Astrophysical Gas Dynamics

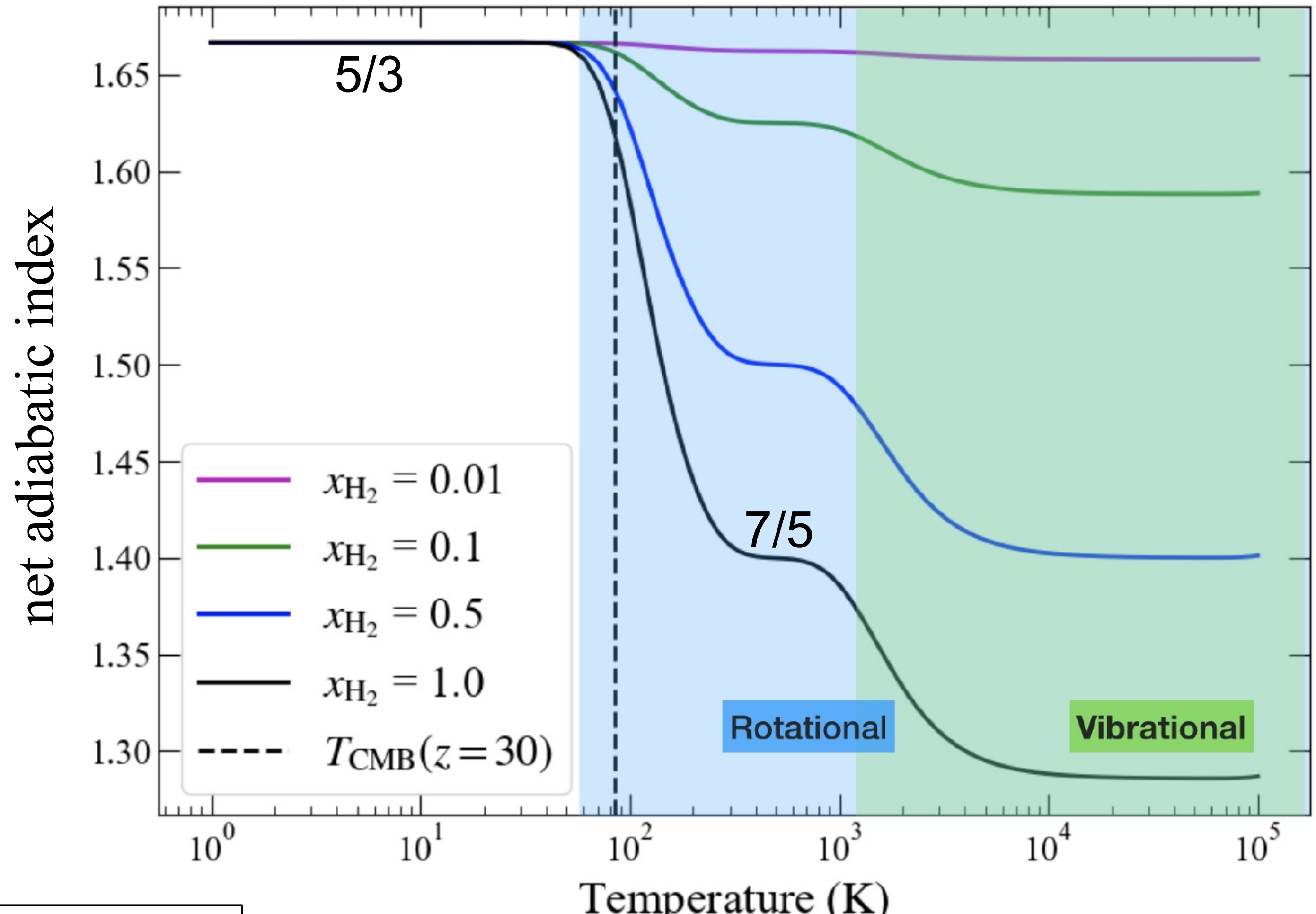
NEXT:

- *Hydrodynamical Equations (recap → notes)*
- *The Equation of State (→ notes)*
- *Derivation of the Energy Equation of Hydrodynamics (→ notes)*

Image credit: M. S. Povich

Adiabatic Index

Temperature dependence of the adiabatic index (γ)



