Star formation

Compact HII regions

Radiative impact

Ionization of surroundings:

- compact/ultracompact/hypercompact HII regions

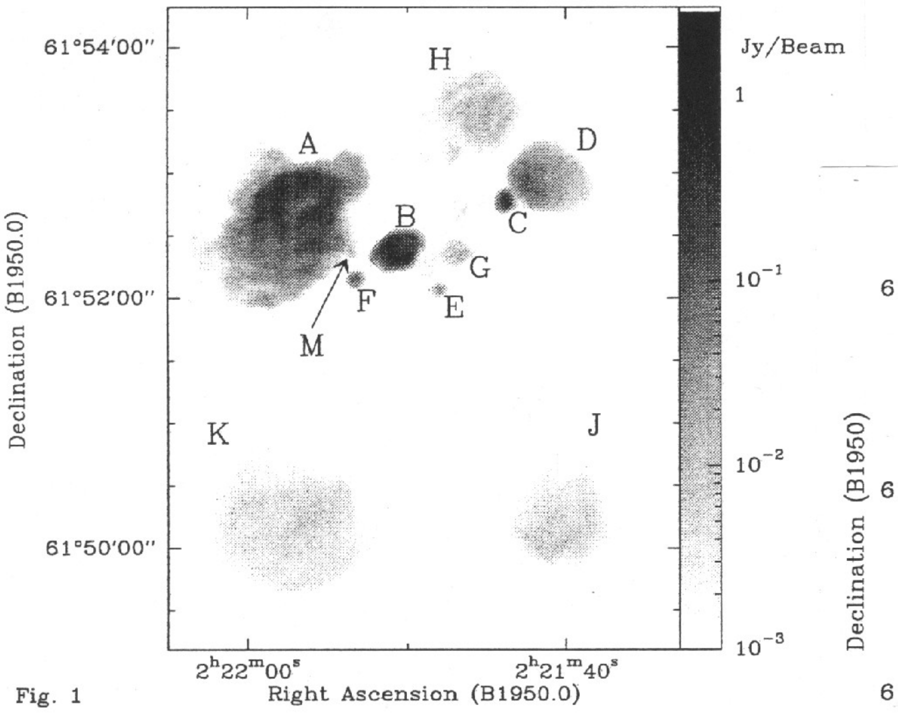
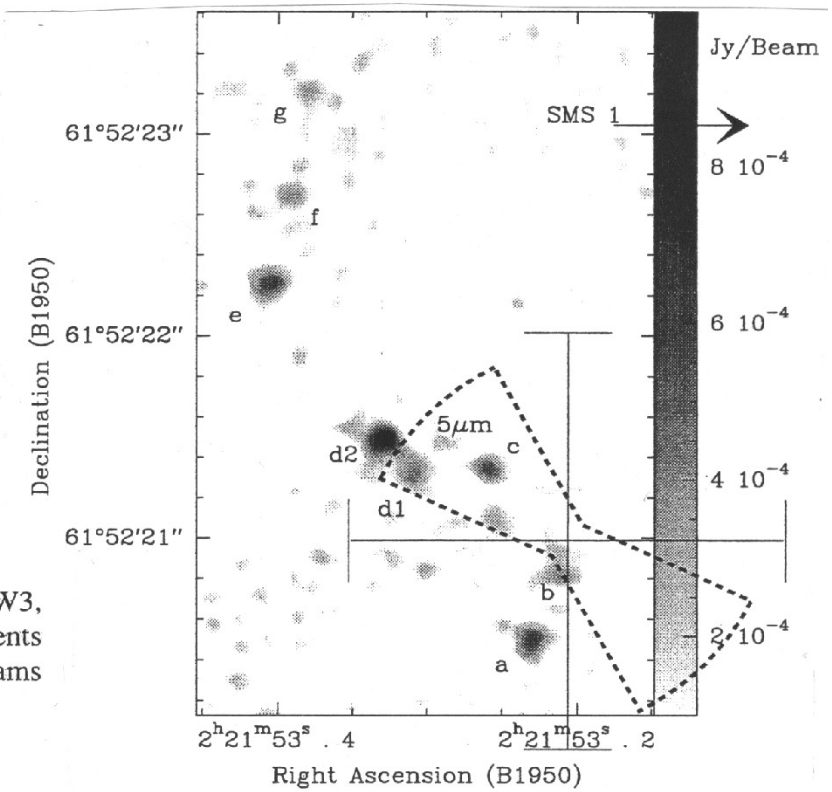


