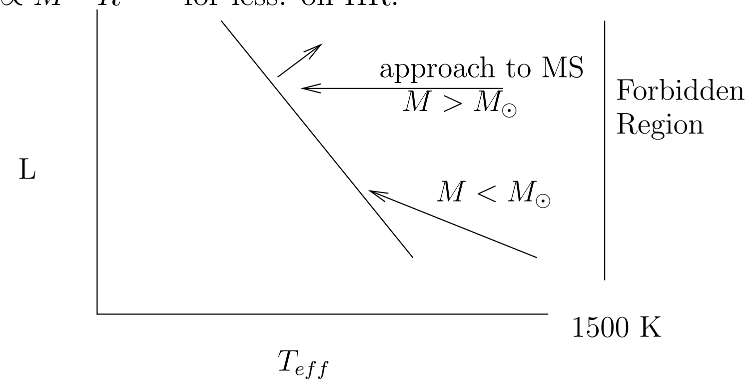
14 Stars notes 2017/09/30 - Mon - Protostars

14.1 Pre Main sequence contraction

Eventually (1-10 Myr) accretion ceases and we can consider a hydrostatic object of fixed M. These objects are fully convective from core to photosphere. This is necessitated by the boundary conditions, radiative transfer just won't work to build a consistent model.

Hayashi showed that a proper treatment of the outer boundary condition actually mattered (unlike for sun's gross structure). We have found that $L \propto M^3$ for $M > M_\odot$ and $L \propto M^{5.5} R^{-1/2}$ for less. on HR:



The temperature scale of 1500 K is the minimum for photons to be able to be produced. Refer to figure below, which actually shows the contraction tracks for different masses. Also showed figures 13 and 15 from first MESA paper.

PASP 100, 1474 (1988)