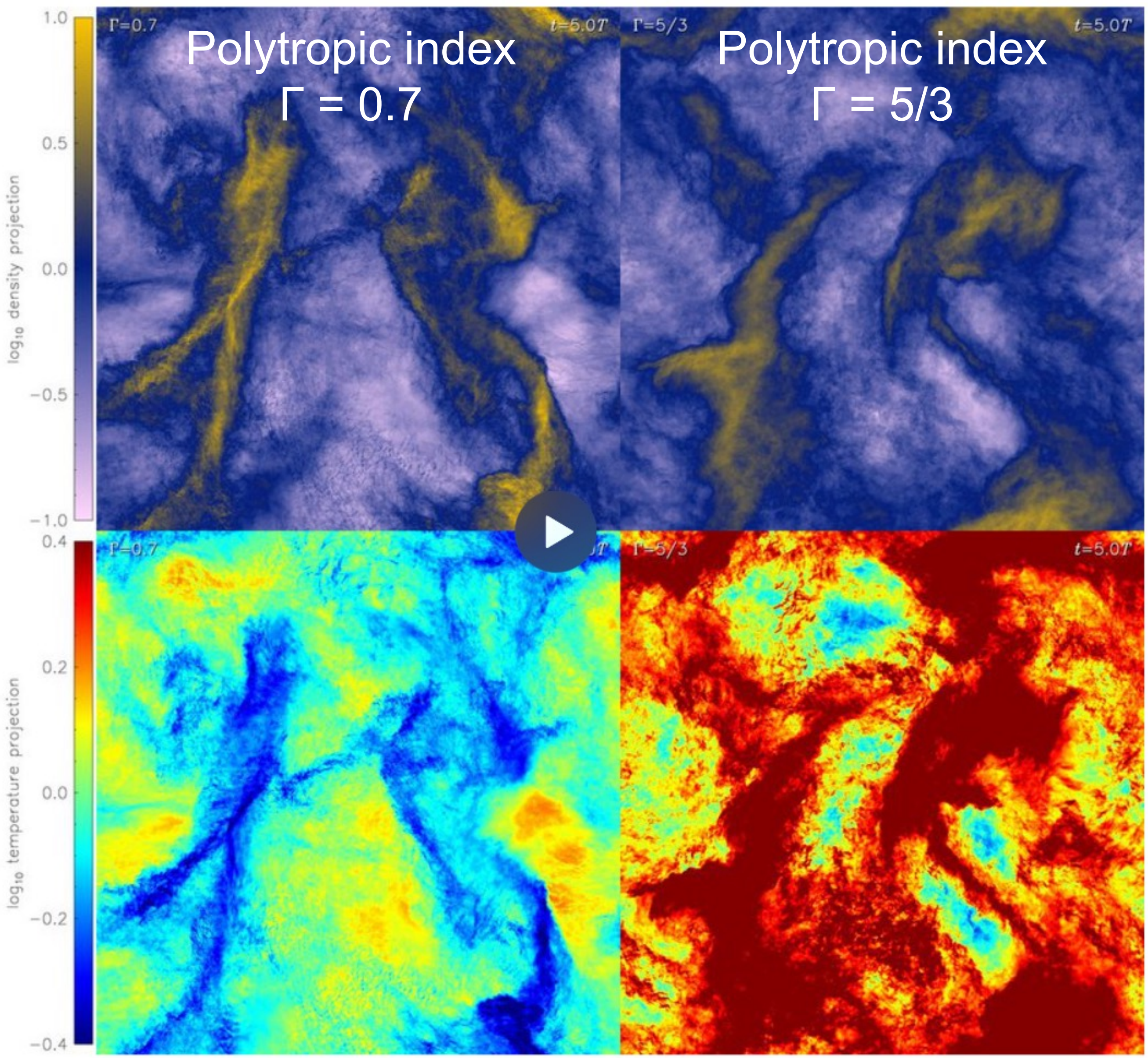
$\gamma = c_P/c_V = 1+2/f$

Number of degrees of freedom (f) depends on excitation of rotational and vibrational states (partition functions: T-dependence).

