Astrophysical Gas Dynamics

TODAY:

- *Python (RSAA computer account)*
- *Bondi accretion, Bondi-Hoyle accretion, Shu accretion rate (→ recap)*
- *Steepening of sound waves → shocks (Rankine-Hugoniot conditions)*
- *Propagation of a 1-dimensional (1D) shock front*

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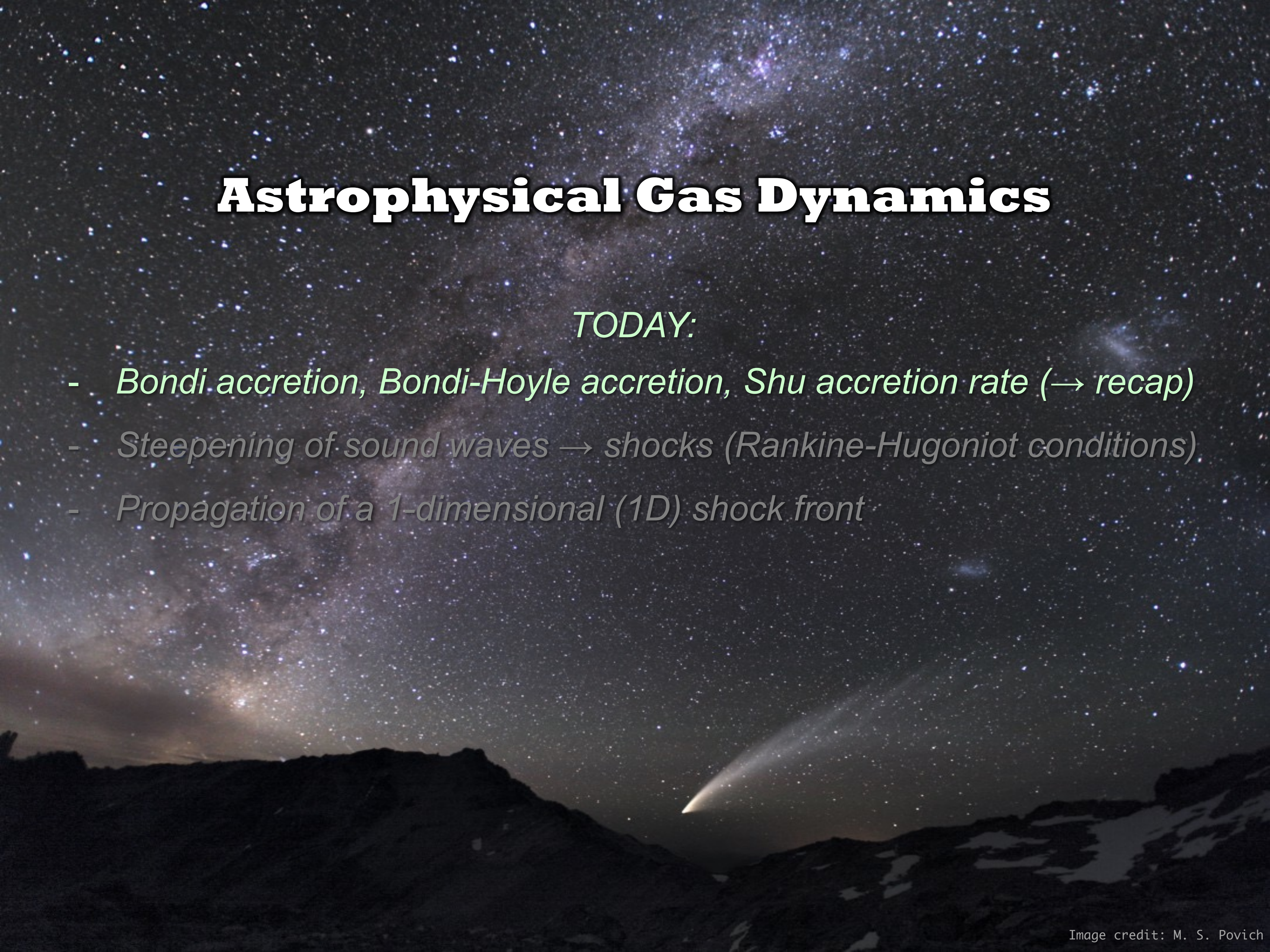
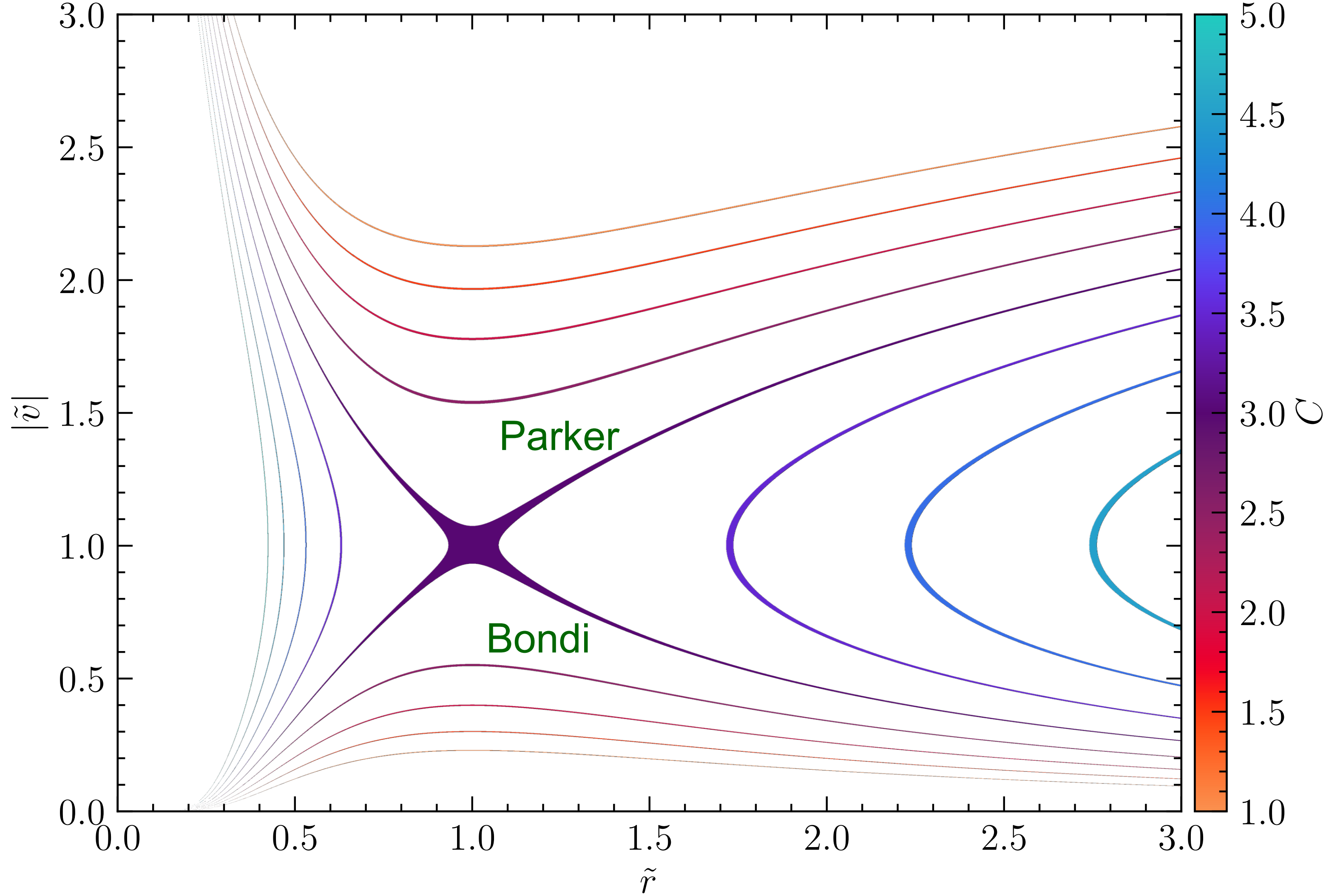


