Dynamics of HII regions

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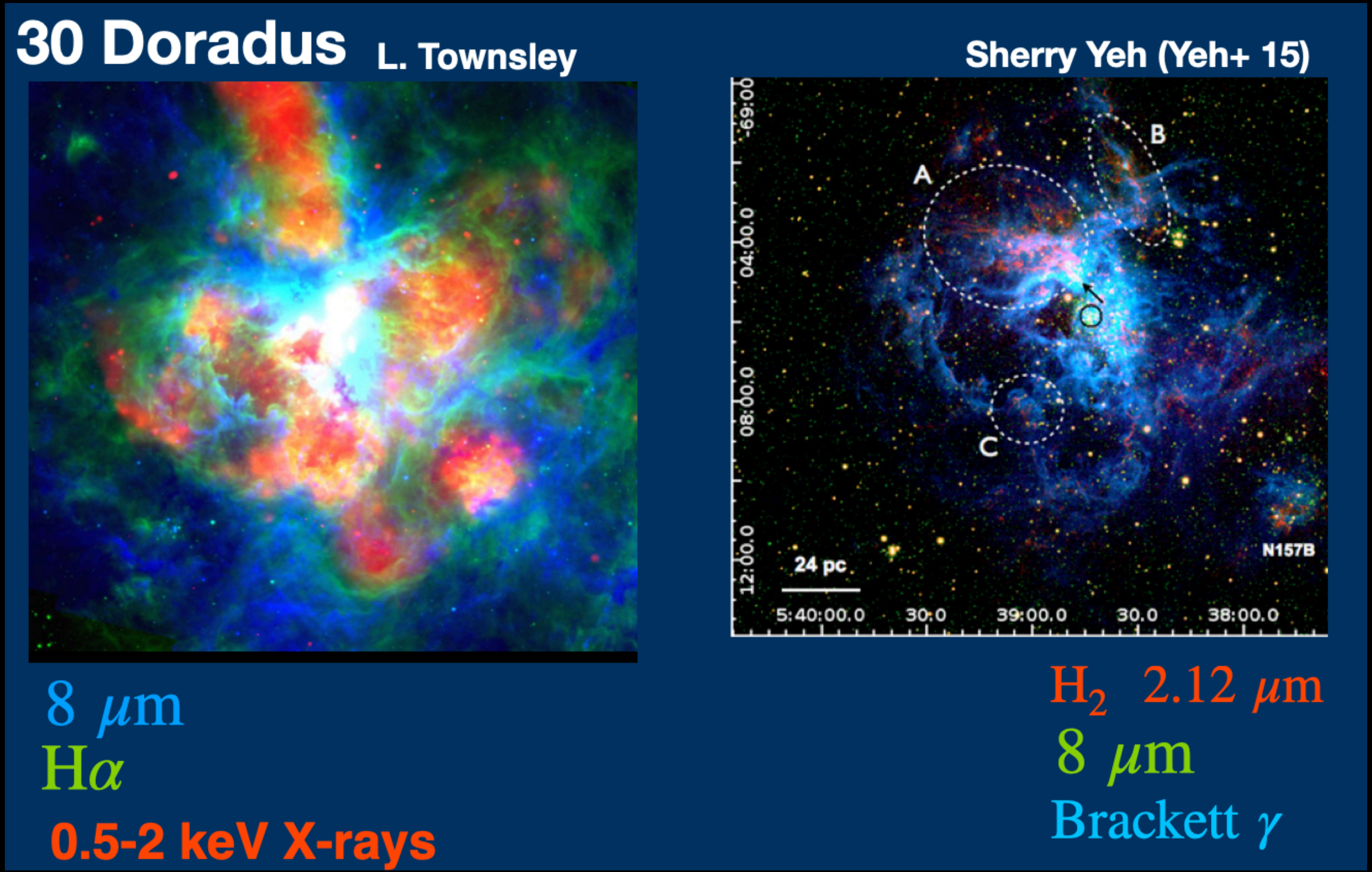
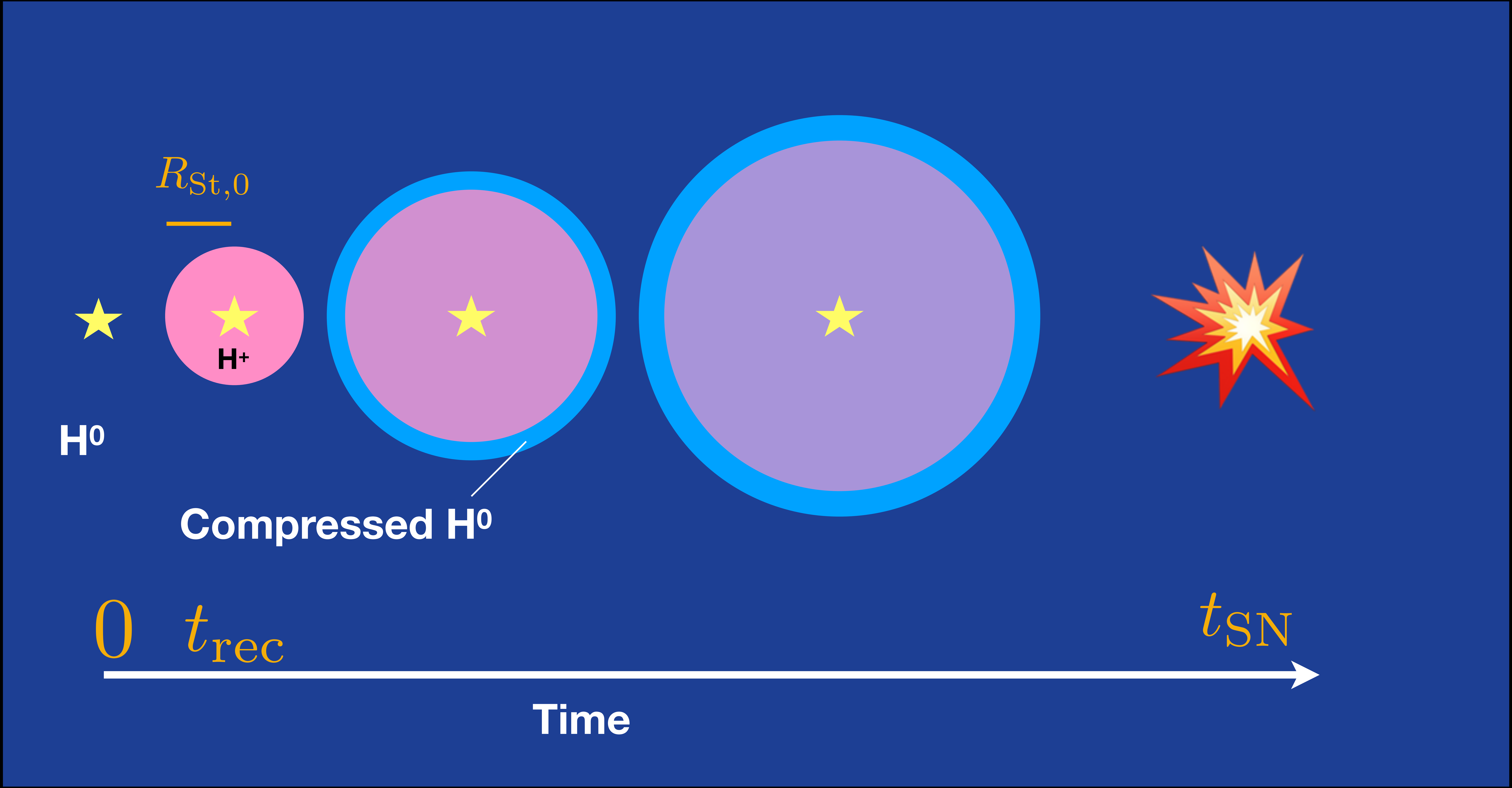
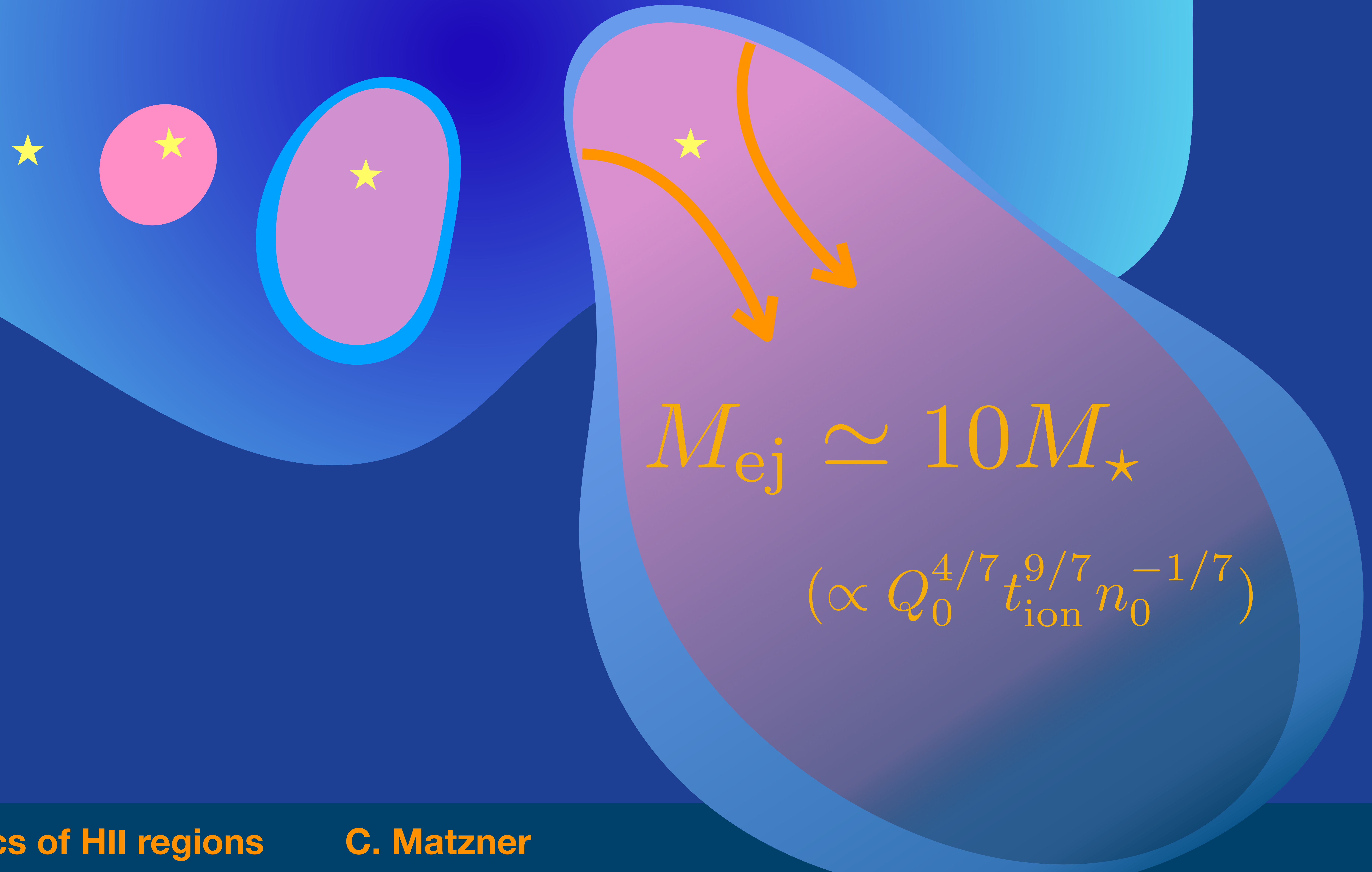
Why consider dynamics of H II regions?