Fig. 1. A gray-scale representation of a 6 cm continuum image of W3, with a FWHM beam size of 3.″38 by 2.″72. Continuum components have been labeled following the scheme introduced by Wynn-Williams (1971) and Harris & Wynn-Williams (1976).



Tieftrunk et al. (1997)

Radiative impact

Ionization balance:

- Consider star with T_* in medium with density n_H

$$n_H \int_{\nu_T}^{\infty} 4\pi N_\nu \alpha_H(\nu) d\nu = n_e n_p \beta_A(T)$$

- ν_T – ionization threshold (912Å = 13.6 eV)
- N_ν – photon density: J(ν)/hν
- $n_e = n_p$ – electron/proton density
- β_A – recombination coeff.: $\beta_A \approx 4.3\, 10^{-13} \frac{\mathrm{cm}^3}{\mathrm{s}} \left(\frac{T_e}{10^4 \mathrm{K}} \right)^{-0.8}$
- $\alpha_H(\nu)$ – ionization cross section

Radiative impact

$\alpha_H(\nu)$ – ionization cross section

- Peaking at ν_T
- $\sim \nu^{-3}$

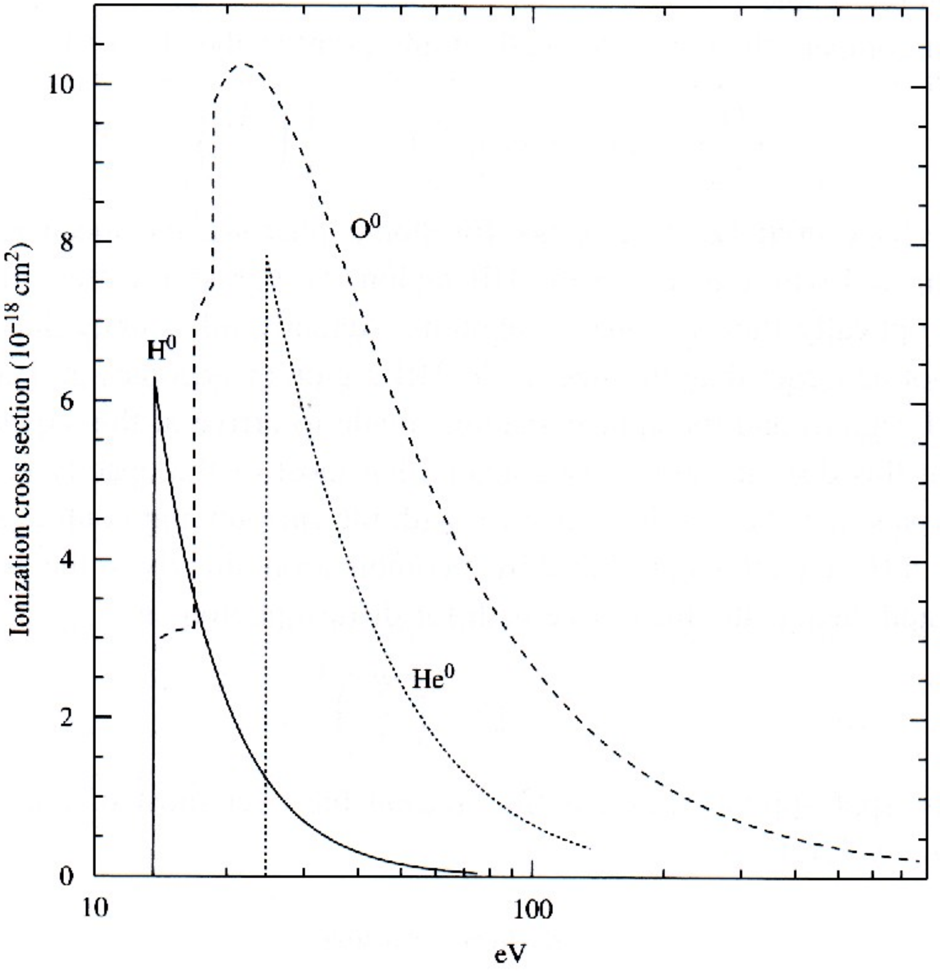


Figure 7.1 The ionization cross sections of hydrogen and helium, showing a maximum at the ionization edge and dropping away approximately as ν^{-3}. The ionization cross section of oxygen shows a more complex behavior due to ionization to excited levels within the same configurations.

Strömgren sphere

Number of UV photons with $\nu > \nu_T$ determines the size of the ionized region

Strömgren radius: $$R_S = 0.032\text{pc}\left(\frac{10^5\text{cm}^{-3}}{n}\right)^{2/3}\left(\frac{N_\nu}{10^{49}\text{s}^{-1}}\right)^{1/3}$$