Image credit: M. S. Povich

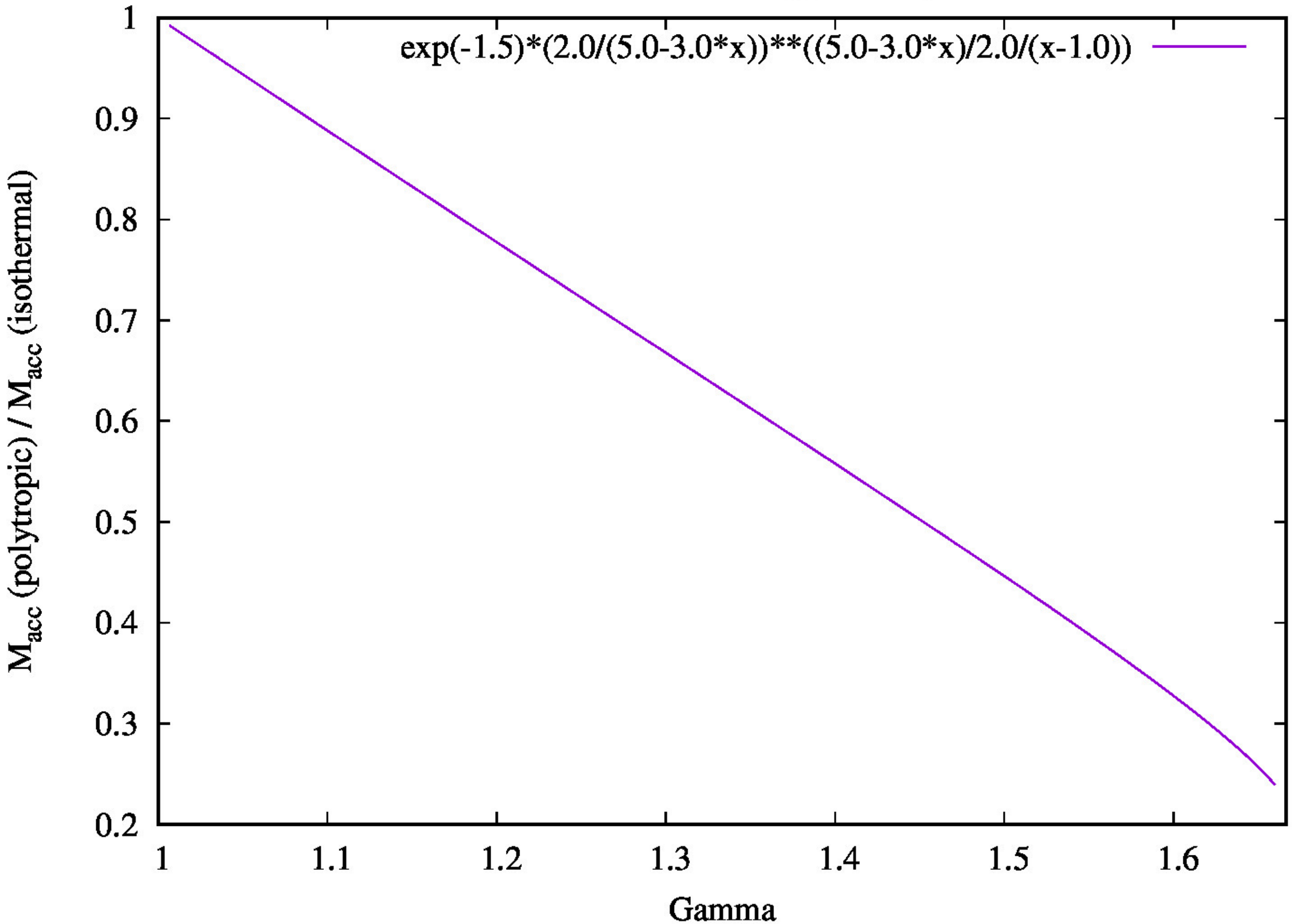
Parker wind versus Bondi accretion

$$\tilde{v}^2 - \log \tilde{v}^2 = 4 \log \tilde{r} + \frac{4}{\tilde{r}} - C$$



Bondi accretion (influence of the EOS)

Bondi accretion rate for isothermal versus adiabatic gas
(Polytropic EOS: $P_{\rm th} = K\rho^{\Gamma}$)