- Local working zone of feedback from massive stars
- Ionized sound speed well matched to formation environment
- Clear a path for wind/SN energy
- Many observational diagnostics




$R_{\mathrm{St},0}$
H^+
H^0
Compressed H^0
0
t_{rec}
t_{SN}
Time

Complication 1: Density gradient

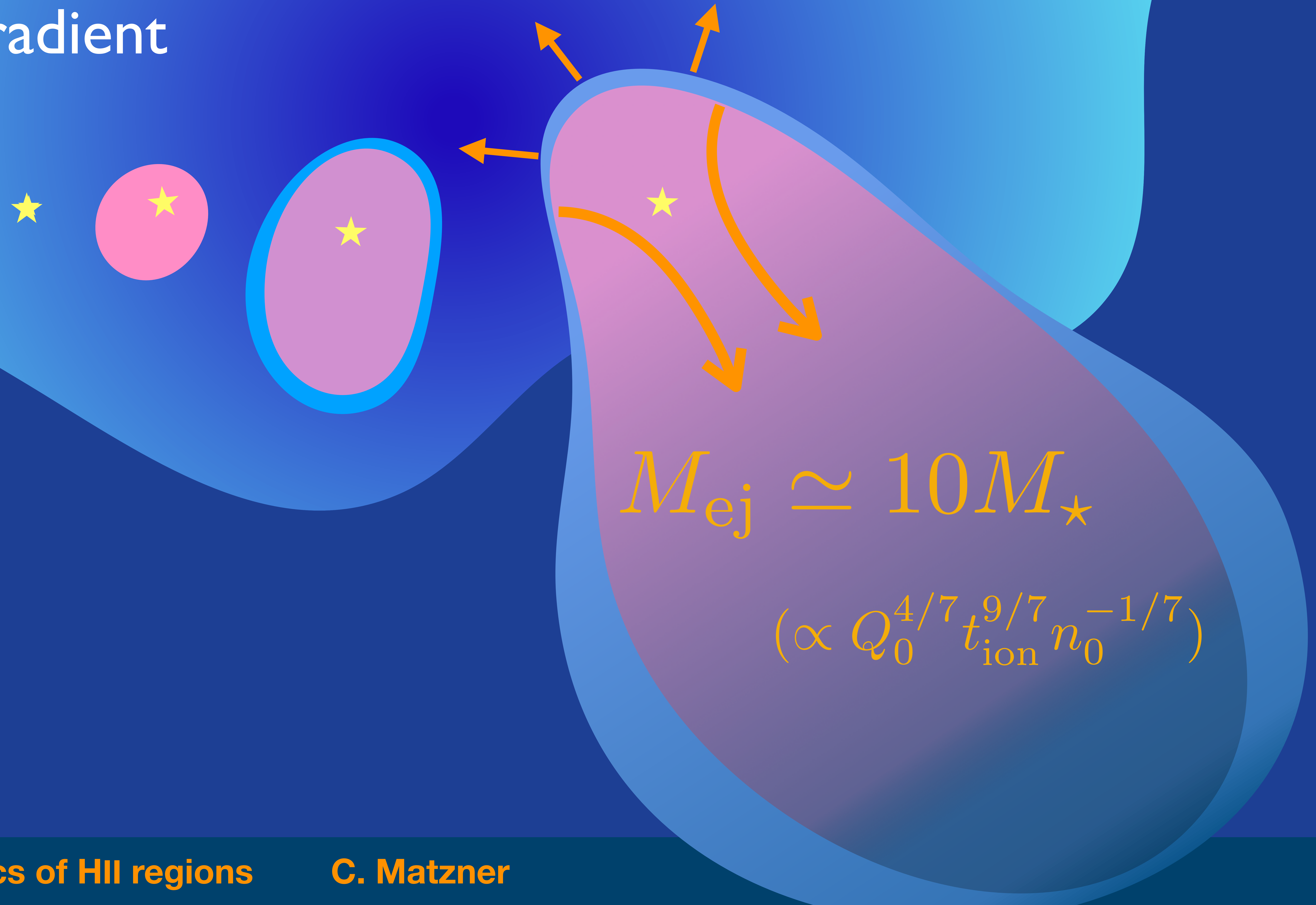


$$M_{\mathrm{ej}} \simeq 10 M_\star$$

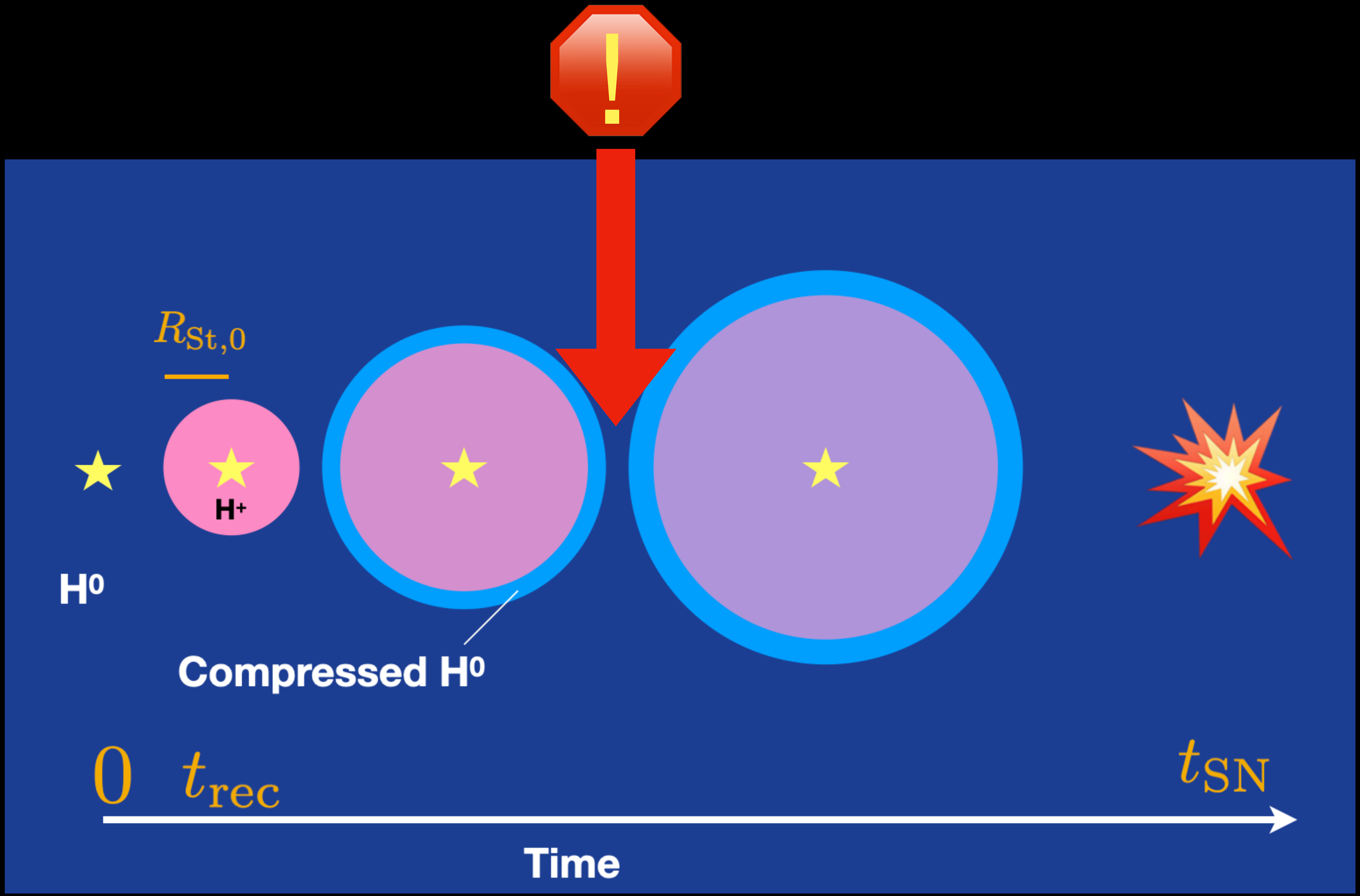
$$(\propto Q_0^{4/7} t_{\mathrm{ion}}^{9/7} n_0^{-1/7})$$

Complication 1: Density gradient

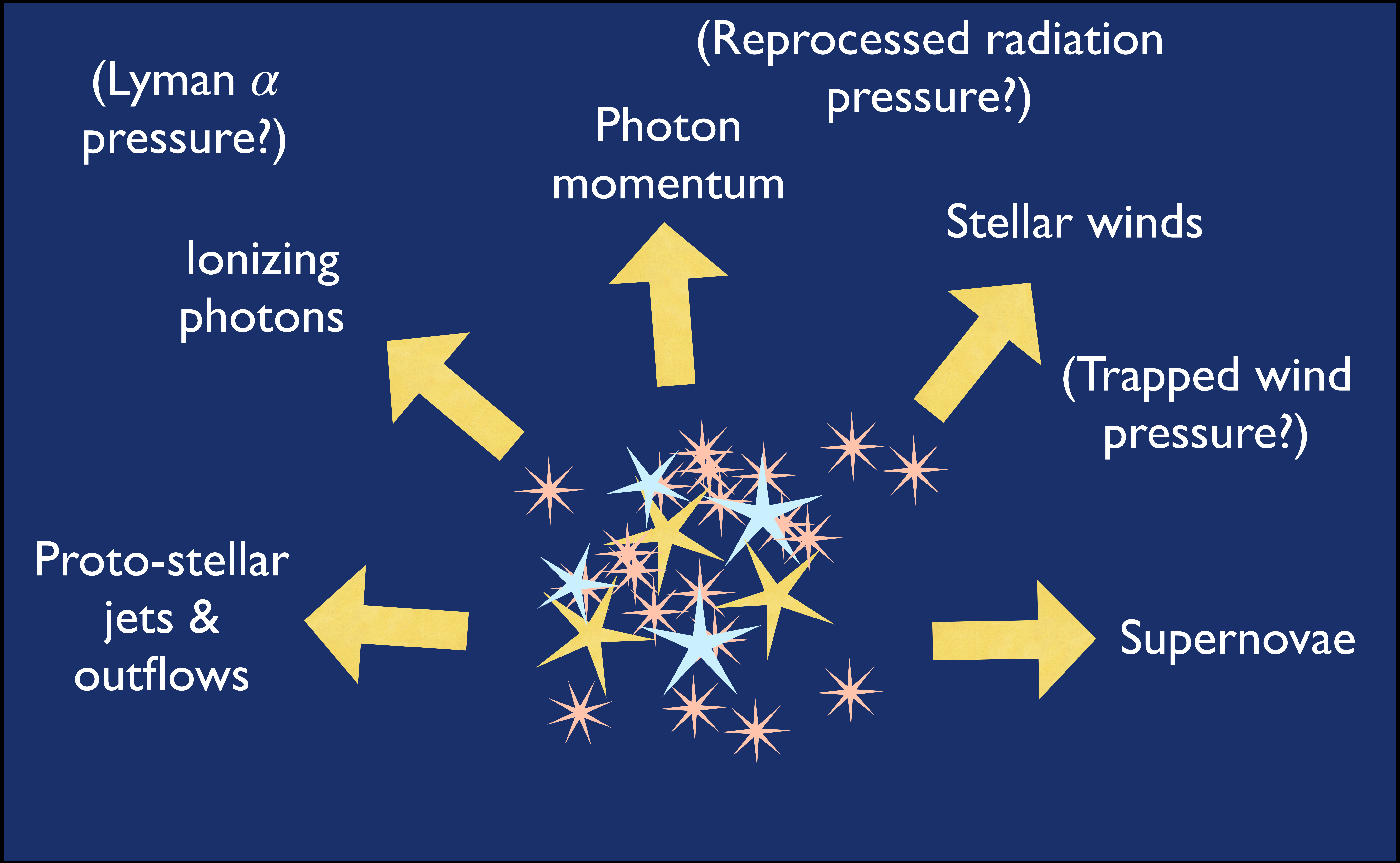
$\delta p \simeq 2 M_{\mathrm{ej}} c_{\mathrm{II}}$