Sharda et al. (2019)

Equation of State – Polytropic EOS

$$P_{\mathrm{th}} = K\rho^{\Gamma}$$



Density

Temperature

Movies available: http://www.mso.anu.edu.au/~chfeder/pubs/polytropic/polytropic.html

Federrath & Banerjee (2015)

Energy equation with heating and cooling

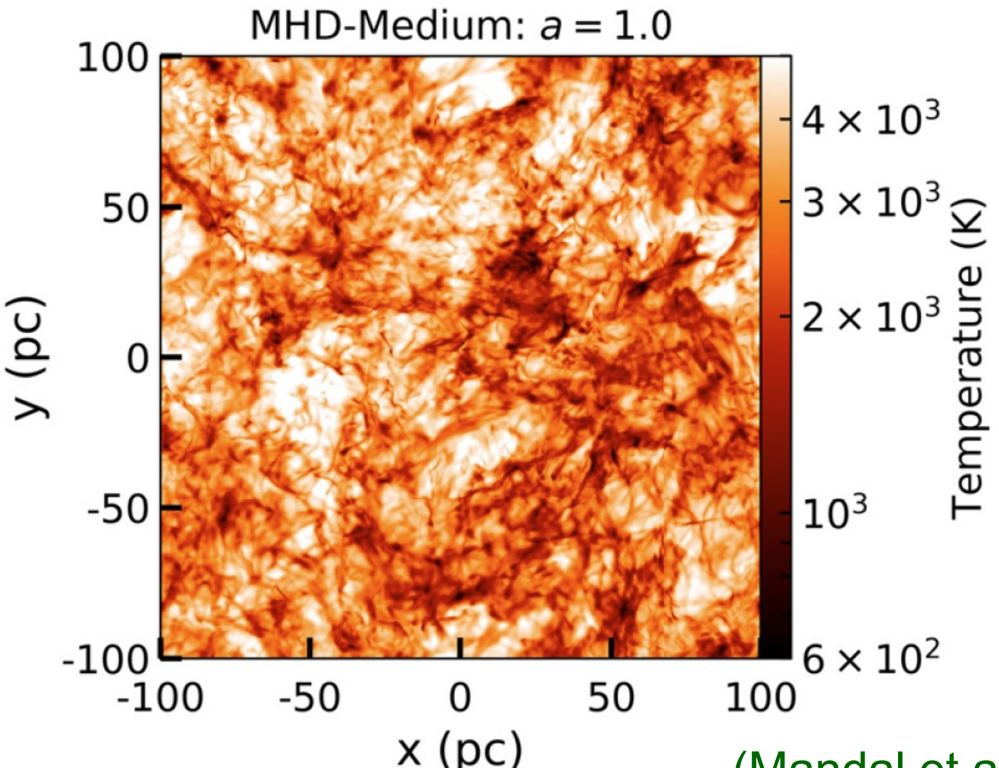
$$\frac{\partial}{\partial t}e_{\rm tot} + \nabla \cdot \left[(e_{\rm tot} + P_{\rm tot})\boldsymbol{v} - \frac{1}{4\pi}(\boldsymbol{B}\cdot\boldsymbol{v})\boldsymbol{B}\right] = \frac{1}{\rho}\left[\frac{\rho}{\mu m_{\rm H}}\Gamma - \left(\frac{\rho}{\mu m_{\rm H}}\right)^2 \Lambda(T)\right]$$

Heating:

$$\Gamma = 2\times 10^{-26}\ \mathrm{erg\ s^{-1}}$$

Cooling:

$$\frac{\Lambda(T)}{\Gamma} = 10^7 \exp\left(\frac{-1.184\times 10^5}{T+1000}\right) + 1.4\times 10^{-2}\sqrt{T}\exp\left(\frac{-92}{T}\right)\ \mathrm{cm^3}$$



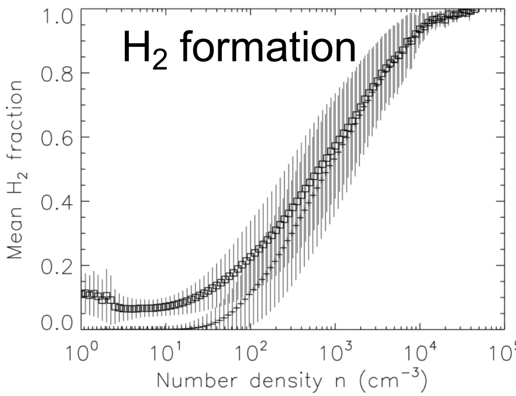
- Photoelectric heating from small grains and polycyclic aromatic hydrocarbons (PAHs)
- Heating and ionization from cosmic rays and X-rays
- H_2 formation and destruction
- Atomic and molecular line cooling

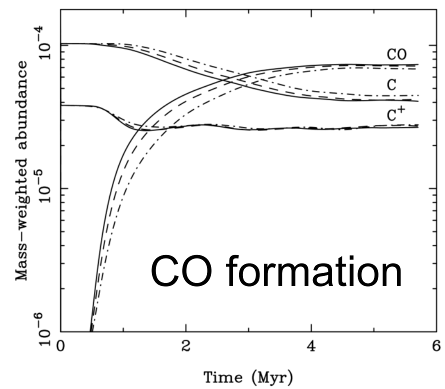
(Sutherland & Dopita 1993; Koyama & Inutsuka 2002; Vazquez-Semadeni et al. 2007)