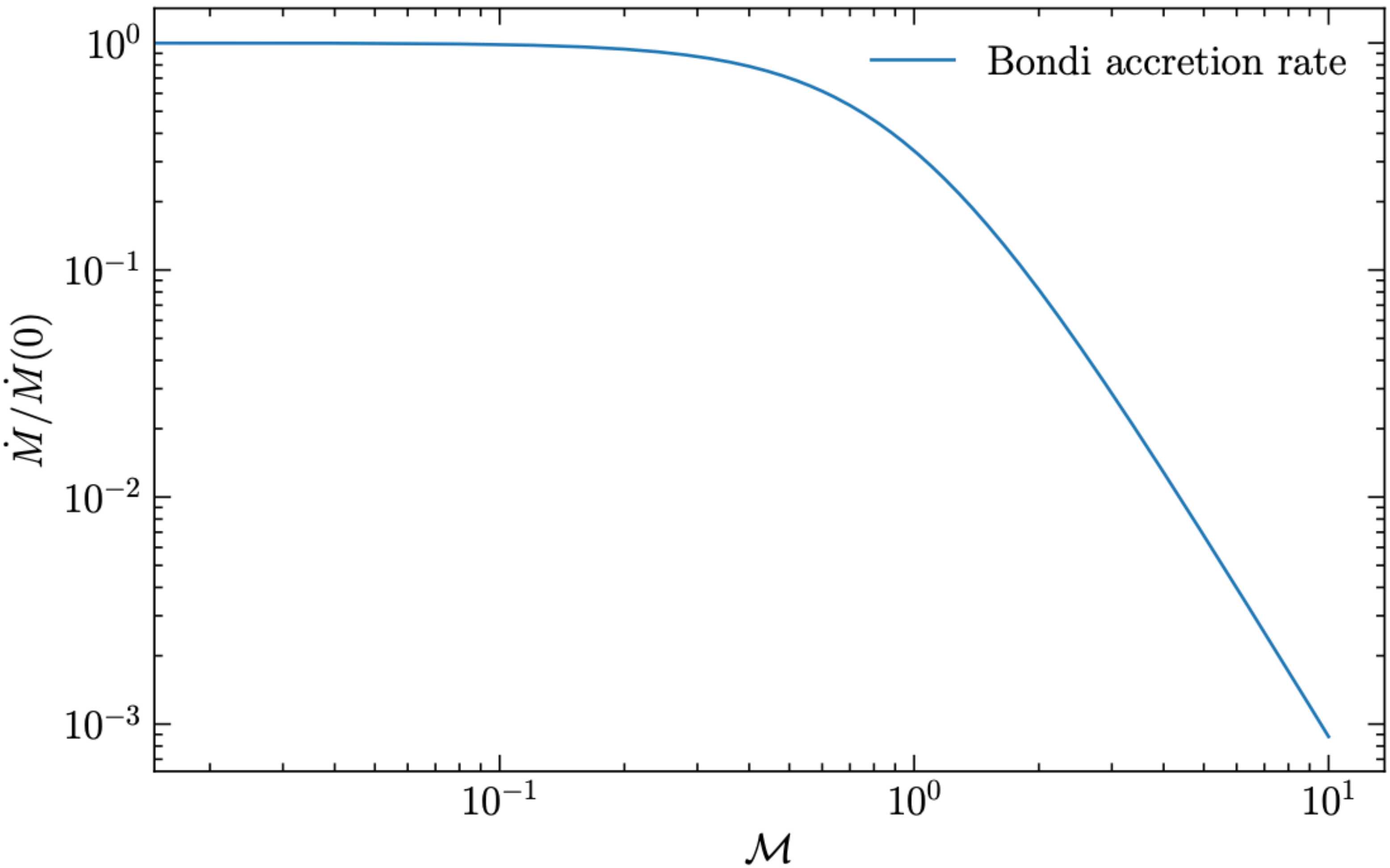
Why is the accretion rate higher for lower Gamma?

Bondi-Hoyle accretion

$$\dot{M}_{\rm BH} = 4\pi\rho_\infty G^2 M^2 c_\infty^{-3}\left[\frac{\lambda^2+\mathcal{M}^2}{\left(1+\mathcal{M}^2\right)^4}\right]^{1/2}$$

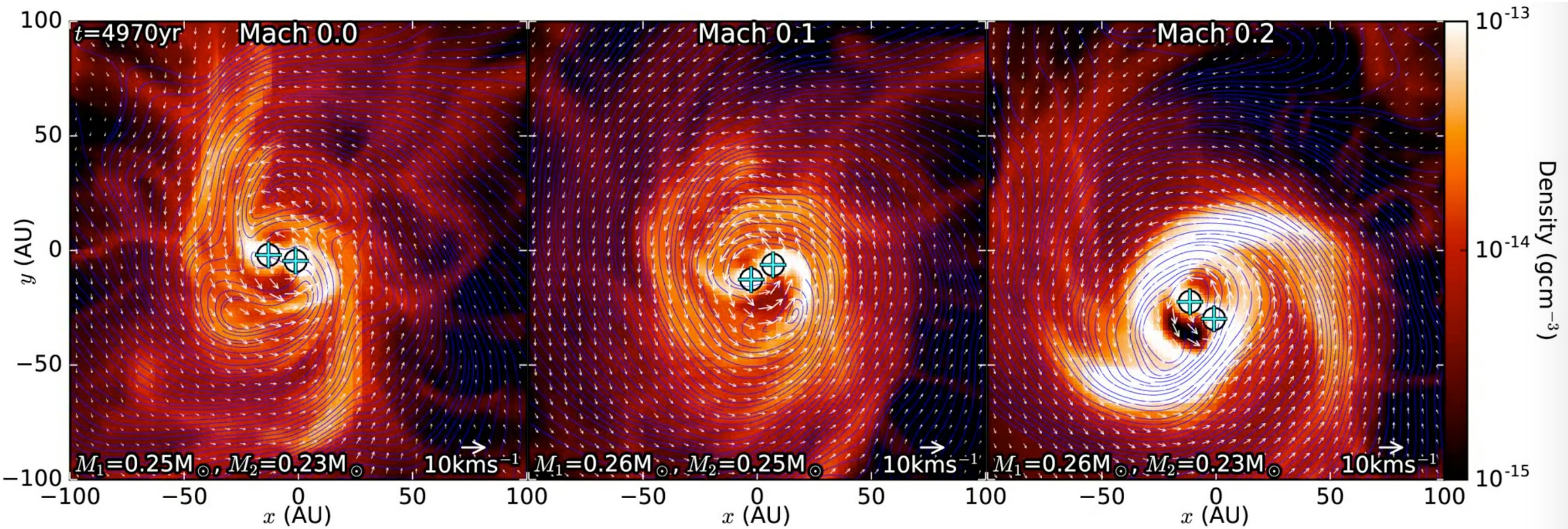
For $\mathcal{M}=0$ (Bondi accretion)