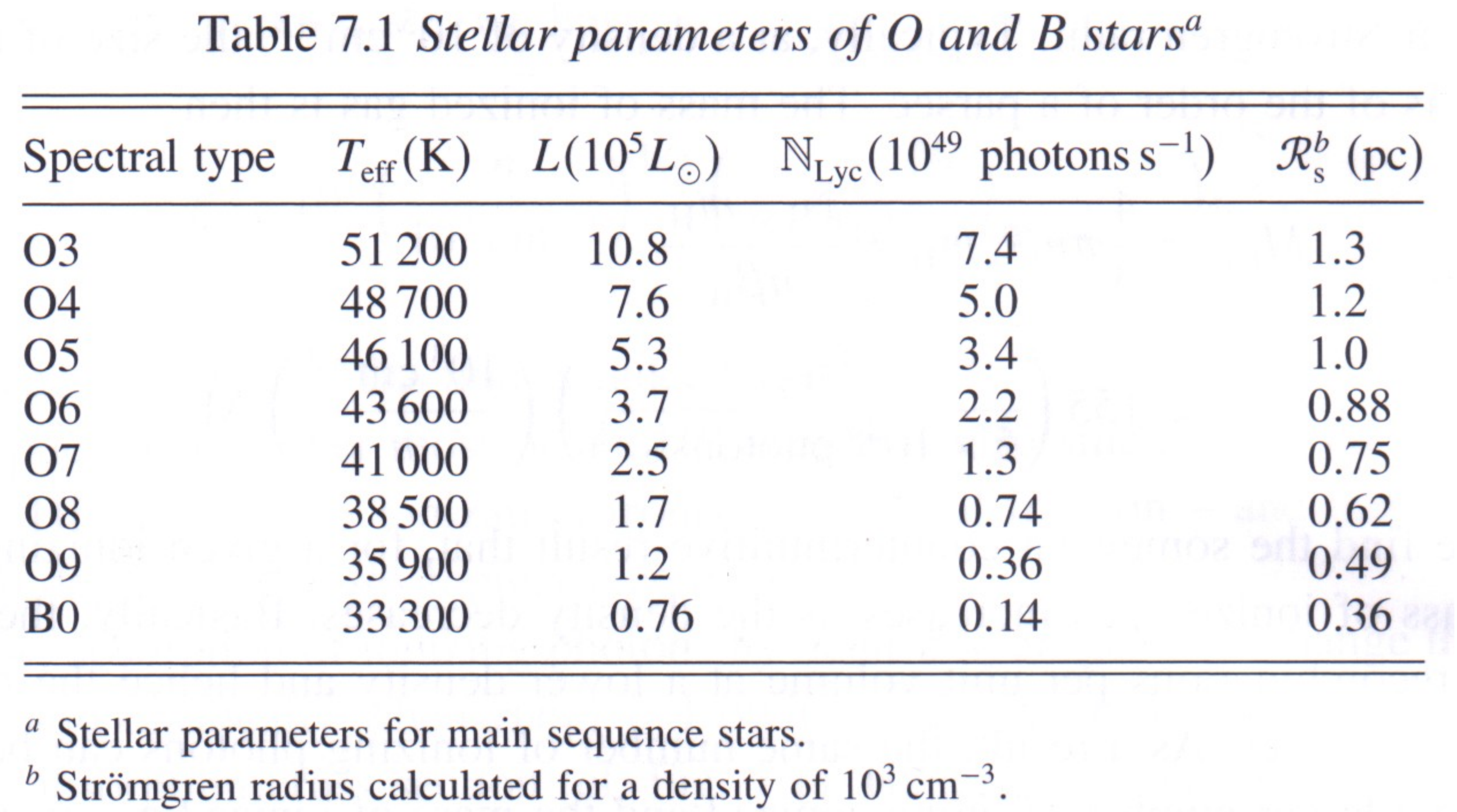


Table 7.1 *Stellar parameters of O and B stars*[a]

Spectral type	T_{eff} (K)	$L(10^5 L_\odot)$	$\mathbb{N}_{\mathrm{Lyc}}(10^{49}$ photons $\mathrm{s}^{-1})$	$\mathcal{R}_s^b$ (pc)
O3	51 200	10.8	7.4	1.3
O4	48 700	7.6	5.0	1.2
O5	46 100	5.3	3.4	1.0
O6	43 600	3.7	2.2	0.88
O7	41 000	2.5	1.3	0.75
O8	38 500	1.7	0.74	0.62
O9	35 900	1.2	0.36	0.49
B0	33 300	0.76	0.14	0.36

[a] Stellar parameters for main sequence stars.

[b] Strömgren radius calculated for a density of $10^3\ \mathrm{cm}^{-3}$.

Quenched HII regions

If more material is replenished by accretion than re-ionized, the HII region will be suffocated

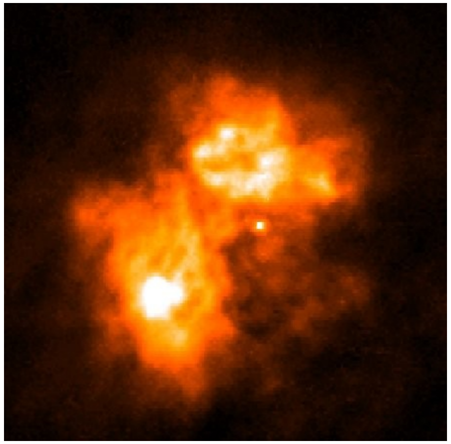
Mass infall rate:

$$\dot{M} > \dot{M}_{\mathrm{crit}} = 2\sqrt{\pi}\mu m_H \left(\frac{N_\nu G M_\star}{\langle \beta_A \rangle}\right)^{1/2}$$

