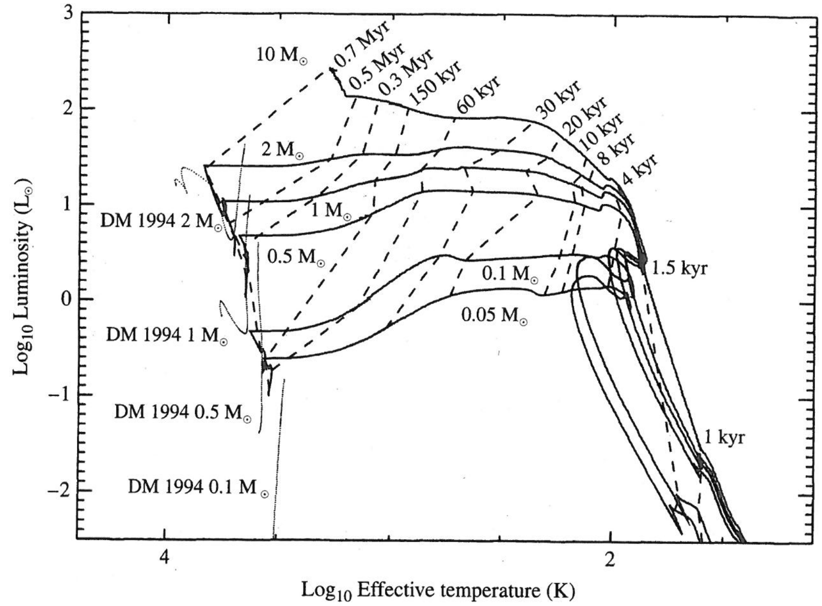

FIGURE 12.9 Theoretical evolutionary tracks of the gravitational collapse of 0.05, 0.1, 0.5, 1, 2, and 10 $M_\odot$ clouds through the protostar phase (solid lines). The dashed lines show the times since collapse began. The light dotted lines are pre-main-sequence evolutionary tracks of 0.1, 0.5, 1, and 2 $M_\odot$ stars from D'Antona and Mazzitelli, *Ap. J. Suppl.*, *90*, 457, 1994. Note that the horizontal axis is plotted with effective temperature increasing to the left, as is characteristic of all H–R diagrams. (Figure adapted from Wuchterl and Tscharnuter, *Astron. Astrophys.*, *398*, 1081, 2003.)

As the overlying material continues to fall onto the hydrostatic core, the temperature of the core slowly increases. Eventually the temperature becomes high enough (approximately 2000 K) to cause the molecular hydrogen to dissociate into individual atoms. This process absorbs energy that would otherwise provide a pressure gradient sufficient to maintain hydrostatic equilibrium. As a result, the core becomes dynamically unstable and a second collapse occurs.[9] After the core radius has decreased to a value about 30% larger than the present size of the Sun, hydrostatic equilibrium is re-established. At this point, the core mass is still much less than its final value, implying that **accretion** is still ongoing.

After the core collapse, a second shock front is established as the envelope continues to accrete infalling material. When the nearly flat, roughly constant luminosity part of the evolutionary track is reached in Fig. 12.9, accretion has settled into a quasi-steady main accretion phase. At about the same time, temperatures in the deep interior of the protostar have increased enough that deuterium ($^2_1$H) begins to burn (Eq. 10.38), producing up to 60% of the luminosity of the 1 $M_\odot$ protostar. Note that this reaction is favored over the first step in the PP I chain because it has a fairly large cross section, $\sigma(E)$, at low temperatures.

With only a finite amount of mass available from the original cloud, and with only a limited amount of deuterium available to burn, the luminosity must eventually decrease. When deuterium burn-out occurs, the evolutionary track bends sharply downward and the

[9]Dynamical instabilities will be discussed further in Chapter 14 in connection with pulsating stars.