$\lambda = \exp(1.5)/4$ in an isothermal medium



Build-up of circum-binary discs

No Turbulence | **Low Turbulence** | **Normal Turbulence**



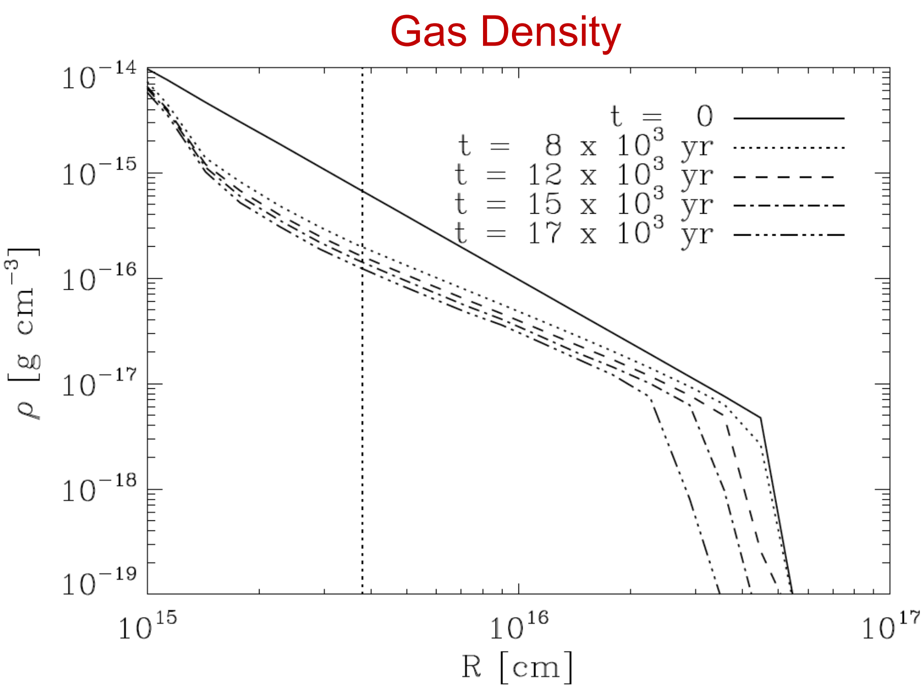
Movies available: https://www.mso.anu.edu.au/~chfeder/pubs/binary_turb/binary_turb.html

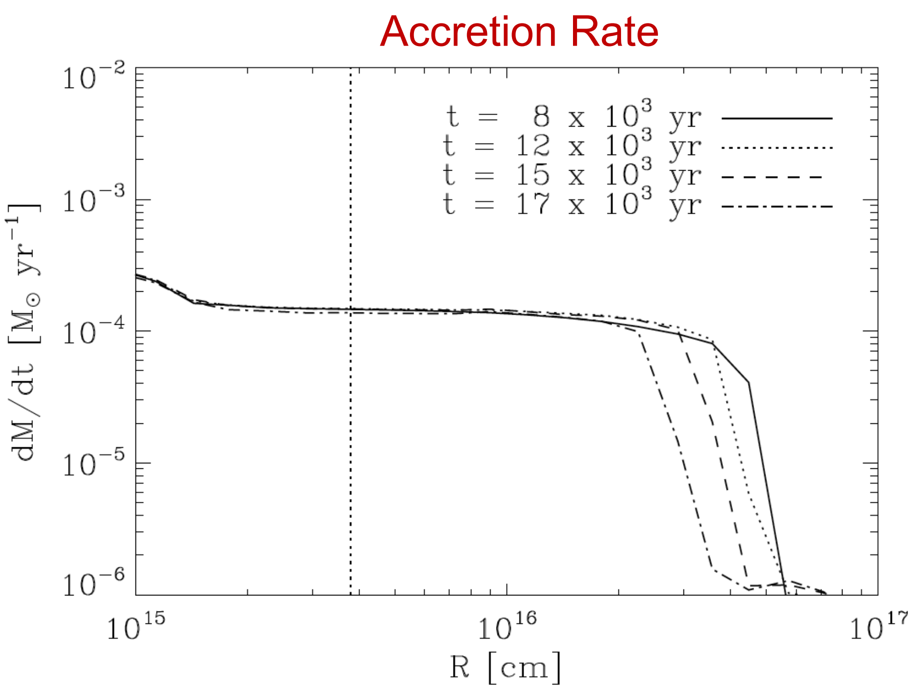
Turbulence makes bigger discs → relevant for planet formation

Kuruwita & Federrath (2019)

Collapse of a singular isothermal gas sphere

Accretion rate: $\dot{M} = m_0 \frac{c_s^3}{G}$ (Shu 1977)





(Federrath et al. 2010)

Shu accretion rate

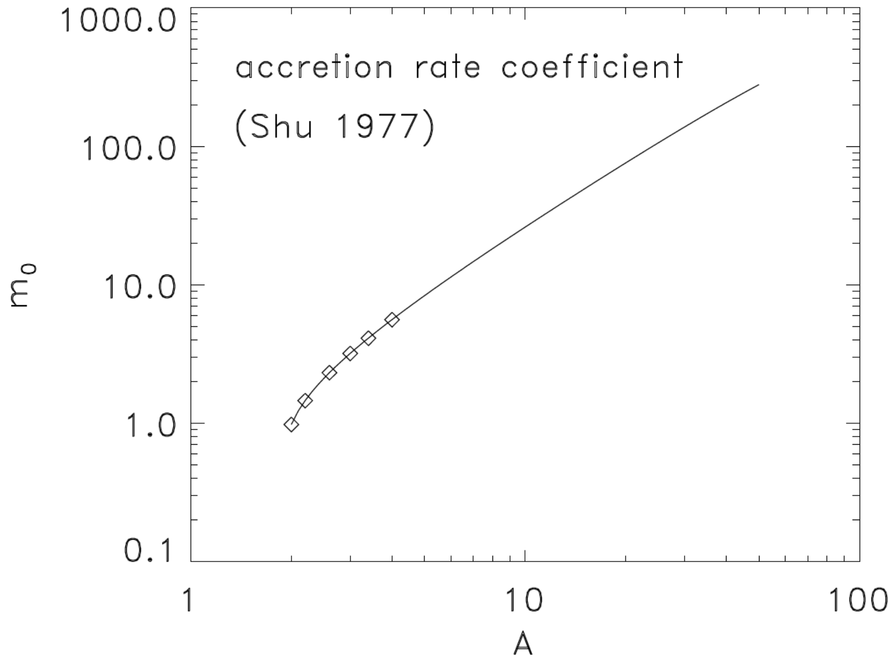
Collapse of a singular isothermal gas sphere