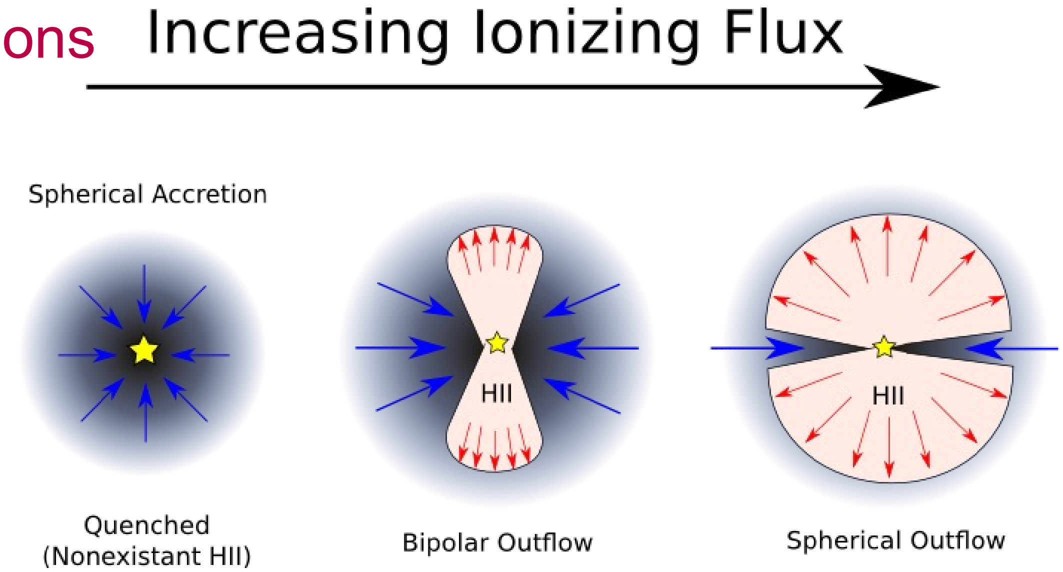
μm_H – mean atomic weight

→ one would expect bipolar HII regions

→ hardly observed



Papillon nebula



→ HII regions form on scales where the infall is still isotropic

Ultracompact HII regions

So far steady-state computation

- Justified only if dynamical timescale τ_{dyn}
  >> recombination timescale τ_{rec}

