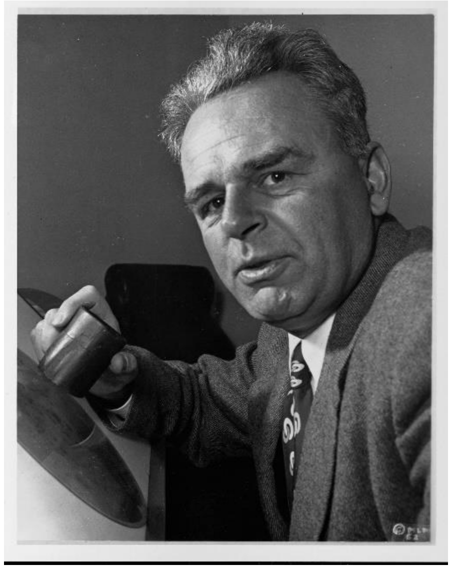
Astronomers

Walter Baade (1893 – 1960)



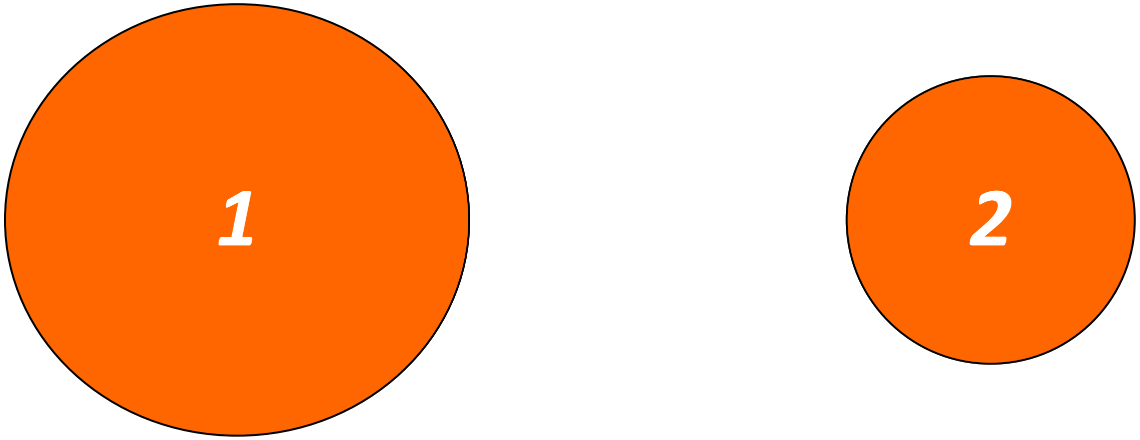
Bart Bok (1906 – 1983)

James Jeans (1877 – 1946)

Ejnar Hertzsprung (1873 – 1967)

Henry Russell (1877 – 1957)

Luminosity versus radius and temperature



$R = 2\ R_\odot$

$T = T_\odot$

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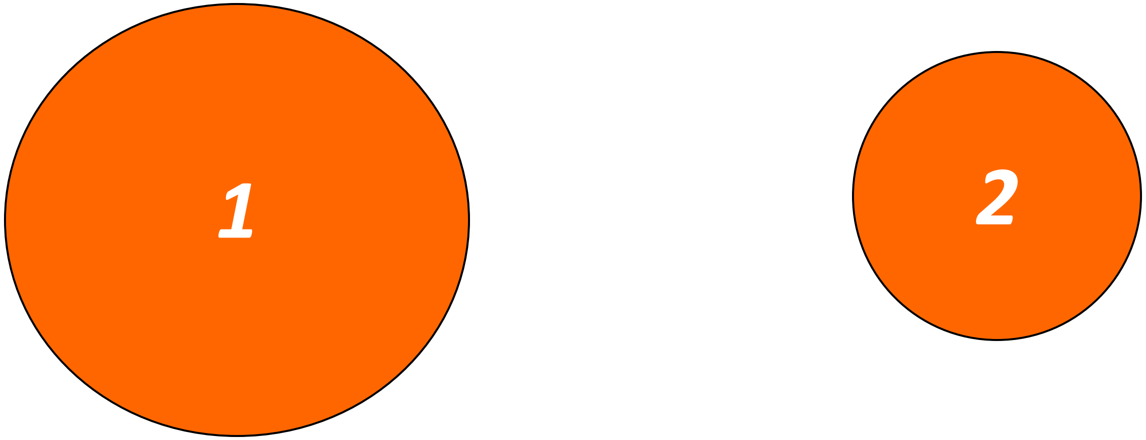
$T = T_\odot$

Which star is more luminous?