Shu (1977)

$$\dot{M} = m_0 \frac{c_\mathrm{s}^3}{G} \quad \text{with} \quad m_0 \;=\; 0.975 \quad \text{would give} \; m_0 c_\mathrm{s}^3/G = 1.06 \times 10^{-6}\, M_\odot\, \mathrm{yr}^{-1}$$

...but here, the gas cloud is highly unstable!

Accretion Rate Coefficient



Instability parameter $A = 4\pi G\, \rho(R)\, R^2/c_\mathrm{s}^2$

With A = 29, we get m_0 ~ 130, which gives exactly the correct accretion rate.

Conclusion:
Beware, m_0 is not necessarily 1.
And hence c_s^3/G may be way off!

(Federrath et al. 2010)

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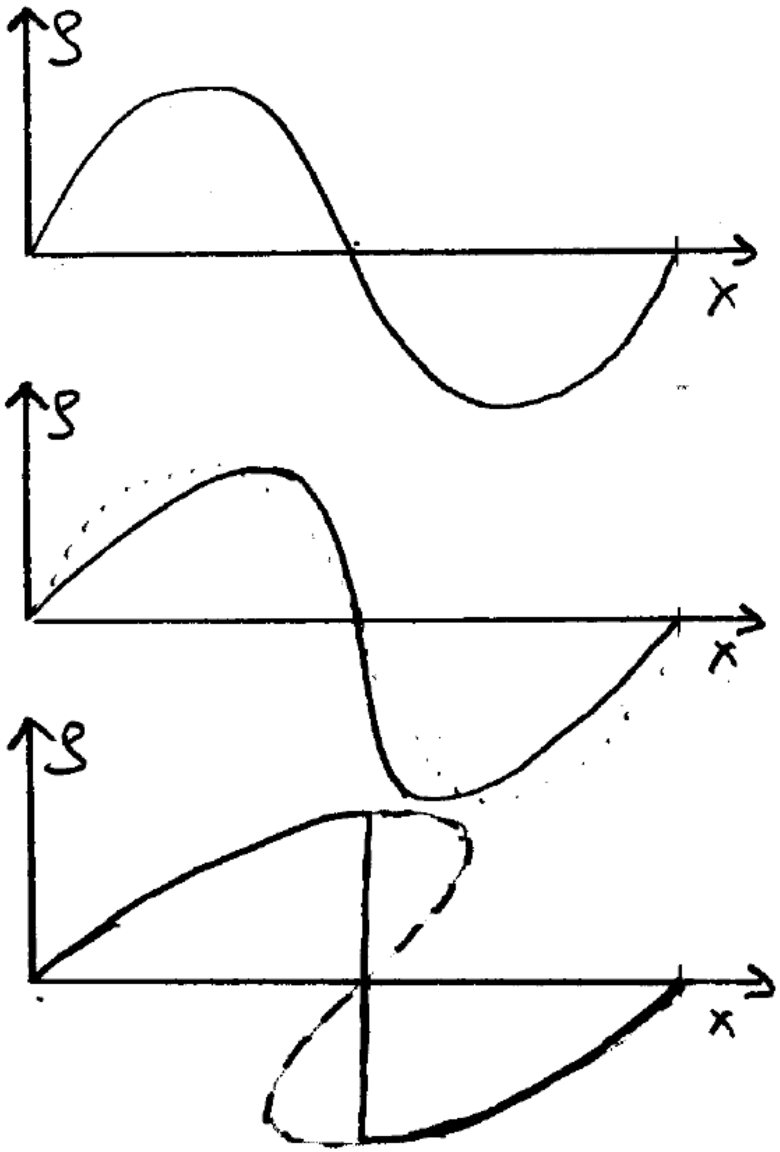
Image credit: M. S. Povich

Carina Nebula, NASA, ESA, N. Smith (University of California, Berkeley), and The Hubble Heritage Team (STScI/AURA), and NOAO/AURA/NSF

Sound waves → Shock waves



Polytropic gas EOS:

$$P \propto \rho^{\Gamma}$$

Sound speed:

$$c_s \propto \rho^{(\Gamma-1)/2}$$

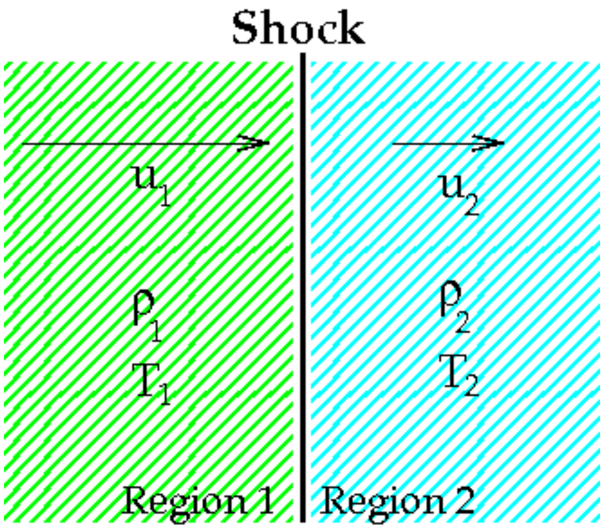
Sound propagates faster in denser regions...