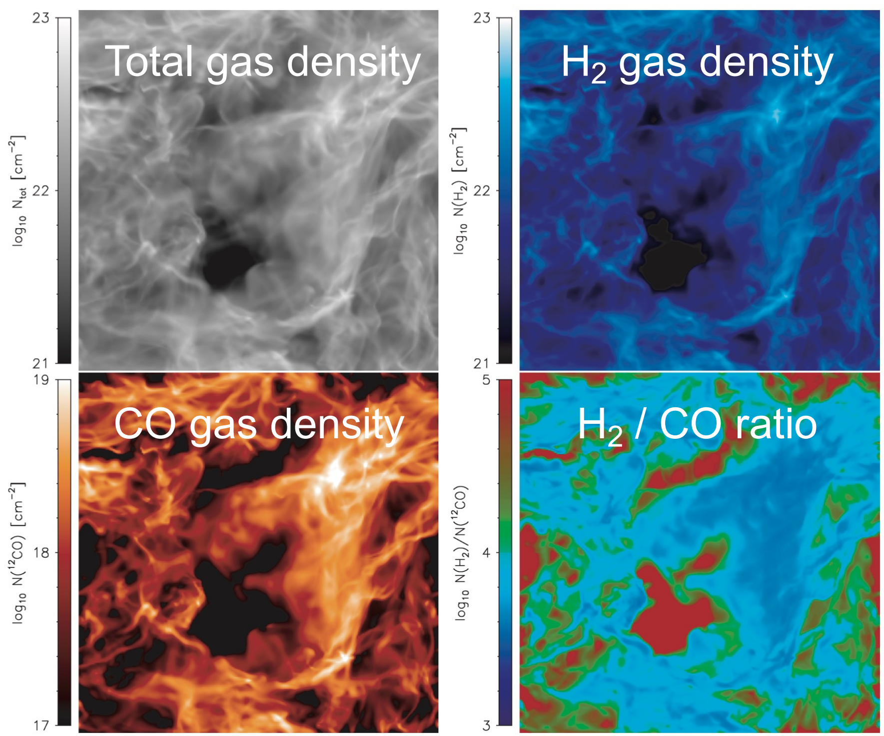
(Mandal et al. 2020)

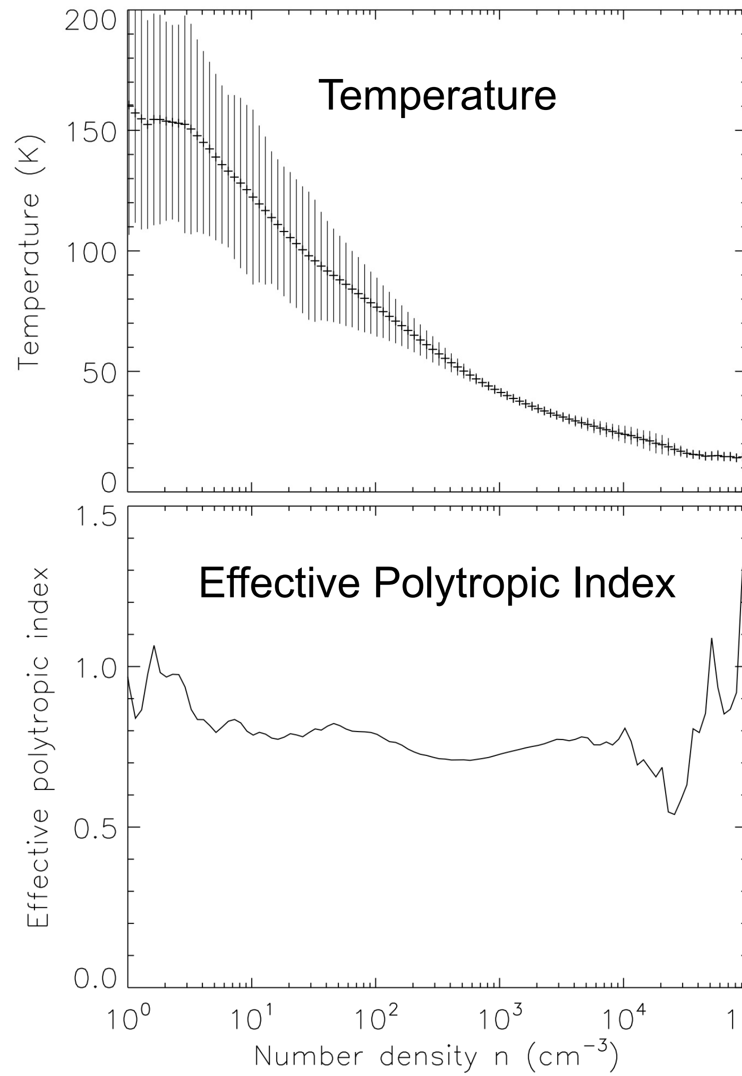
Equation of State – Chemistry / Heating / Cooling