$$\tau_{\text{rec}} = \frac{1}{\langle \beta_A \rangle n}$$

- τ_{rec} ~ 100a for $n=10^5$ cm^{-3} → massive star switch-on is faster

→ initial size of HII region determined by total number of Lyman photons produced so far:

$$N_\nu t = \frac{4\pi}{3} n R_{\text{IF}}^3(t)$$

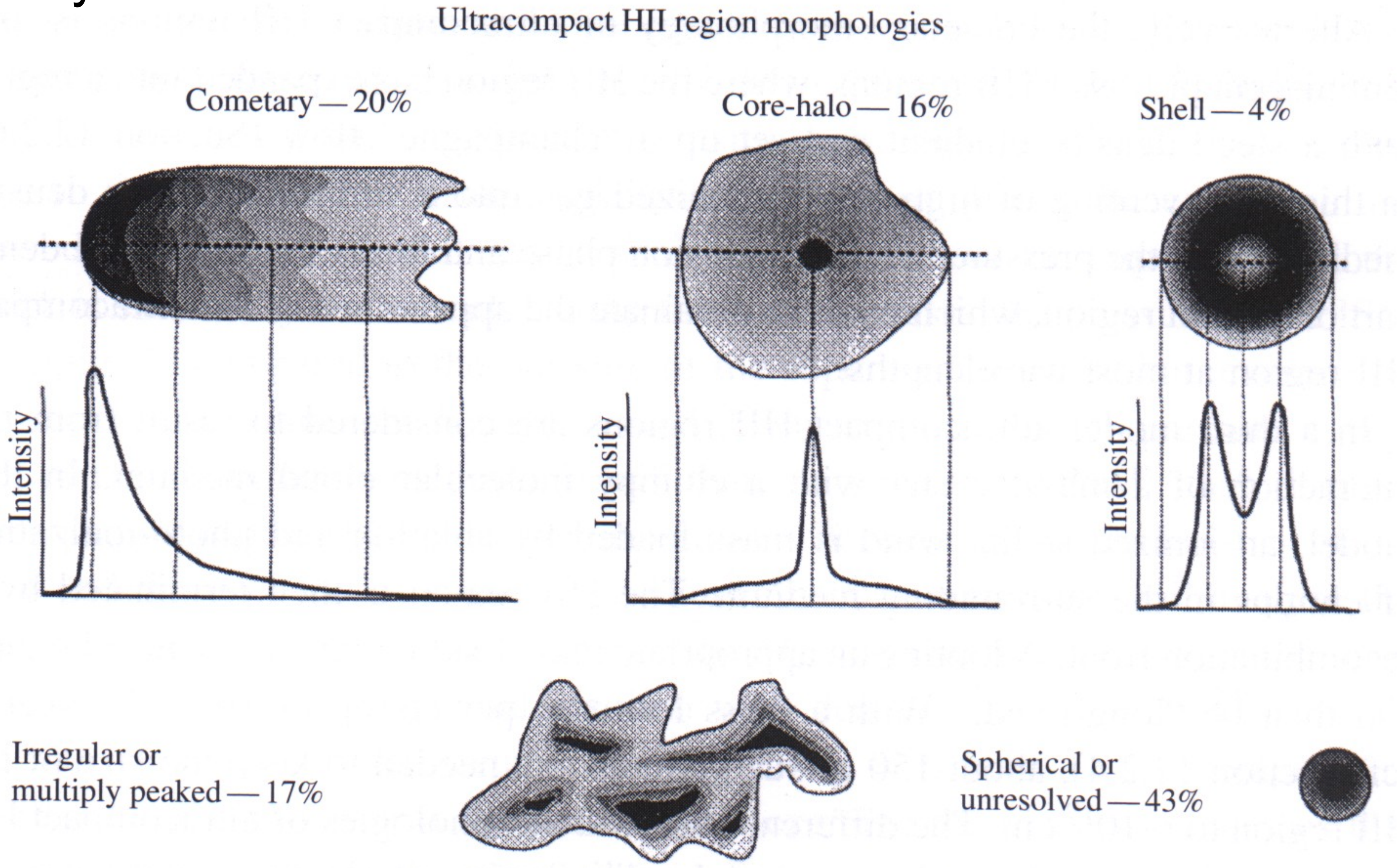
neglecting all recombination, i.e. for $t < \tau_{\text{rec}}$