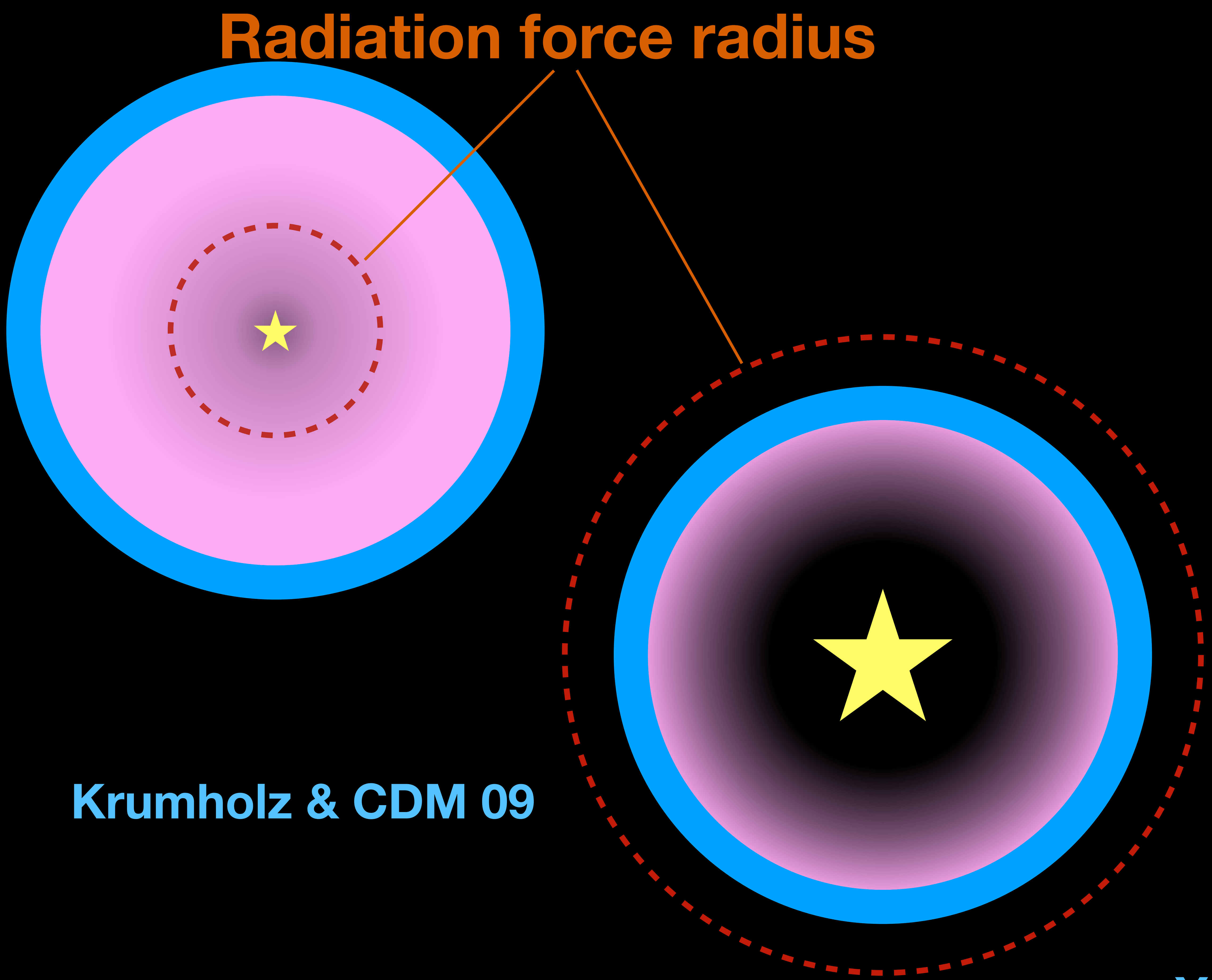
Complication 2: Confinement



Complication 3: Radiation pressure

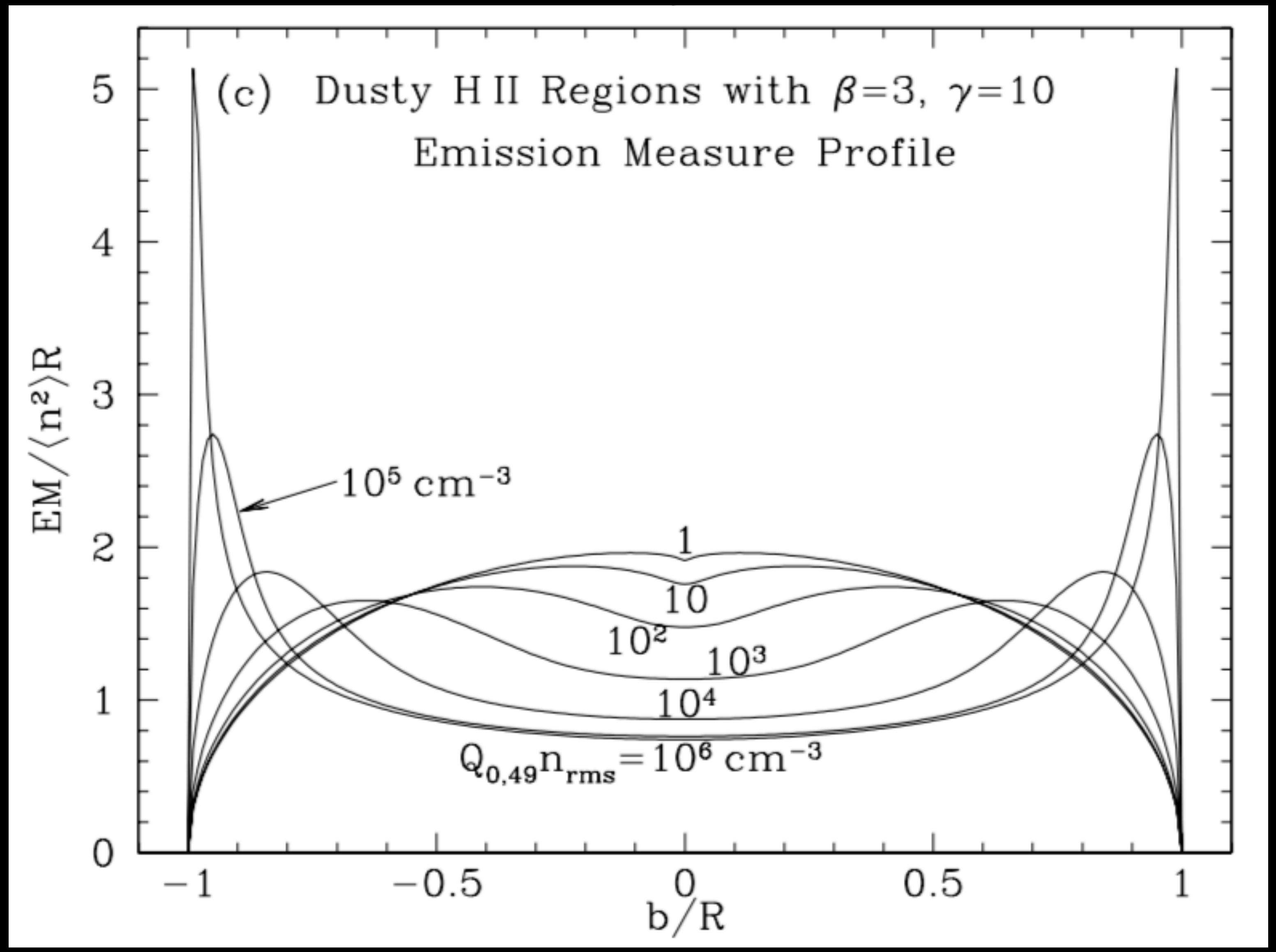


Direct radiation pressure



Krumholz & CDM 09

Draine 2011



Ionization parameter

$$\mathcal{U} = \frac{n_{\gamma,\mathrm{ion}}}{n} \propto \frac{P_{\mathrm{rad}}}{P_{\mathrm{gas}}}$$ **saturates**

Dust optical depth $\tau_d \propto \mathcal{U}$

also saturates

Yeh & CDM 12
Verdolini et al 13

HII rgn. in a cloud: compare the pressures

Assumptions:

Stars: normal-IMF, ZAMS output
Cloud is virialized
Ionized gas at 7000 K
Lyman α pressure: ignored
Working radius: that of cloud

Cloud properties:

Mass/Area: Σ **Star fraction:** f_*

Velocity dispersion: σ

Hydrostatic pressure

$$\sim 0.5 G\Sigma^2$$

Photo-ionized gas pressure

$$\rho_{\rm II} c_{\rm II}^2 \propto f_*^{1/2}\Sigma/\sigma$$

Direct radiation pressure

$$\frac{L_*}{4\pi R^2 c} \propto f_*\Sigma$$

Ionized > hydrostatic

$$\frac{\Sigma}{\rm g\,cm^{-2}}\frac{\sigma}{\rm km\,s^{-1}} < 1.9 f_*^{1/2}$$

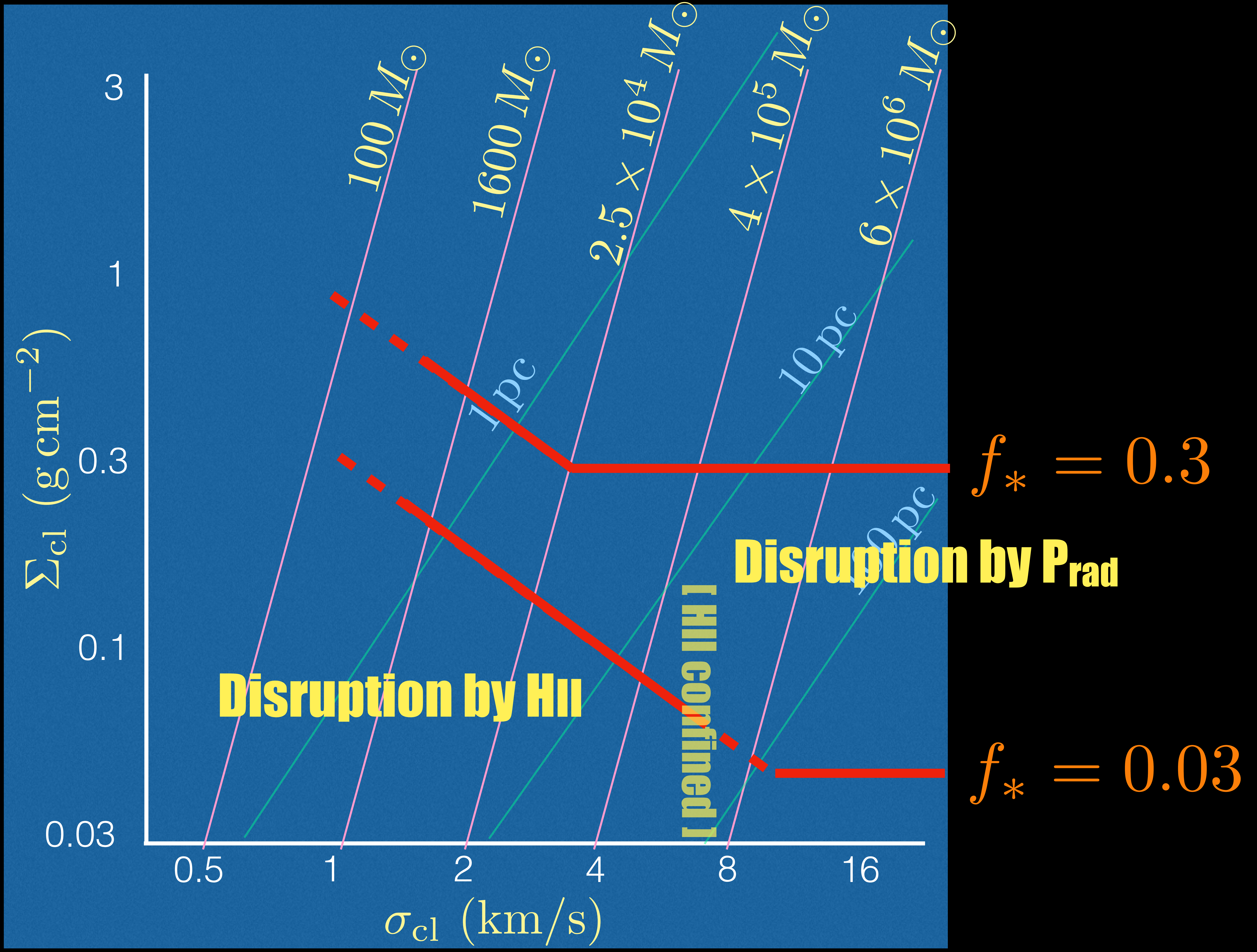
Radiation > hydrostatic