→ Steepening → Shock

Steepening of a sound wave (Klessen lecture notes on Theoretical Astrophysics)

Shock waves

- IDL program to solve 1D hydro equations: hydro_1d.pro
- IDL> .r hydro_1d
- IDL> hydro_test
- IDL> shocktube_test



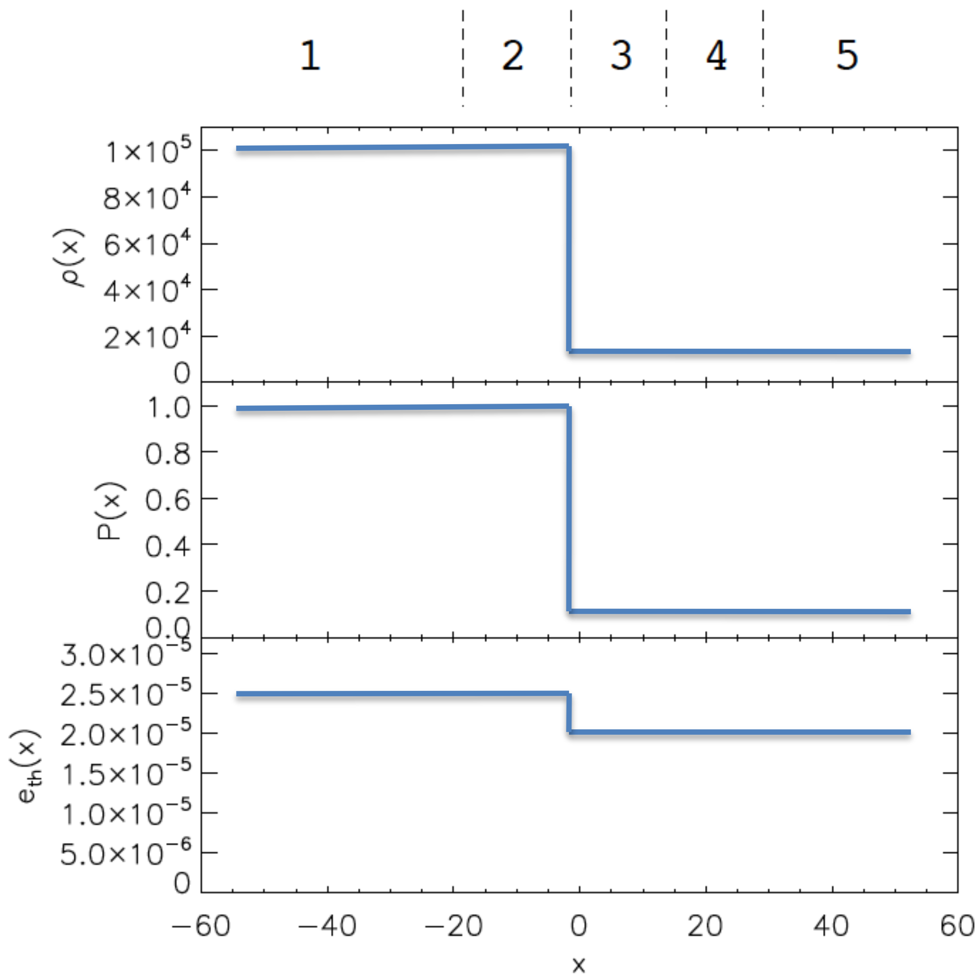
→ Now let's derive the Rankine-Hugoniot shock jump conditions.

You can use IDL (Interactive Data Language) yourself, e.g., on motley.anu.edu.au:

- First connect to miasma > **ssh -Y username@msossh1.anu.edu.au**
- Then to motley > **ssh -Y username@motley.anu.edu.au**
- You will need to copy (**scp**) the hydro_1d.pro to miasma/motley
- Finally, to start IDL type > **idl**

Sod shocktube test: $\rho_l = 10^5, P_l = 1$ $\rho_r = 1.25 \times 10^4$ and $P_r = 0.1$

(Sod 1978)