Luminosity versus radius and temperature



$R = 2\,R_\odot$

$T = T_\odot$

$R = R_\odot$

$T = T_\odot$

- Each cm^2 of each surface emits the same amount of radiation.
- The larger star emits more radiation because it has a larger surface. It emits 4 times as much radiation.

Luminosity versus radius and temperature

$R = R_\odot$

$T = T_\odot$

$R = R_\odot$

$T = 2\,T_\odot$

Which star is more luminous?

Luminosity versus radius and temperature

$R = 2\,R_\odot$ $R = R_\odot$

$T = T_\odot$ $T = 2\,T_\odot$

Which star is more luminous?

The hotter star is more luminous.

Luminosity varies as T^4 (Stefan-Boltzmann Law)

Luminosity Law

$$L \propto R^2\ T^4$$

$$Luminosity \propto surface\ area \propto (Radius)^2$$

$$Luminosity \propto (Temperature)^4$$

If star A is 2 times as hot as star B, and the same radius, then it will be $2^4 = 16$ times as luminous.

Where do stars form?

- Bok globules for low mass stars

Rosette Nebula

Characteristics of the Globules:
$r < 1$ pc
$M < 1000\ M_{\odot}$
$T \approx 10$ K

Where do stars form?

- Giant Molecular Clouds (GMC)

Characteristics of GMCs:
$10 < r < 100$ pc
M up to a few $10^6\ M_\odot$
$T \approx 10$ K

Jeans Length - When does Gravity win?

- $\boldsymbol{N}$ molecules of mass $\boldsymbol{m}$ in a box of size $\boldsymbol{L}$ (do not confuse with the luminosity) at temperature $\boldsymbol{T}$
- Gravitational Energy: $E_G \sim -\frac{G\,M^2}{L}$
- Thermal Energy: $E_T \sim N\,k\,T$
- Total mass: $M = N\,m \sim L^3\rho$
- Ratio: $\frac{E_G}{E_T} \sim \frac{G\,M^2}{L\,N\,k\,T} \sim \frac{G\,(\rho\,L^3)\,m}{L\,k\,T} = \left(\frac{L}{L_J}\right)^2$
- Jeans Length: $L_J \sim \sqrt{\frac{k\,T}{G\,\rho\,m}}$
- Gravity wins when $L > L_J$

Jeans Mass

- Jeans Length: $L_J \sim \sqrt{\frac{k\,T}{G\,\rho\,m}}$
- Jeans Mass: $M_J = L_J^3\,\rho = \ \rho\ \left(\frac{k\,T}{G\,\rho\,m}\right)^{3/2} \quad \propto$ $T^{3/2}\,\rho^{-1/2}$
- Lowest Jeans Mass for cool and dense clouds

The first stage

- Gravity tries to pull material in < = > Pressure tries to push it out
- Time to collapse = free fall time t_G
- Gravitational acceleration: $g \sim \frac{G\ M}{L^2} \sim \frac{L}{t_G^2}$
- Time to collapse: $t_G \sim \sqrt{\frac{L}{g}} \sim \sqrt{\frac{L^3}{G\ M}} \sim \frac{1}{\sqrt{G\ \rho}}$
- Note:
  - Denser regions collapse faster
  - Independent of the size

The first stage

- Pressure waves travel at the sound speed c_S
- For ideal gas: $c_S \sim \sqrt{\frac{P}{\rho}} \sim \sqrt{\frac{k\,T}{m}}$
- Sound crossing time: $t_S \sim \frac{L}{c_S} \sim L\sqrt{\frac{m}{k\,T}}$
- Note: faster for smaller and hotter regions