Chemistry / Heating / Cooling: (Glover et al. 2007, 2010)



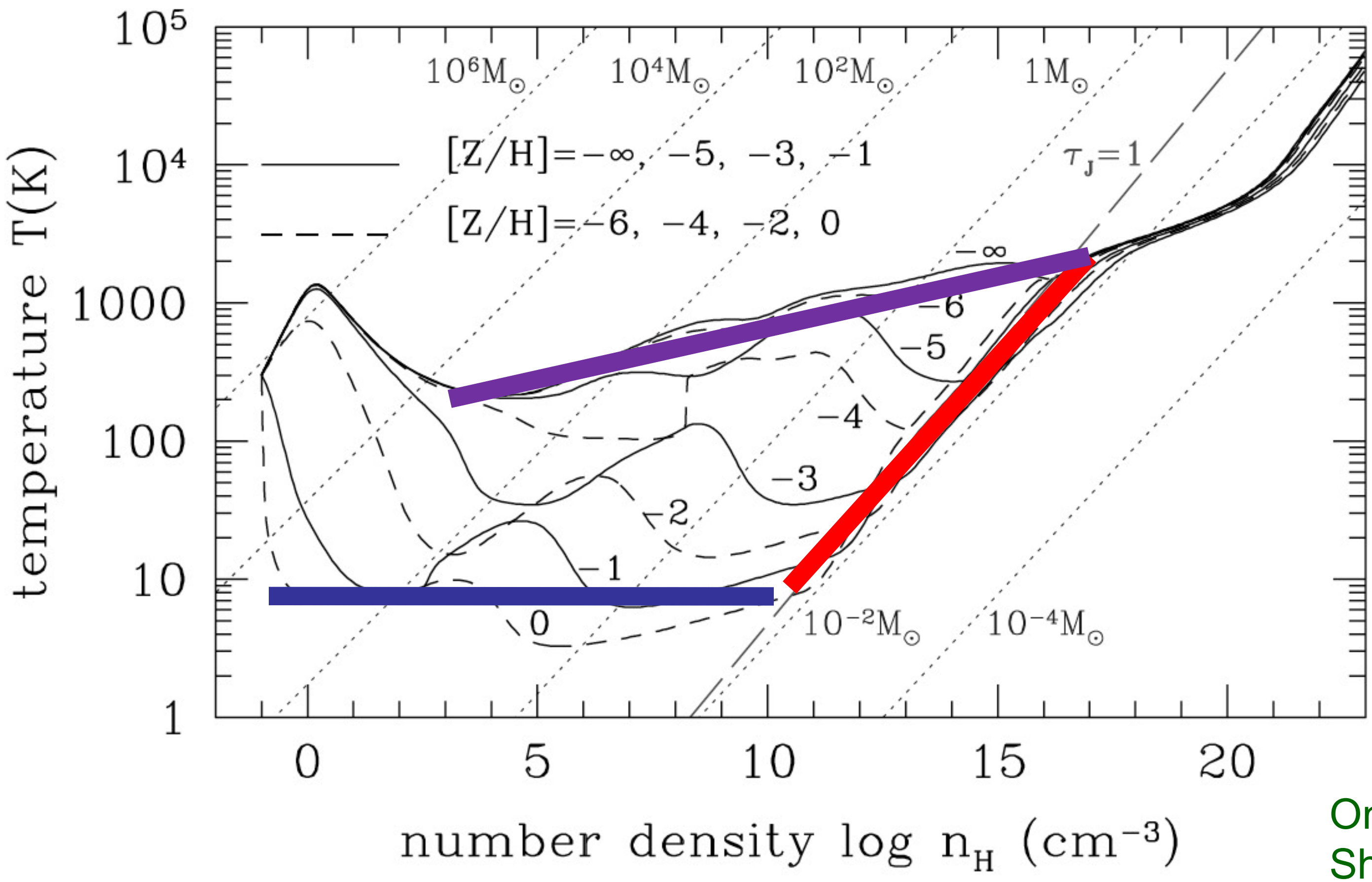






Equation of State – Chemistry / Heating / Cooling

Chemistry / Heating / Cooling: (Glover+07,10, Micic+12, Clark+12)