shocktube_test

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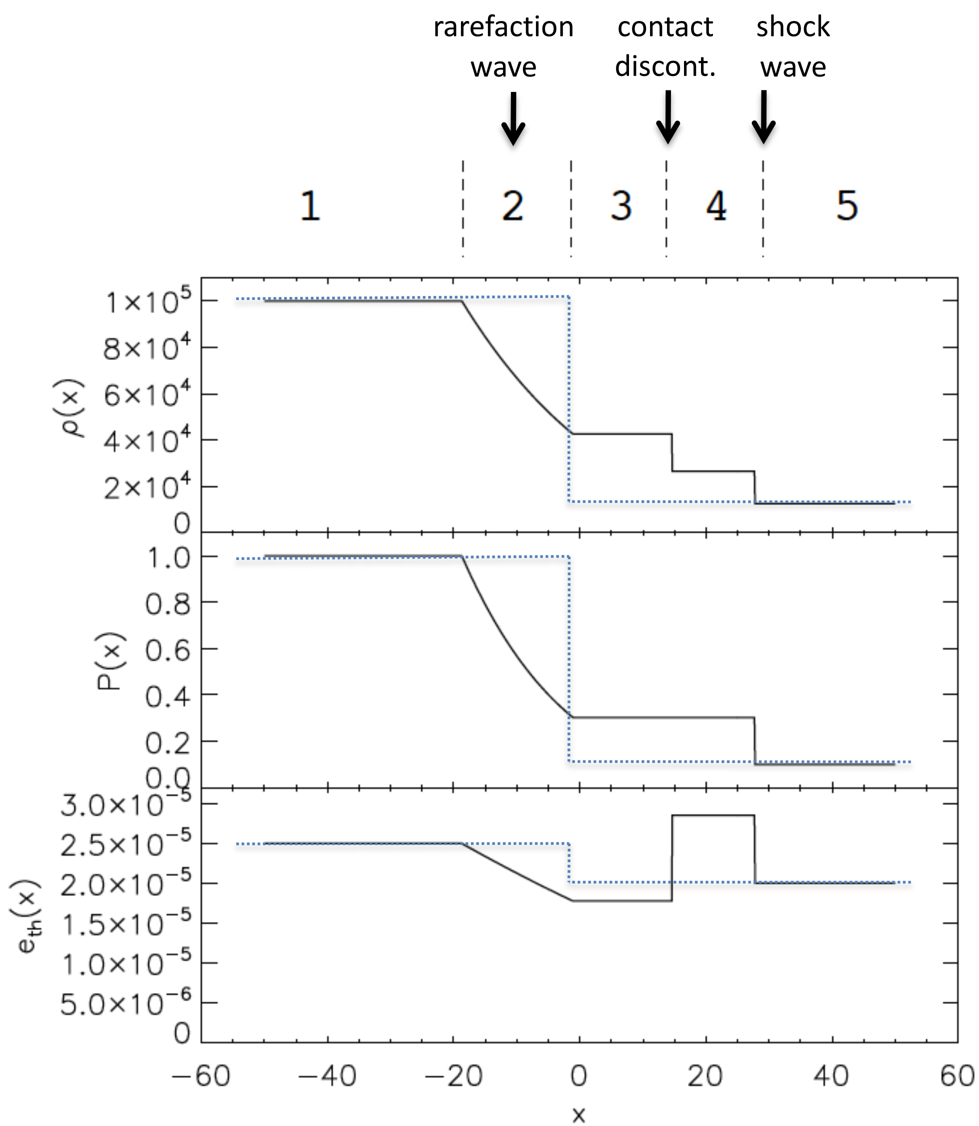
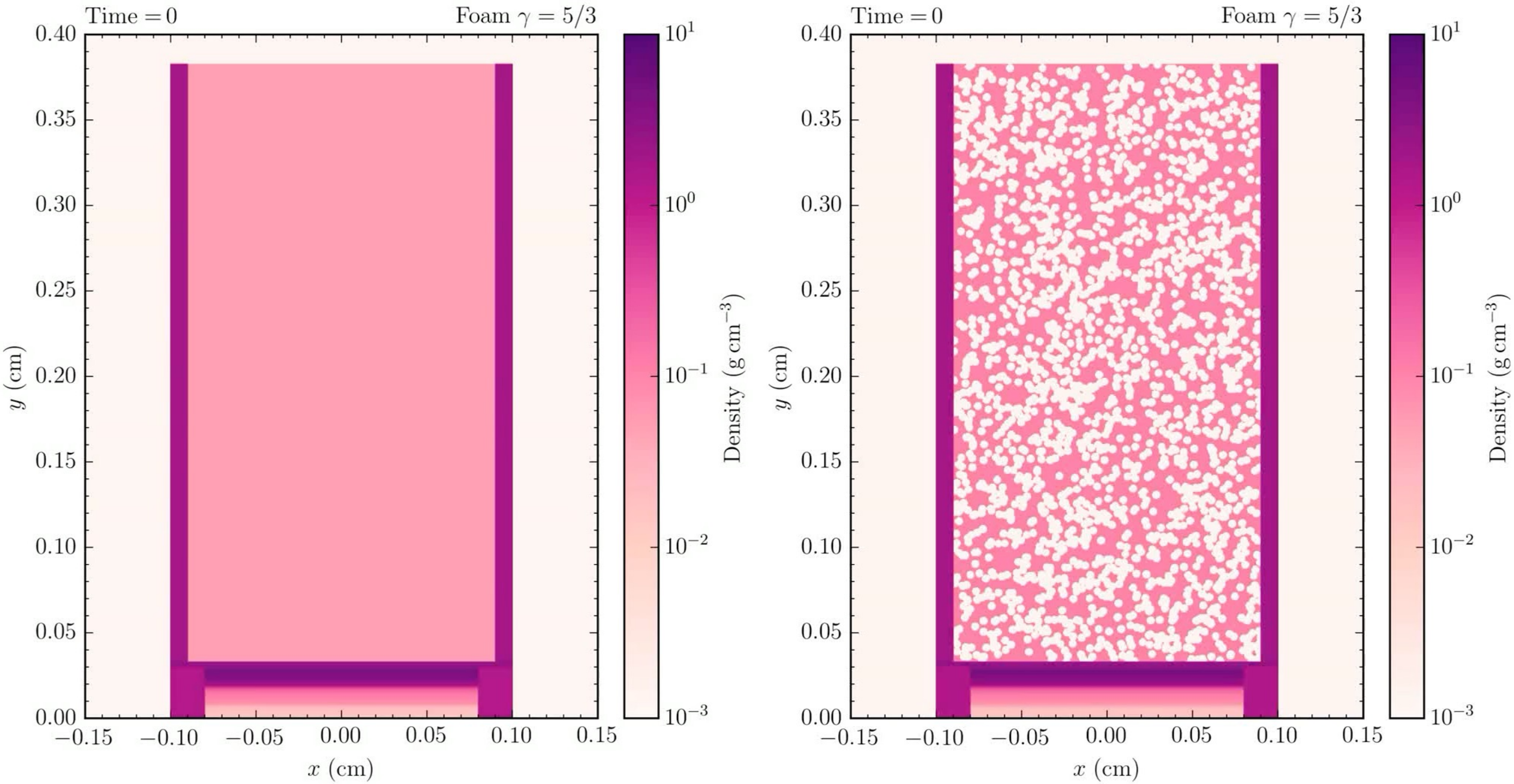