The first stage

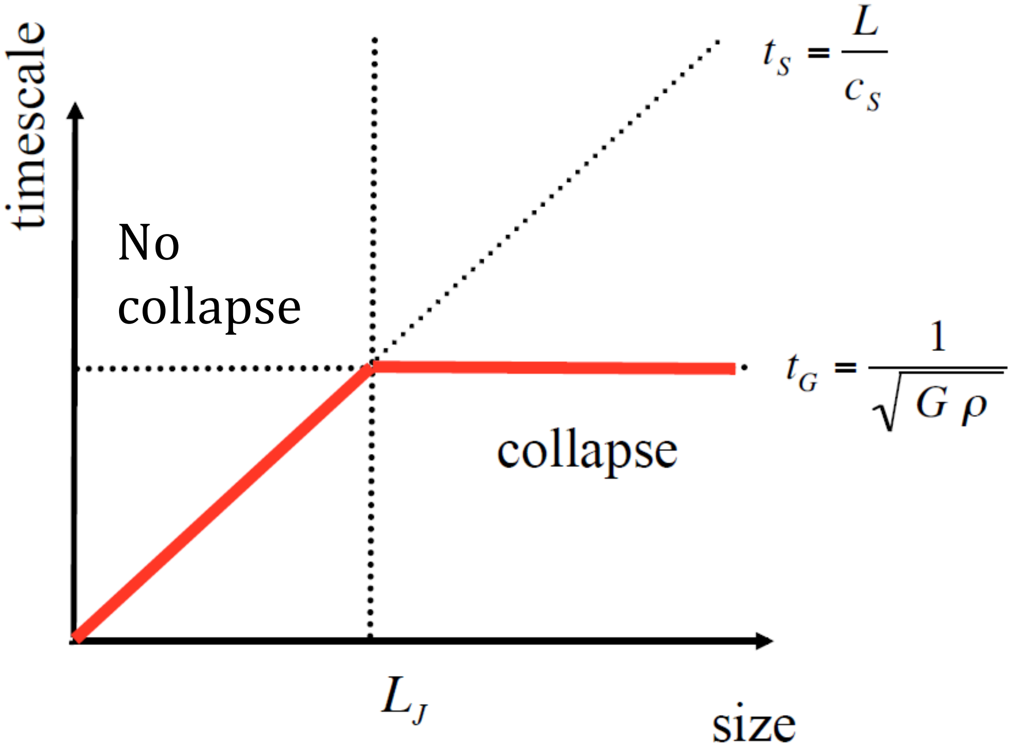
- Ratio of time scales:

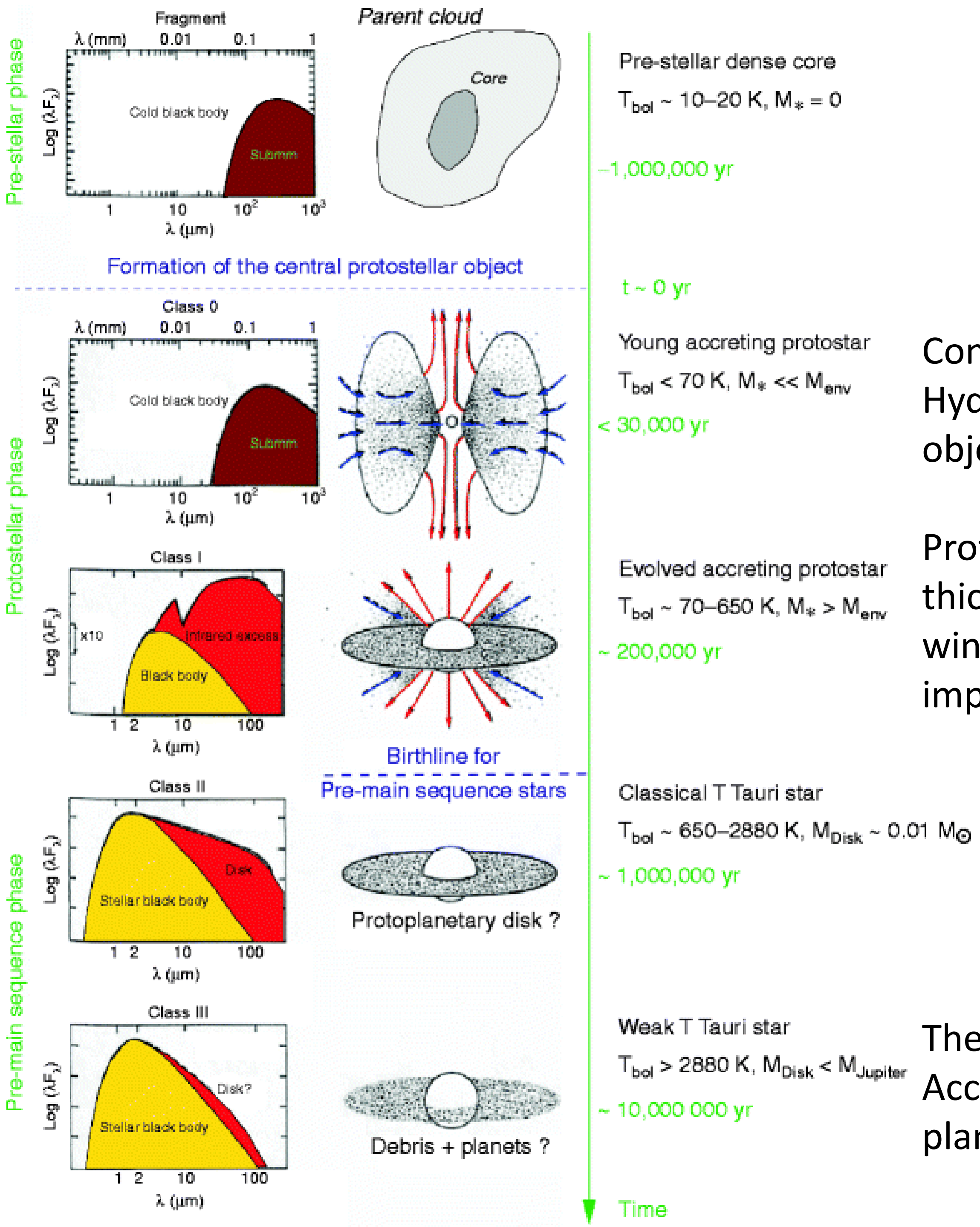
$$\frac{t_S}{t_G} \sim \frac{L\sqrt{G\,\rho}}{c_S} \sim L\sqrt{\frac{G\,\rho\,m}{k\,T}} \sim \frac{L}{L_J}$$

- Jeans Length:

$$L_J \sim \frac{c_S}{\sqrt{G\,\rho}}$$

- Larger clouds are more likely to collapse





Condensation of in-falling molecular gas
Hydrostatic low-luminosity proto-stellar object

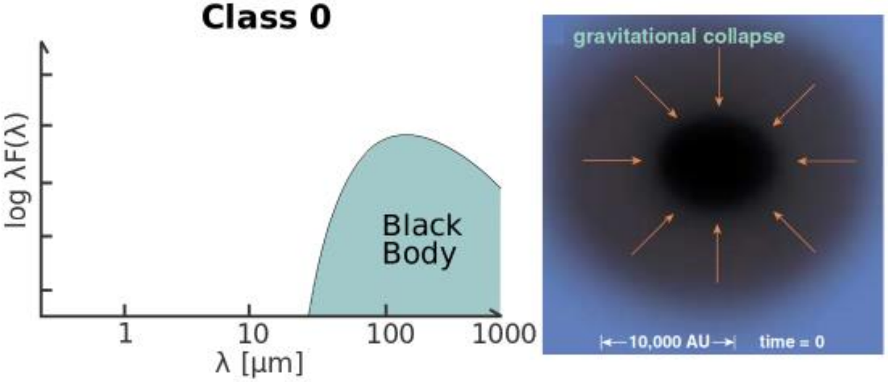
Protostar still enshrouded by optically thick material. Emission from thermal winds/jets ionized by neutral winds impacting the ambient medium

Optical emission starts to come out along with an outflow and wind

The star approaches the main sequence. Accretion substantially halted, proto-planetary disks may be present.