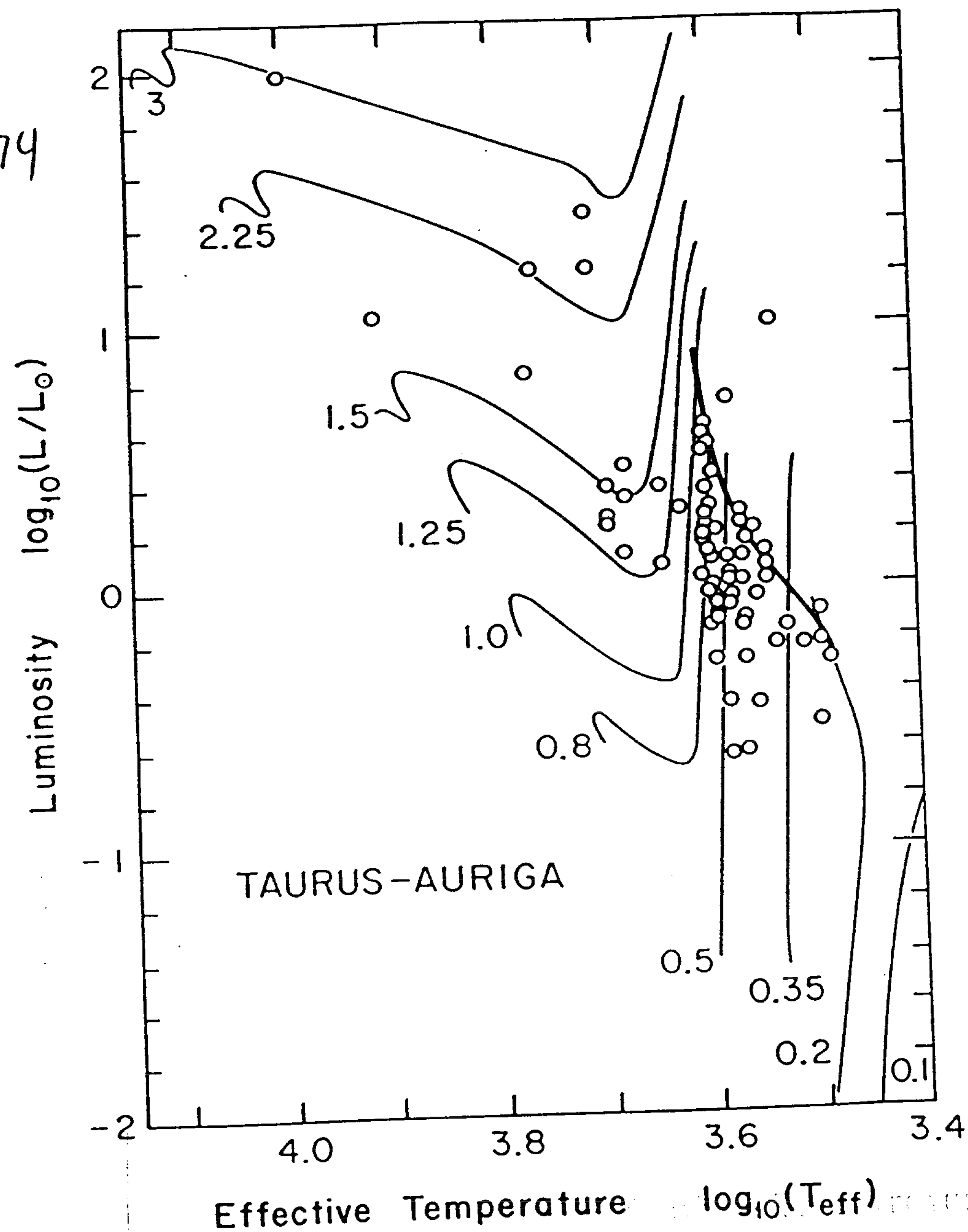


FIG. 4—Observational H-R diagram of the Taurus-Auriga molecular cloud complex. Open circles represent the T Tauri observations of Cok Kuhi (1979). The light solid lines are the theoretical pre-main-sequence tracks of Iben (1965) and Grossman and Graboske (1971), with the appr masses (in solar units) labeled. The heavy solid line is the birthline of Stahler (1983).

+ Iben ApJ, 141, 993

+ Stahler ApJ, 274, 822
332, 804

Pre Main sequence stars with the calculated track. Can see the bend in the data for startup of radiative transfer. i.e. can see data points starting to move off to the left.