$$\Sigma < 1.2 f_*\ \rm g\,cm^{-2}$$

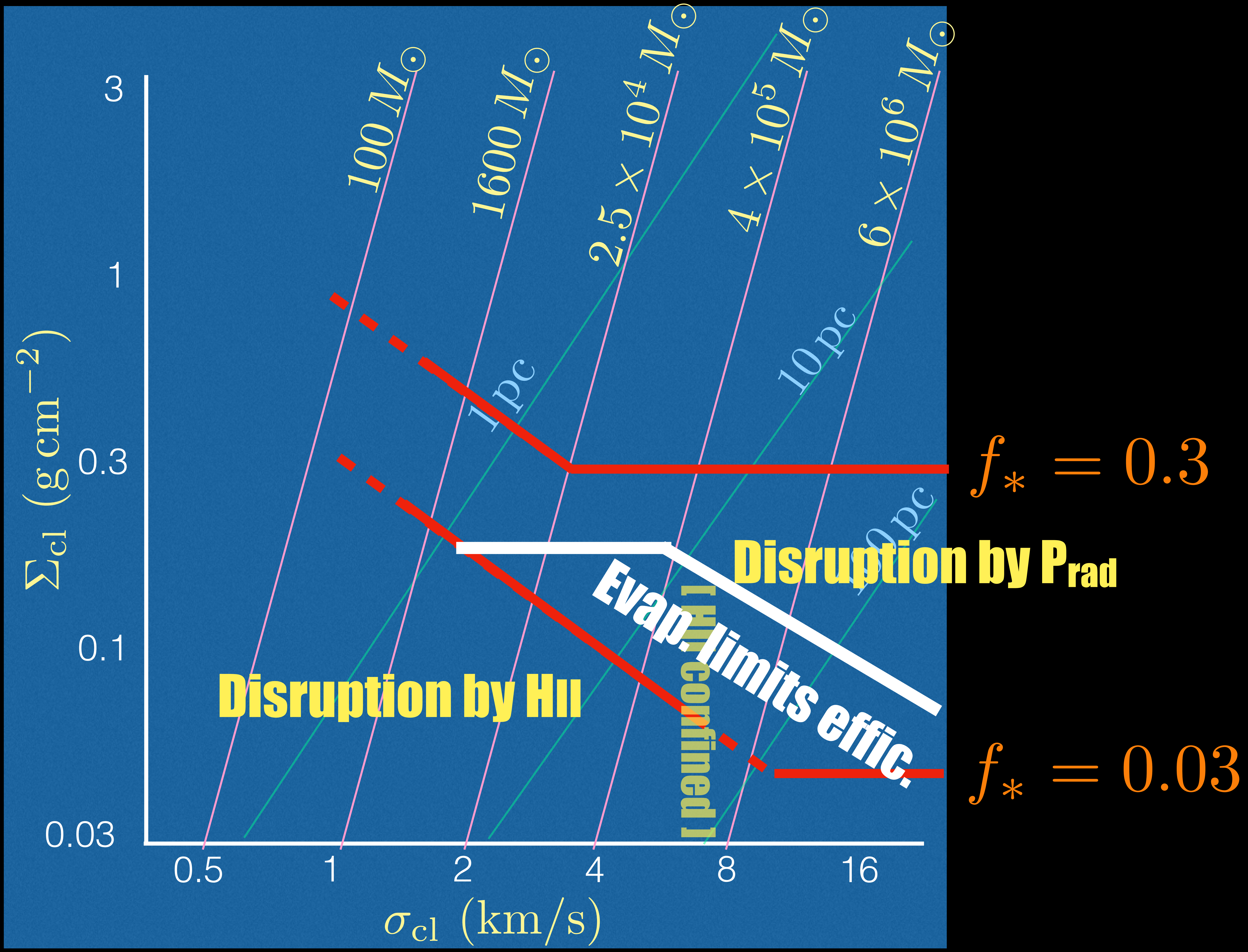
Radiation > Ionized

$$\sigma > \frac{1.6}{f_*}\ \rm km/s$$

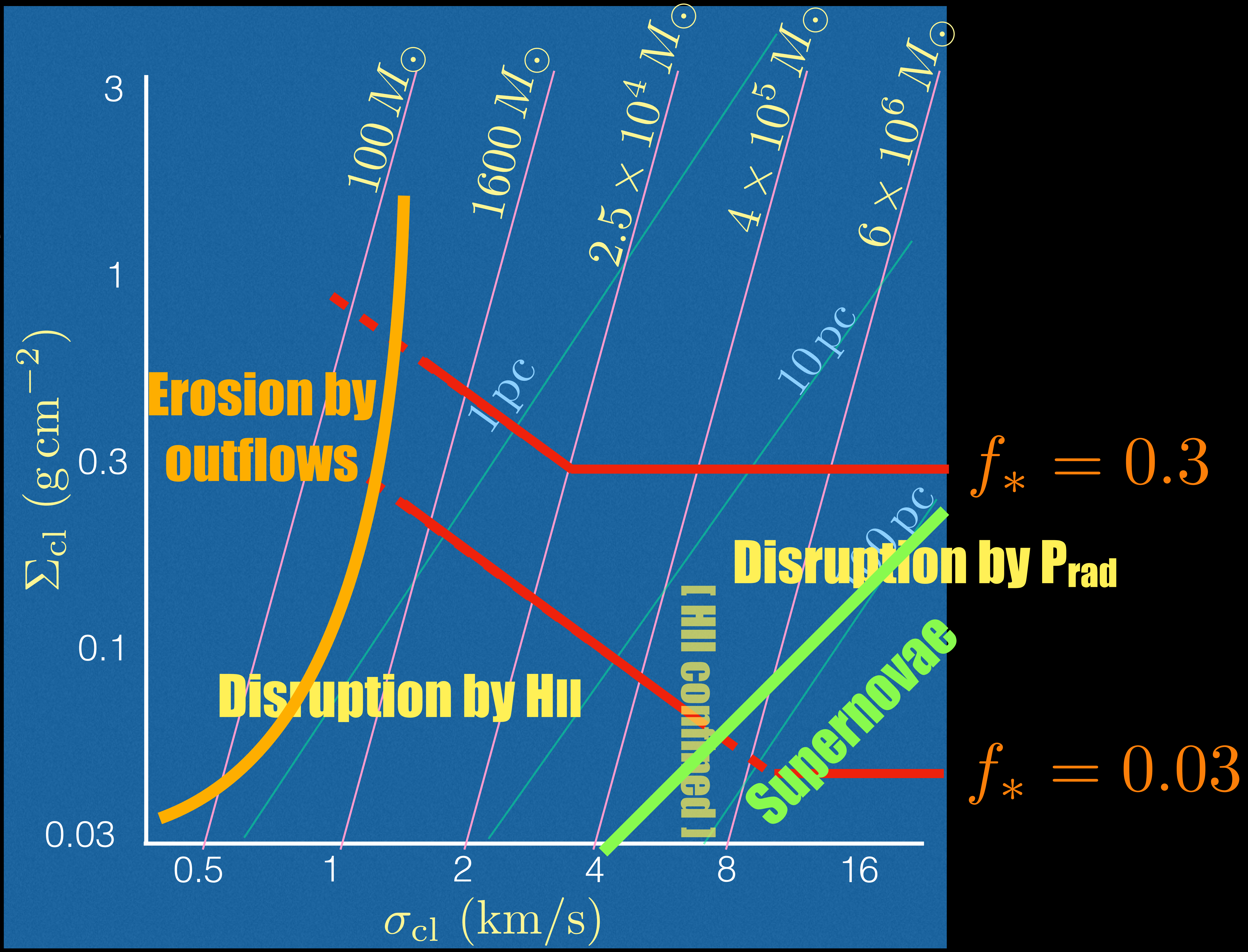
Potential for disruption:



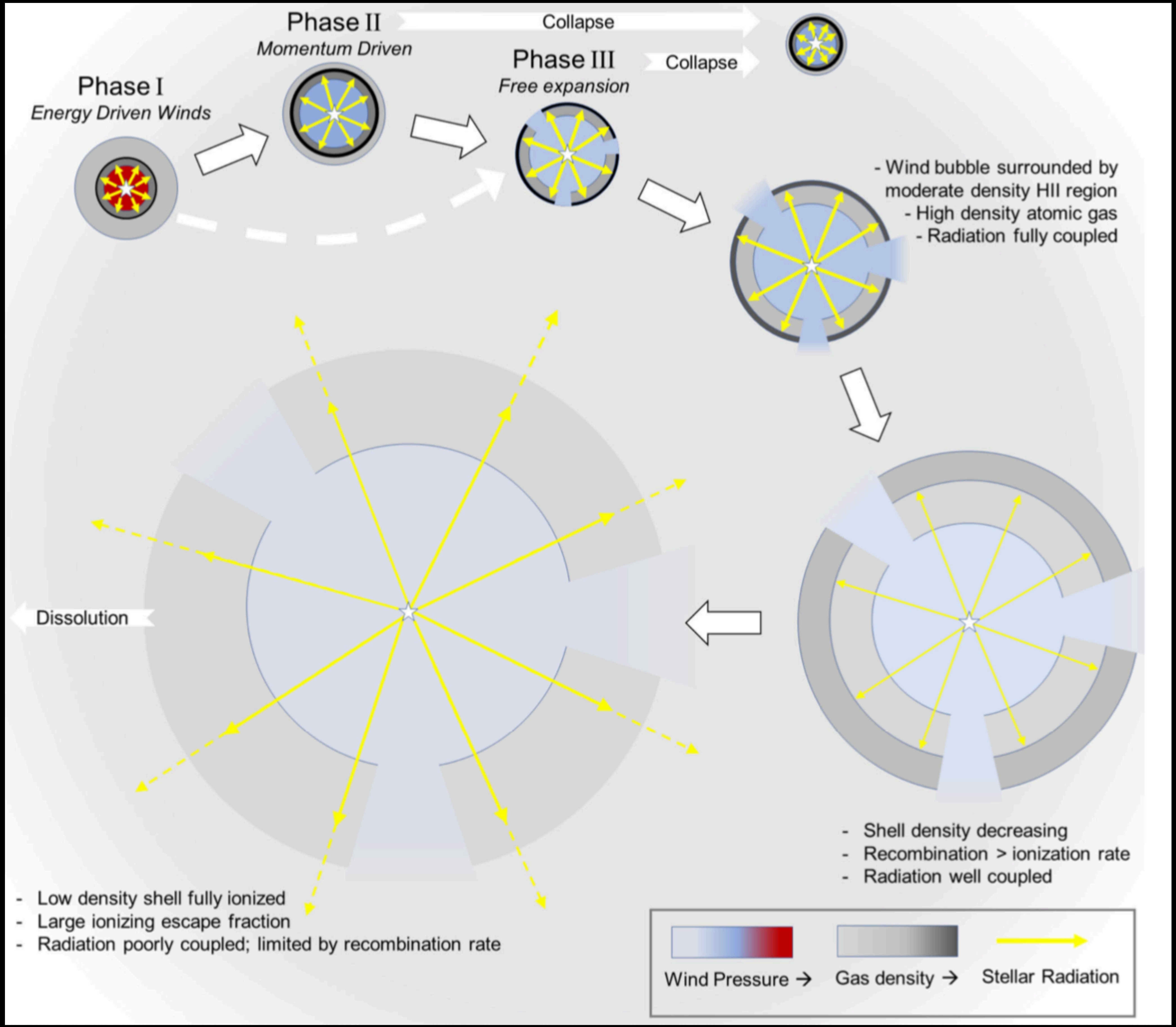
What about evaporation?



Complication 4: Outflows & SNe



Complication 5: Trapped wind pressure?



Rahner+17

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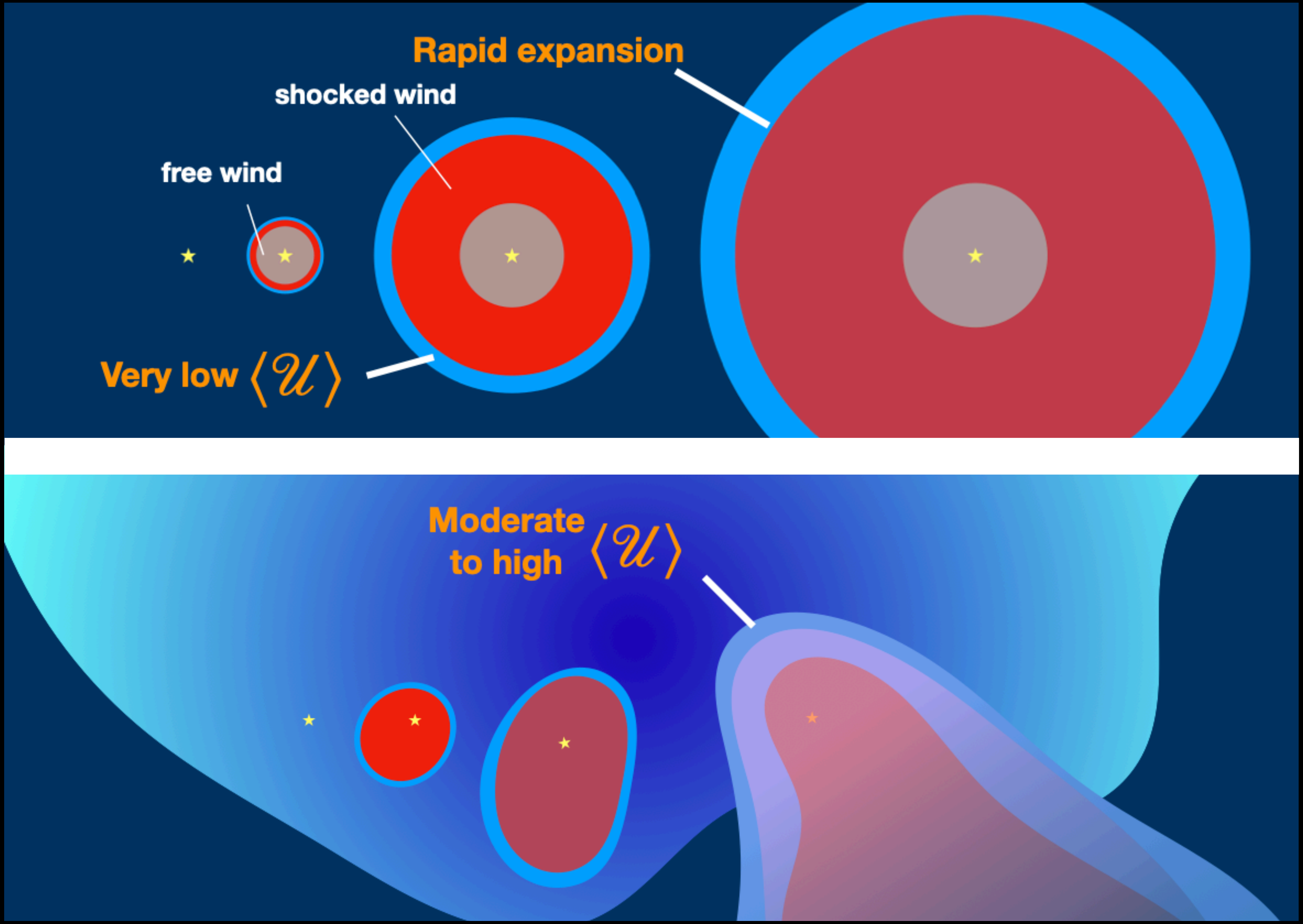