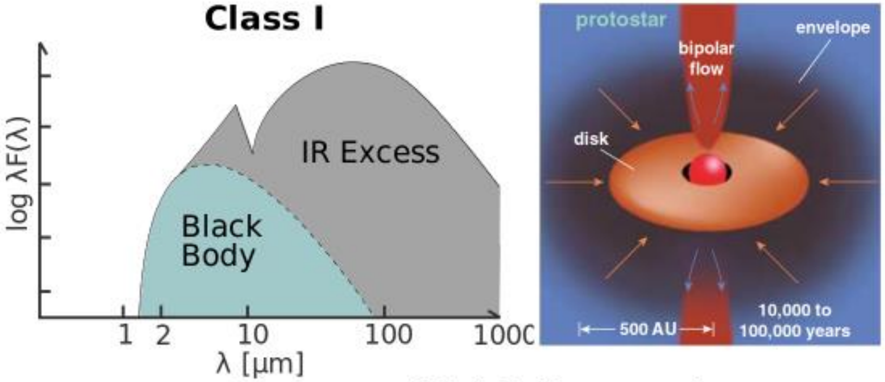
Protostars evolve into main-sequence stars

Class 0



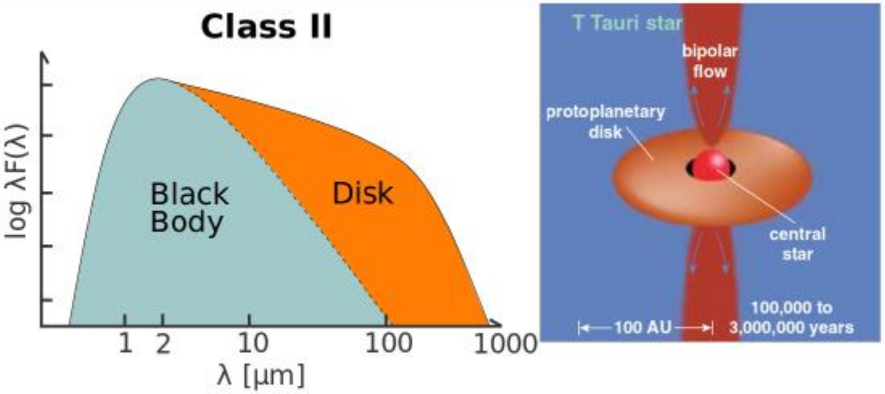
Faint protostar deeply embended

Class I



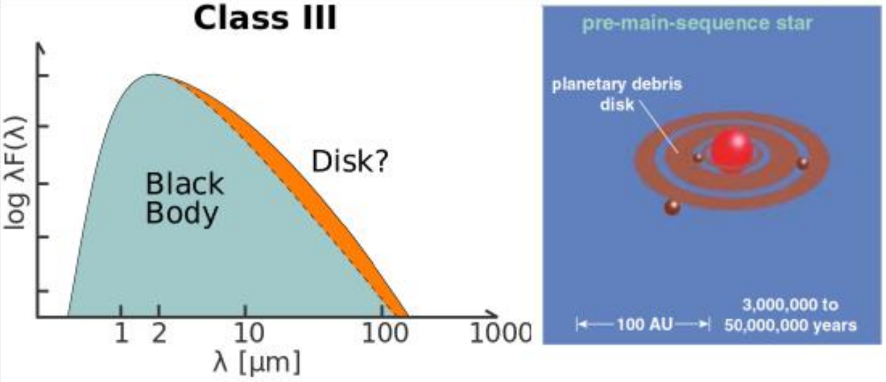
Protostar with infalling envelop

Class II



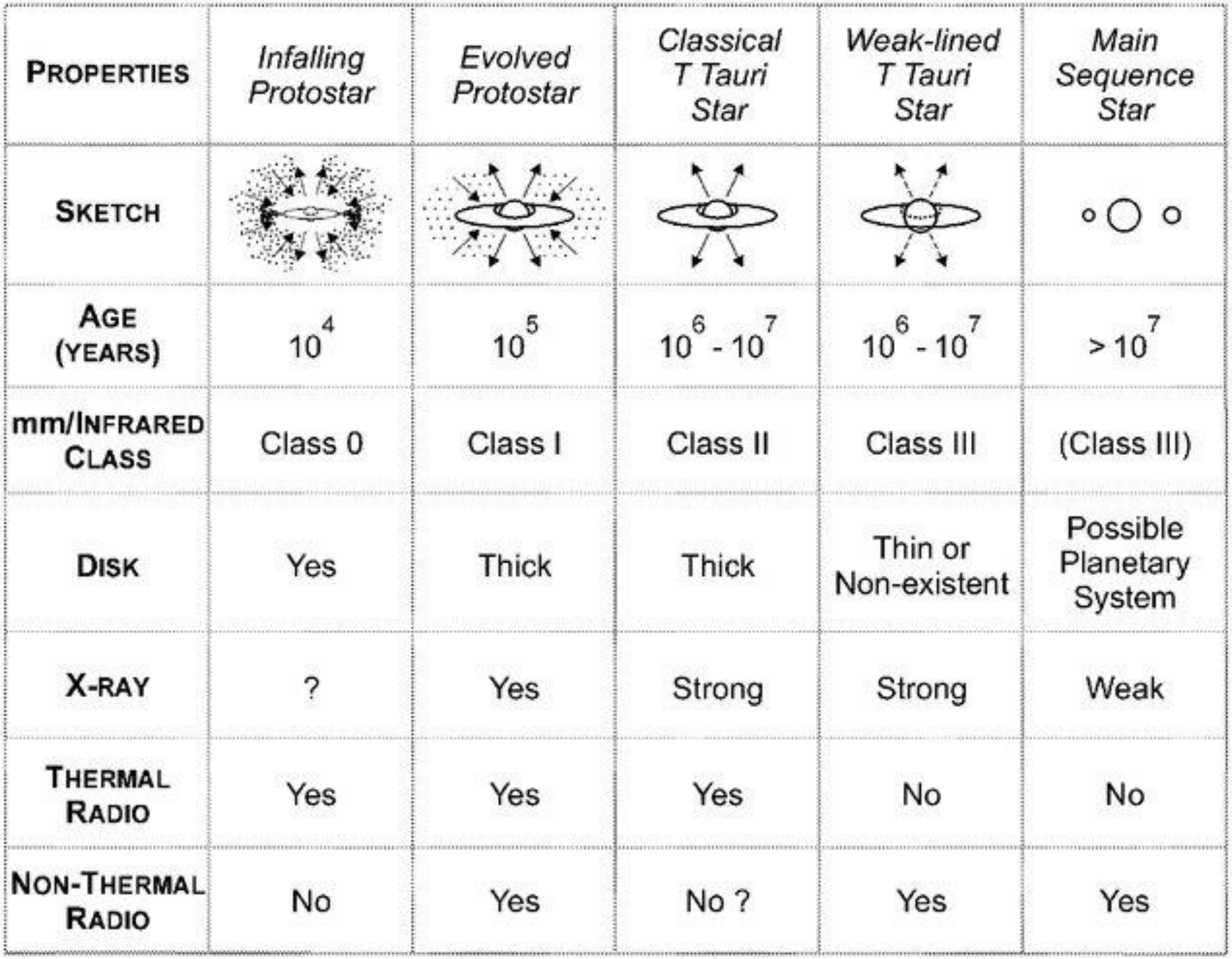
Pre main sequence with thick disk