AJ, 121, 1040

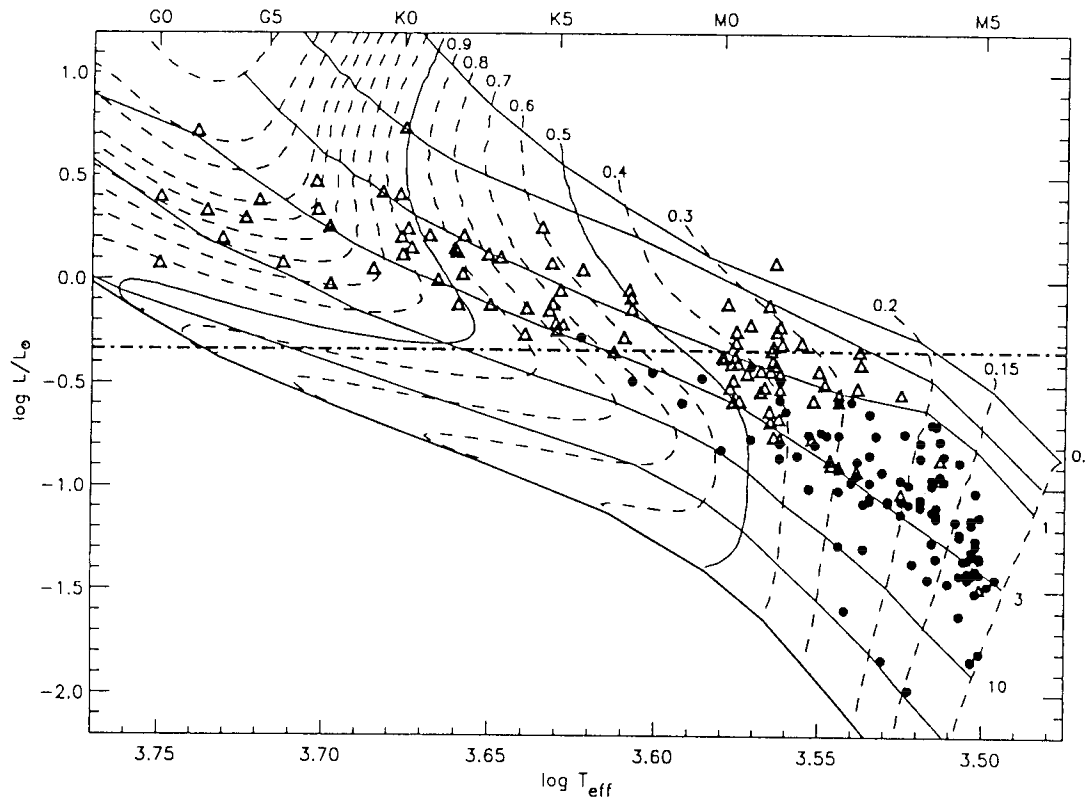


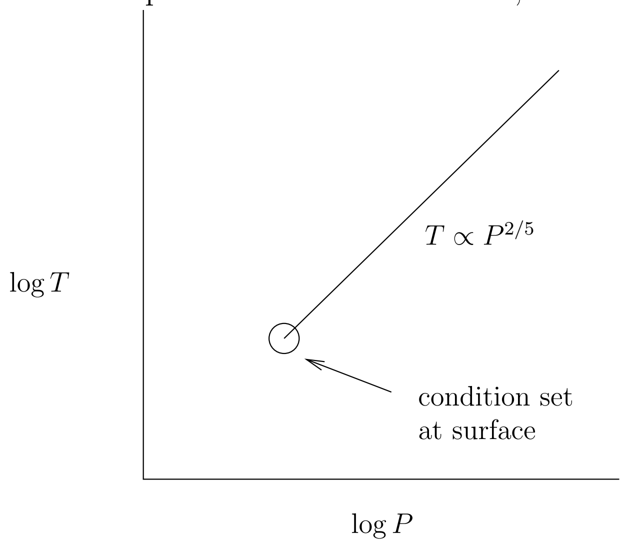
FIG. 8.—H-R diagram for the PMS stars in Upper Sco. The previously known PMS stars from PZ99 are shown as triangles, and the new PMS detected in this study are shown as circles. The dashed lines show the evolutionary tracks from D'Antona & Mazzitelli (1994) and are labeled by their masses in solar units. The 1 $M_\odot$ and 0.5 $M_\odot$ tracks are shown as solid lines. The other solid lines show the D'Antona & Mazzitelli (1994) isochrones for the ages of 0.1, 0.3, 1, 3, 10, and 30 Myr and finally the main sequence. The gray band shows the region in which we expect 90% of the PMS stars to lie, based on the assumption of a common age of 5 Myr for all stars and taking proper account of the uncertainties and the effects of unresolved binaries (see text for details). The dash-dotted line indicates the sensitivity limit of the X-ray observations that were the basis of the X-ray selected PMS sample (see PZ99).

14.2 Hayashi contraction phase

we have at the photosphere:

$$P_{ph} = \frac{g}{\kappa}$$

inside of this point the star is convective, which we showed last time gave $T \propto P^{2/5}$.



Matching up

$$\frac{T_c}{P_c^{2/5}} \sim \frac{T_{ph}}{P_{ph}^{2/5}} = \frac{T_{eff}\kappa^{2/5}}{g^{2/5}}$$

For a fully convective star, the polytropic relations give

$$P_c = 0.77\frac{GM^2}{R^4}$$

and

$$T_c = 0.54\frac{GM\mu m_p}{k_B R}$$

this gives that

$$k_B T_{eff} = 0.6\frac{GM\mu m_p}{R}\left[\frac{R^2}{M\kappa_{ph}}\right]^{2/5}$$

So now we NEED to understand the opacity at the photosphere. Putting in Thomson scattering gives a solution that is so cold that electrons can't be free, inconsistent. What Hayashi did is find that the main opacity is from H^-. The last electron is very weakly bound, about 0.75 eV. We'll find that the temperatures are 2000-3000 K. Electrons come from reactive(or low valence energy) elements Na, Li, etc. This process is very temperature senative, at lower temp, metals not ionized, at higher there is no H^-.

14.3 Hayashi contraction continued

Last time we found that, for a fully convective star (polytrope),

$$k_B T_{eff} = 0.6 \frac{GM\mu m_p}{R} \left[\frac{R^2}{M\kappa_{ph}} \right]^{2/5}$$

So now we NEED to understand the opacity at the photosphere. Putting in Thomson scattering gives a solution that is so cold that electrons can't be free, inconsistent. What Hayashi did is find that the main opacity is from H^-. The last electron is very weakly bound, about 0.75 eV. We'll find that the temperatures are 2000-3000 K. Electrons come from reactive(or low valence energy) elements Na, Li, etc. This process is very temperature senative, at lower temp, metals not ionized, at higher there is no H^-.

The opacity is from the photo-ionization of H^-, $\gamma + H^- \to H + e^-$. Figuring out the opacity is hard microphysics. The fitting form is

$$\kappa_H = 2.5 \times 10^{-31} \rho^{1/2} T^9 \text{ cm}^2/\text{gr}$$

put this into the above and you get

$$T_{eff} \simeq 2500 \text{ K} \left(\frac{M}{M_\odot} \right)^{1/7} \left(\frac{R}{R_\odot} \right)^{1/49}$$

Almost independent of the radius, so the lines are vertical. Also the increase in effective temperature with mass.

14.4 Contraction timescales

So far we have discussed three of the 4 equations of stellar structure. Two equations determine physical structure:

$$\frac{dP}{dr} = -\frac{Gm(r)}{r^2}\rho \quad \text{and} \quad \frac{dm(r)}{dr} = 4\pi r^2 \rho$$

And one describes heat transfer, which for radiation is

$$L(r) = \frac{16\pi ac T^4 Gm(r)}{3P\kappa} \frac{d\ln T}{d\ln P}$$

We will now discuss the 4th. The energy equation. Necessary for evolution – i.e. time-dependence.

14.4.1 Entropy/energy Equation

We've written down hydrostatic balance and heat transfer, now we need the energy equation.

$$T\frac{ds}{dt} = \frac{dQ}{dt} = \text{energy lost or gained by a fluid element}$$

Several ways for a fluid element to change energy

1. Heat gained by nuclear reaction ϵ units erg/gr s
2. Heat gained (or lost) by transport