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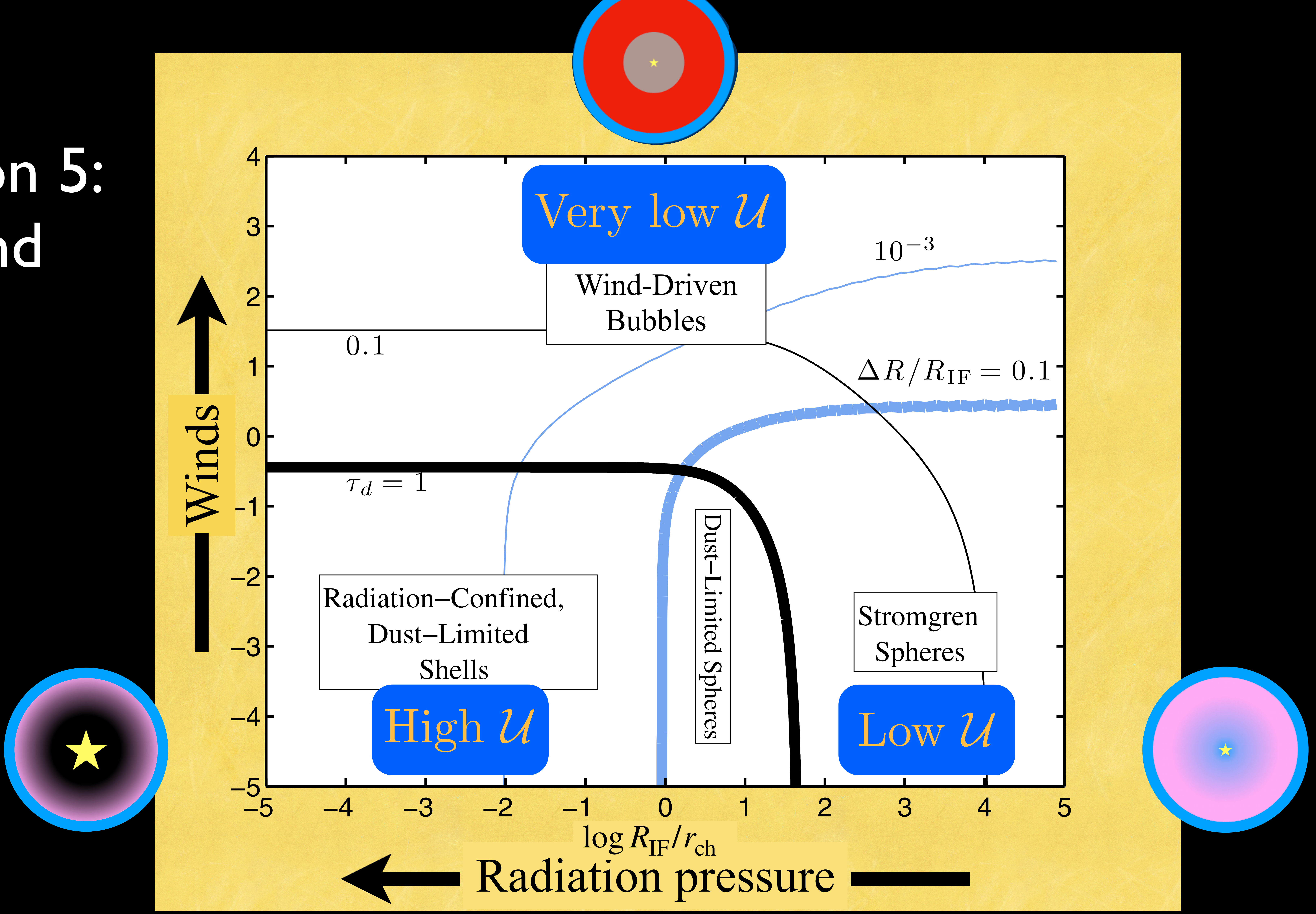
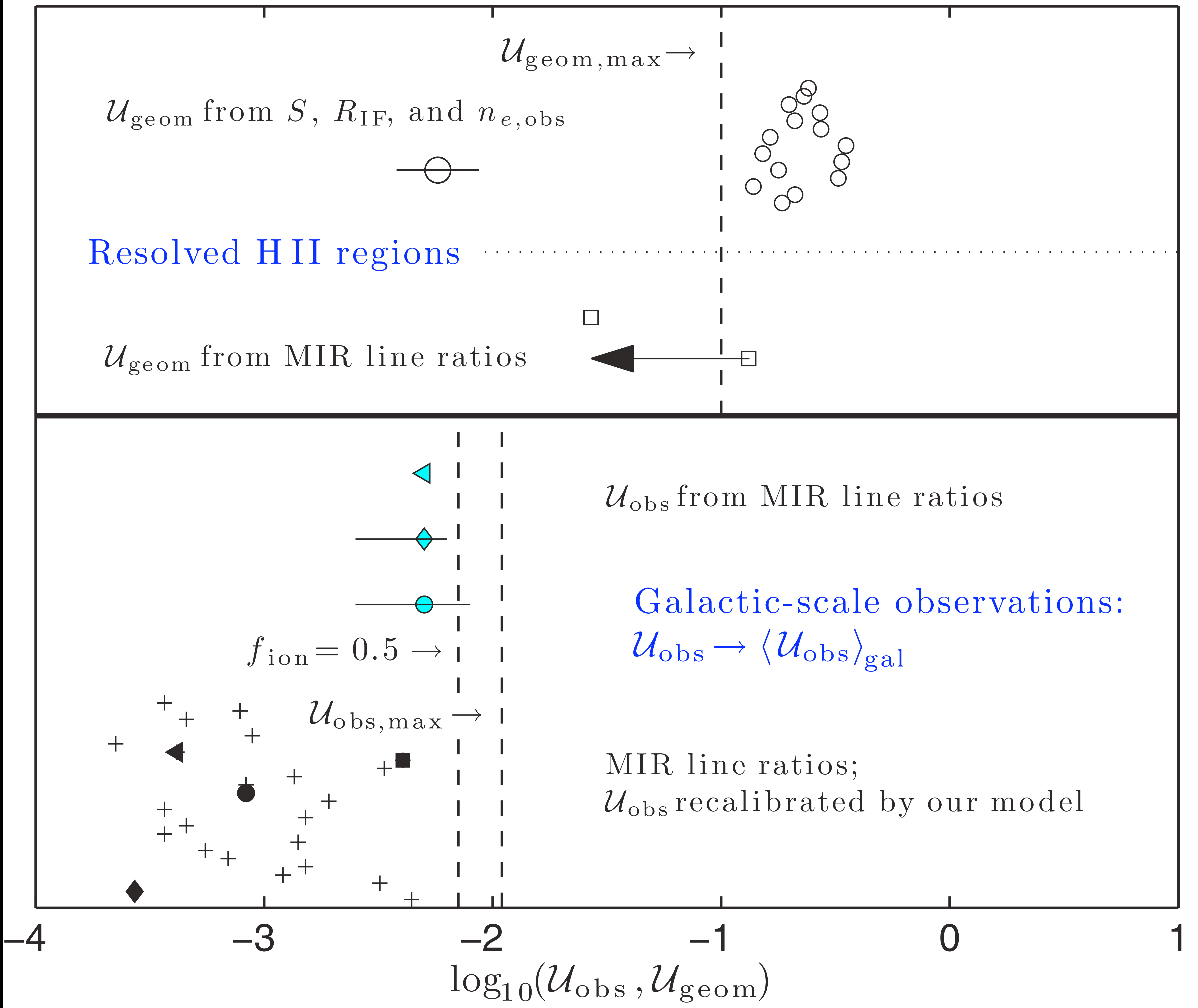


Yeh & CDM 12

Complication 5: Trapped wind pressure?