Class III



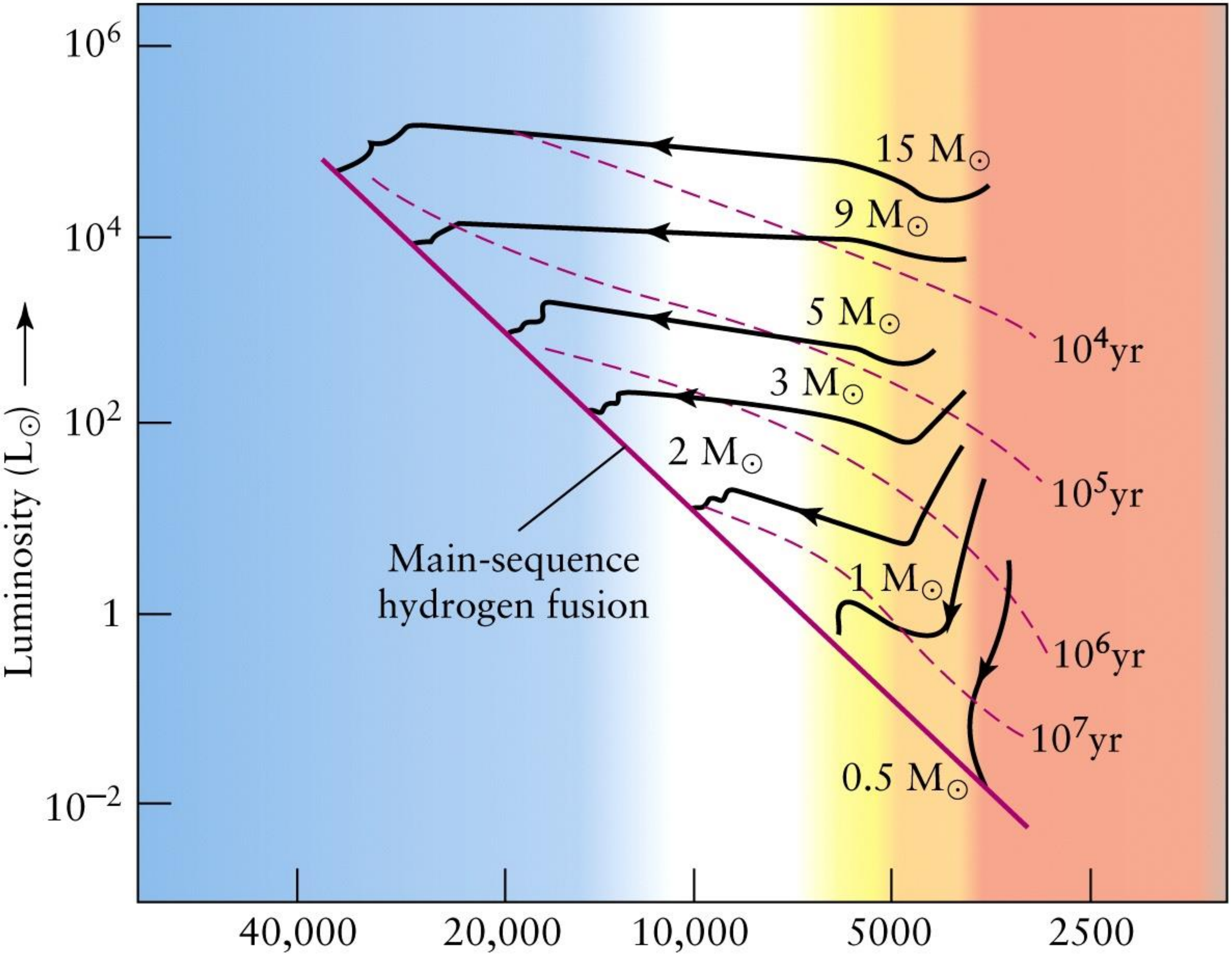
Diskless pre main sequence

Protostars evolve into main-sequence stars



PROPERTIES	*Infalling Protostar*	*Evolved Protostar*	*Classical T Tauri Star*	*Weak-lined T Tauri Star*	*Main Sequence Star*
SKETCH					
AGE (YEARS)	10^4	10^5	$10^6 - 10^7$	$10^6 - 10^7$	$> 10^7$
mm/INFRARED CLASS	Class 0	Class I	Class II	Class III	(Class III)
DISK	Yes	Thick	Thick	Thin or Non-existent	Possible Planetary System
X-RAY	?	Yes	Strong	Strong	Weak
THERMAL RADIO	Yes	Yes	Yes	No	No
NON-THERMAL RADIO	No	Yes	No ?	Yes	Yes

Protostars evolve into main-sequence stars



Protostars evolve into main-sequence stars