Omukai et al. (2005);
Sharda et al. (2020)

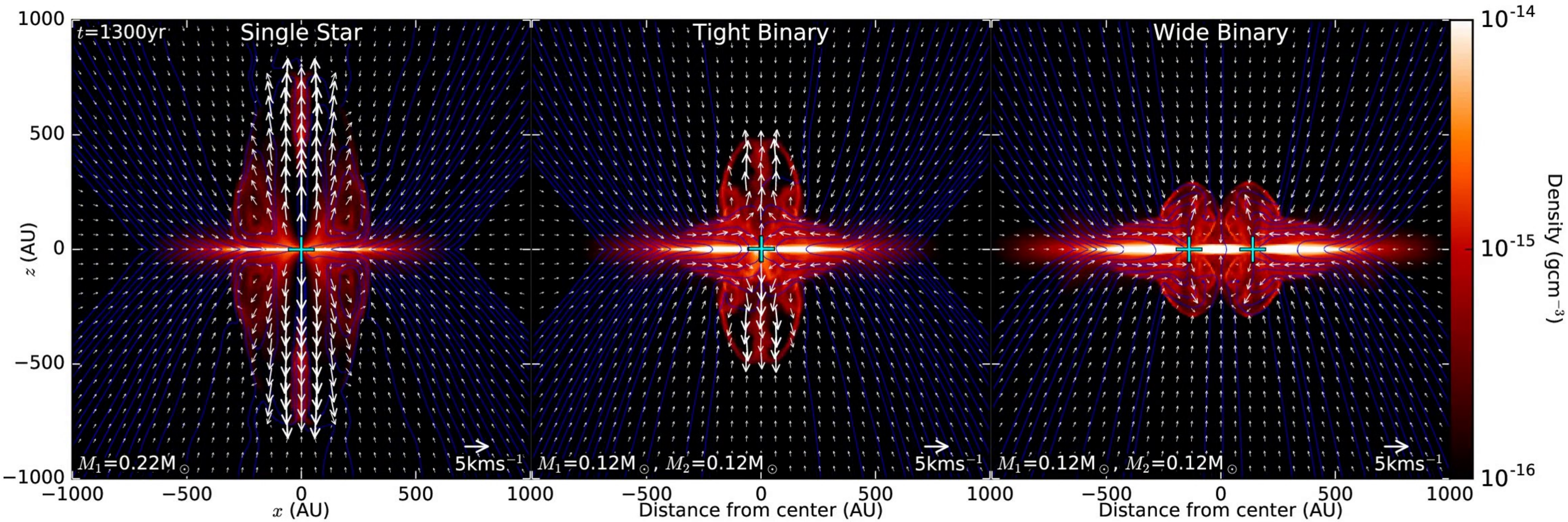
Molecule formation in high-density gas: $t_{form} \sim 1/n$

Micic et al. (2012),
Hollenbach et al. (1971)

Equation of State – Polytropic EOS for Star Formation

$$P_{\mathrm{th}} = K\rho^{\Gamma} \quad \text{with} \quad \Gamma = \begin{cases} 1 & \text{for} \quad \rho \le \rho_1 \equiv 2.50 \times 10^{-16}\,\mathrm{g\,cm^{-3}}, \\ 1.1 & \text{for} \quad \rho_1 < \rho \le \rho_2 \equiv 3.84 \times 10^{-13}\,\mathrm{g\,cm^{-3}}, \\ 1.4 & \text{for} \quad \rho_2 < \rho \le \rho_3 \equiv 3.84 \times 10^{-8}\,\mathrm{g\,cm^{-3}}, \\ 1.1 & \text{for} \quad \rho_3 < \rho \le \rho_4 \equiv 3.84 \times 10^{-3}\,\mathrm{g\,cm^{-3}}, \\ 5/3 & \text{for} \quad \rho > \rho_4 . \end{cases}$$

Movies available:
https://www.mso.anu.edu.au/~chfeder/pubs/binary_jets/binary_jets.html



Kuruwita et al. (2017); Gerrard et al. (2018)