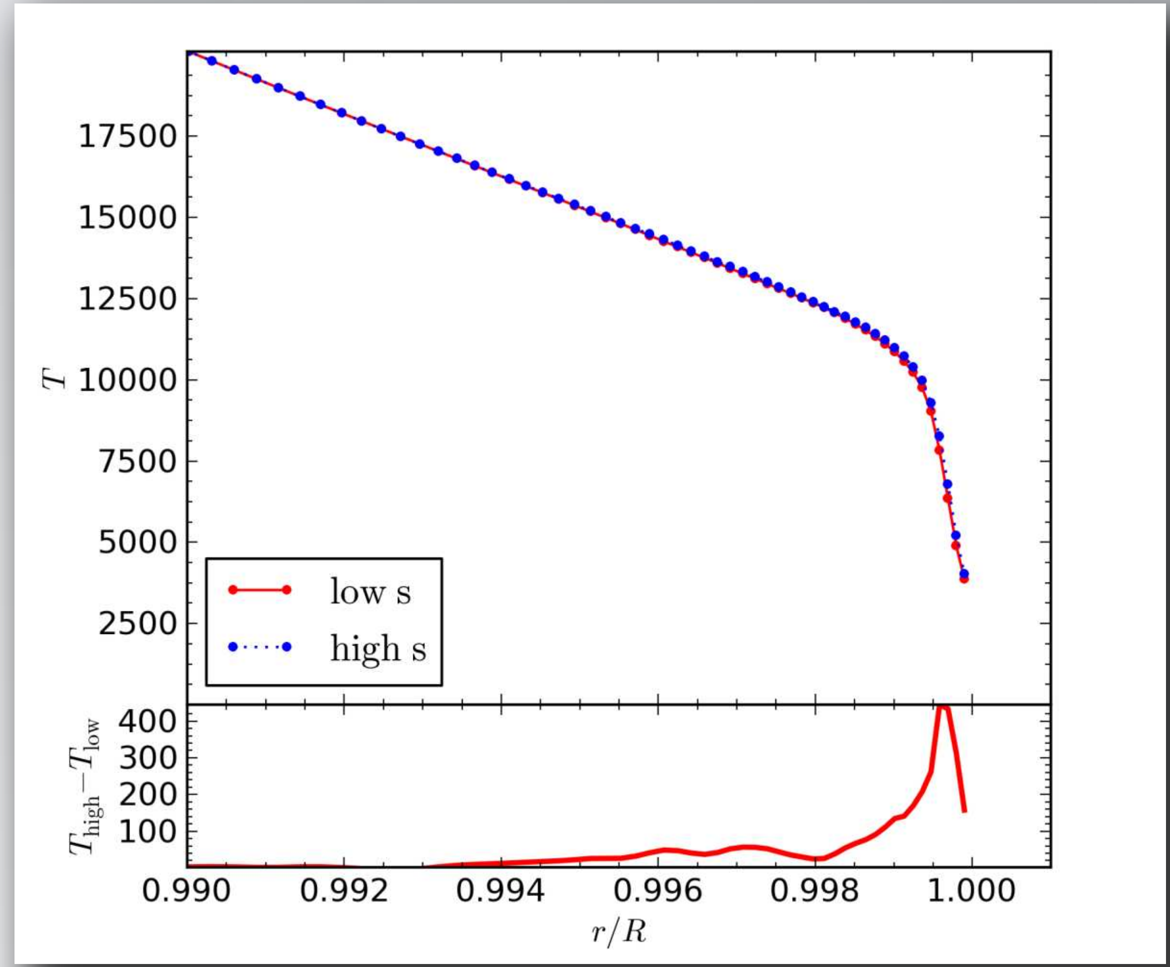
1D Accretion Model Compared to 2D Simulation

- Tuning parameters can fit 2D Model penetration function



Varying Entropy of Accreted Material

- Higher entropy material raises the temperature of star
- How large could this increase be?
- If large enough it may change the structure enough to turn a convective region into a radiative region



Future Work

- Longer 2D simulations (more matter accreted)
- 3D simulations of accretion
- Accrete onto younger lower mass objects