Astrophysical Gas Dynamics - Shocks

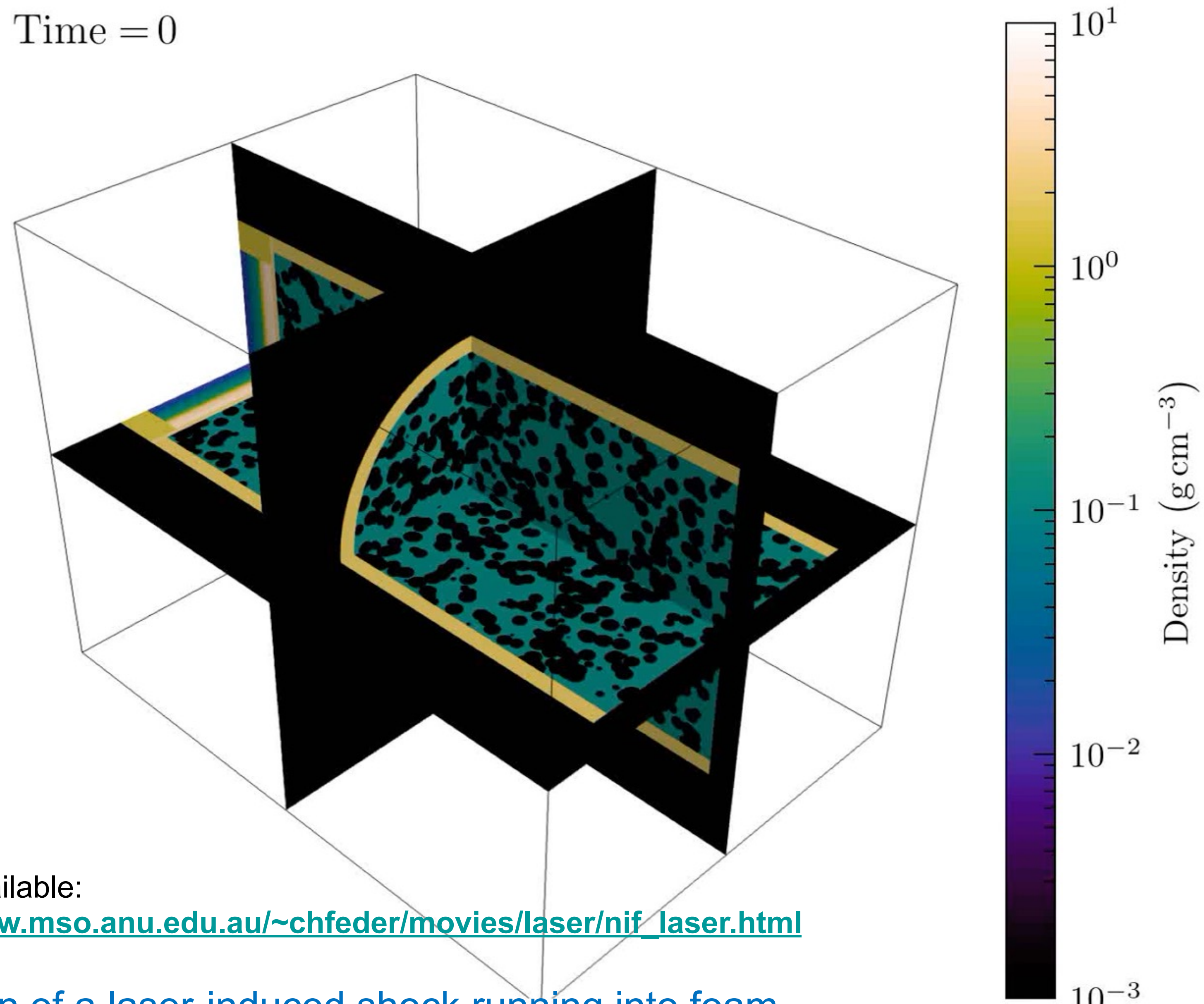


Movies available: https://www.mso.anu.edu.au/~chfeder/movies/laser/nif_laser.html

Simulation of a laser-induced shock running into foam

(Dhawalikar et al. 2022)

Astrophysical Gas Dynamics - Shocks



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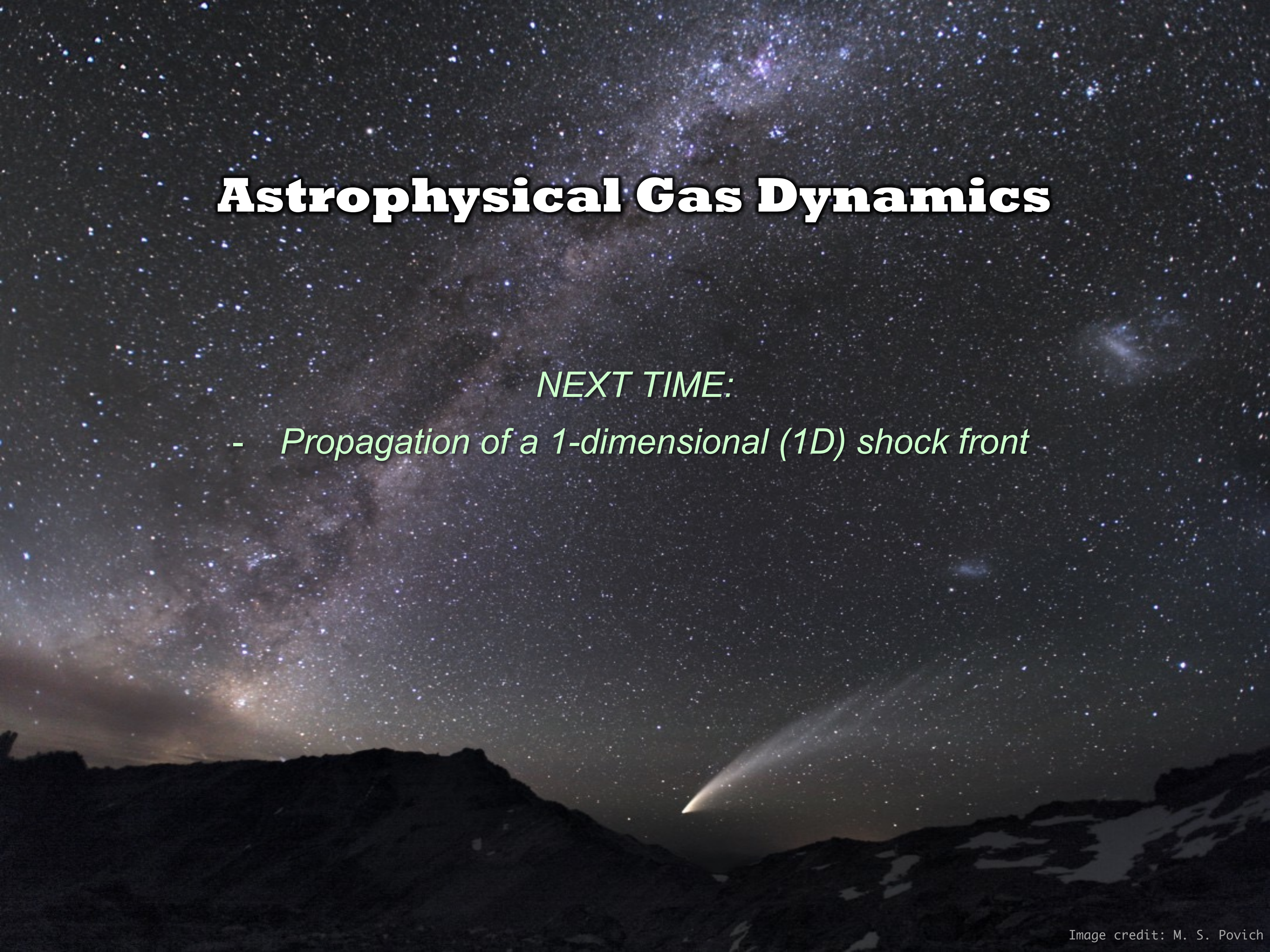

Astrophysical Gas Dynamics

NEXT TIME:

- *Propagation of a 1-dimensional (1D) shock front*

Image credit: M. S. Povich