→ formation of hypercomapct/ultracompact HII regions

Ultracompact HII regions

Hypercomapct/ultracompact HII regions

- Lasts only ~ 100a



Ultracompact HII regions

Include recombination:

$$R_{\rm IF}^3 = R_S^3\,(1 - \exp(-t/\tau_{\rm rec}))$$

- Asymptotic approa to R_S
- Steady-state reach after ~ 4 τ_{rec}
- Initial expansion velocity > 1000km/s >> c_S

→ strong shock driven through envelope

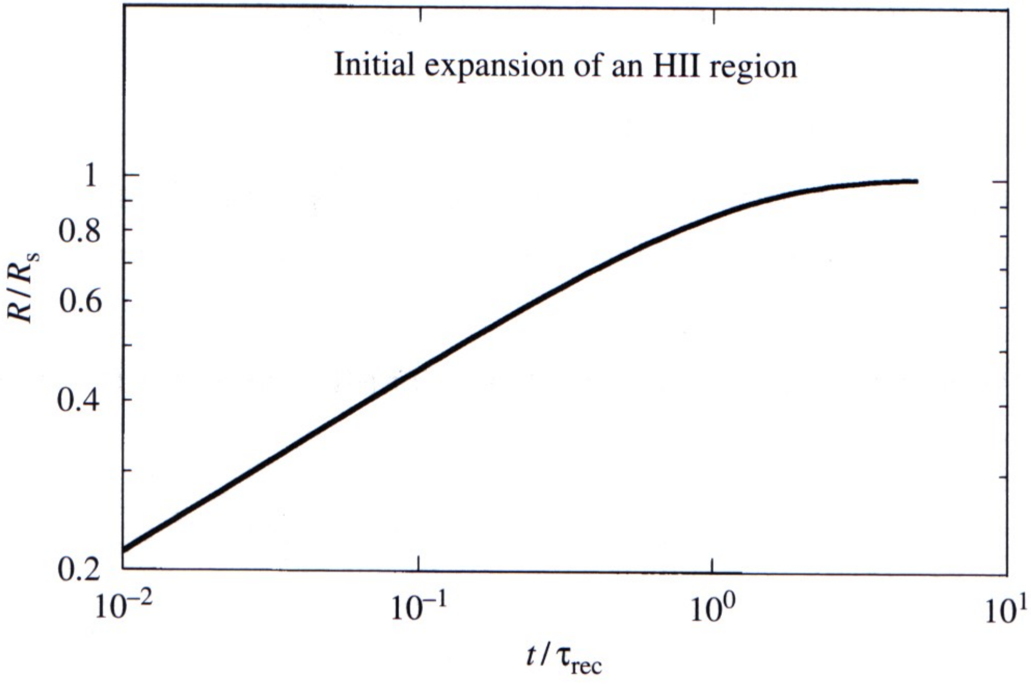
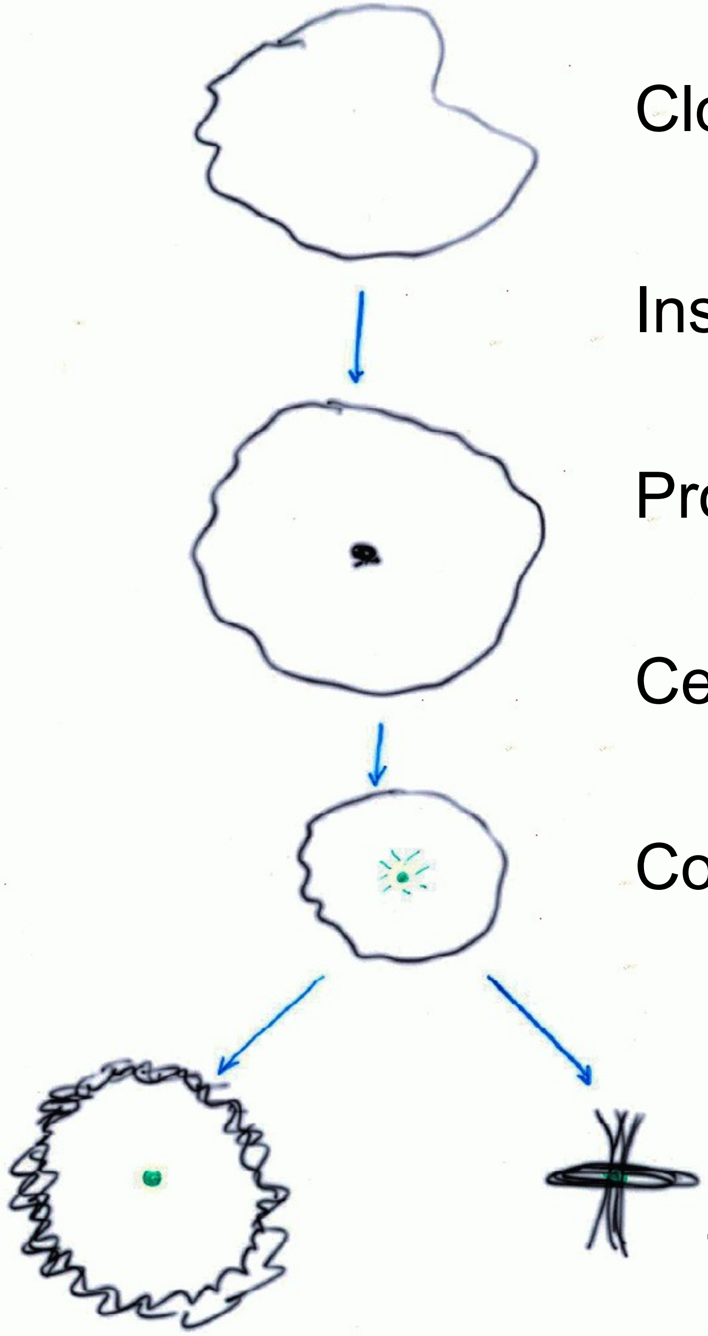


Figure 12.2 The initial expansion of the ionization front after the sudden "turn on" of a massive star in a uniform density cloud. The size is plotted (relative to the Strömgren radius) as a function of the time in units of the recombination time scale, $\tau_{\rm rec} = (\beta_{\rm B} n)^{-1}$.

Global picture

Interaction of infall and radiation:



Cloud with $M > M_J$

Inside-out collapse: 10^6a

Protostellar core

Central collapse: 10^5a

Cocoon star

$M > 3M_\odot$: 10^6a

BN object with HII

$M < 3M_\odot$: 10^7a

T Tau star