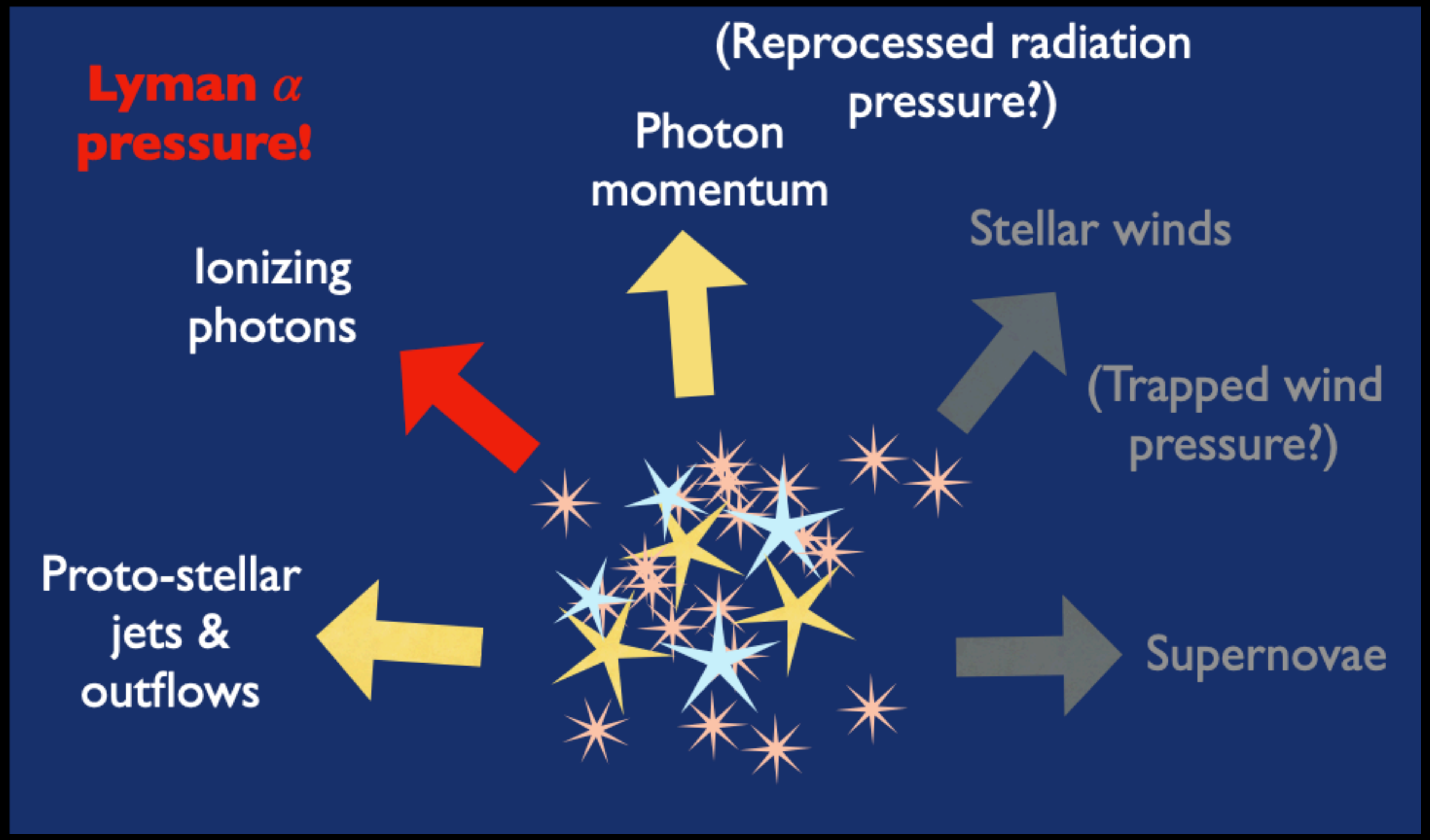


Yeh & CDM 12

Further complications…

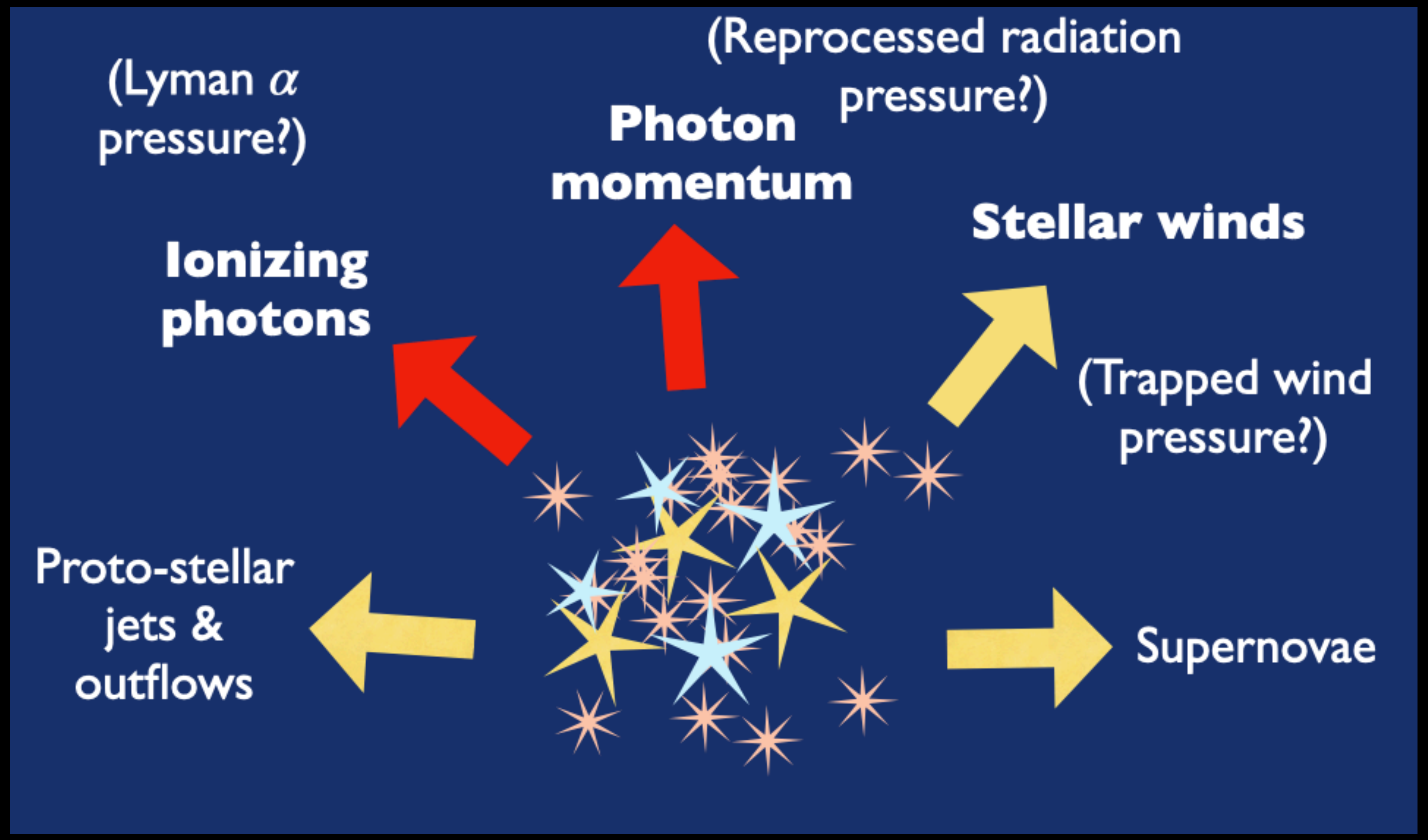
5. Low metallicity

- Winds and supernovae suppressed
- Photo-ionized gas is warmer
- Lyman α photon pressure can be significant
- Very massive stars form more readily



6. Top-heavy IMF

- Luminosity enhanced
- Ionization strongly enhanced



In summary:

HII regions are important for patterning the matter for shocks and for hadronic interactions.

Modelling them analytically is useful even when everything can be simulated.