Astrophysical Gas Dynamics

TODAY:

- *The validity of the gas/fluid approximation (→ recap notes)*
- *Gravitational instabilities: Jeans and Toomre (→ recap and finish)*
- *Kelvin-Helmholtz and Rayleigh-Taylor instability*

Image credit: M. S. Povich

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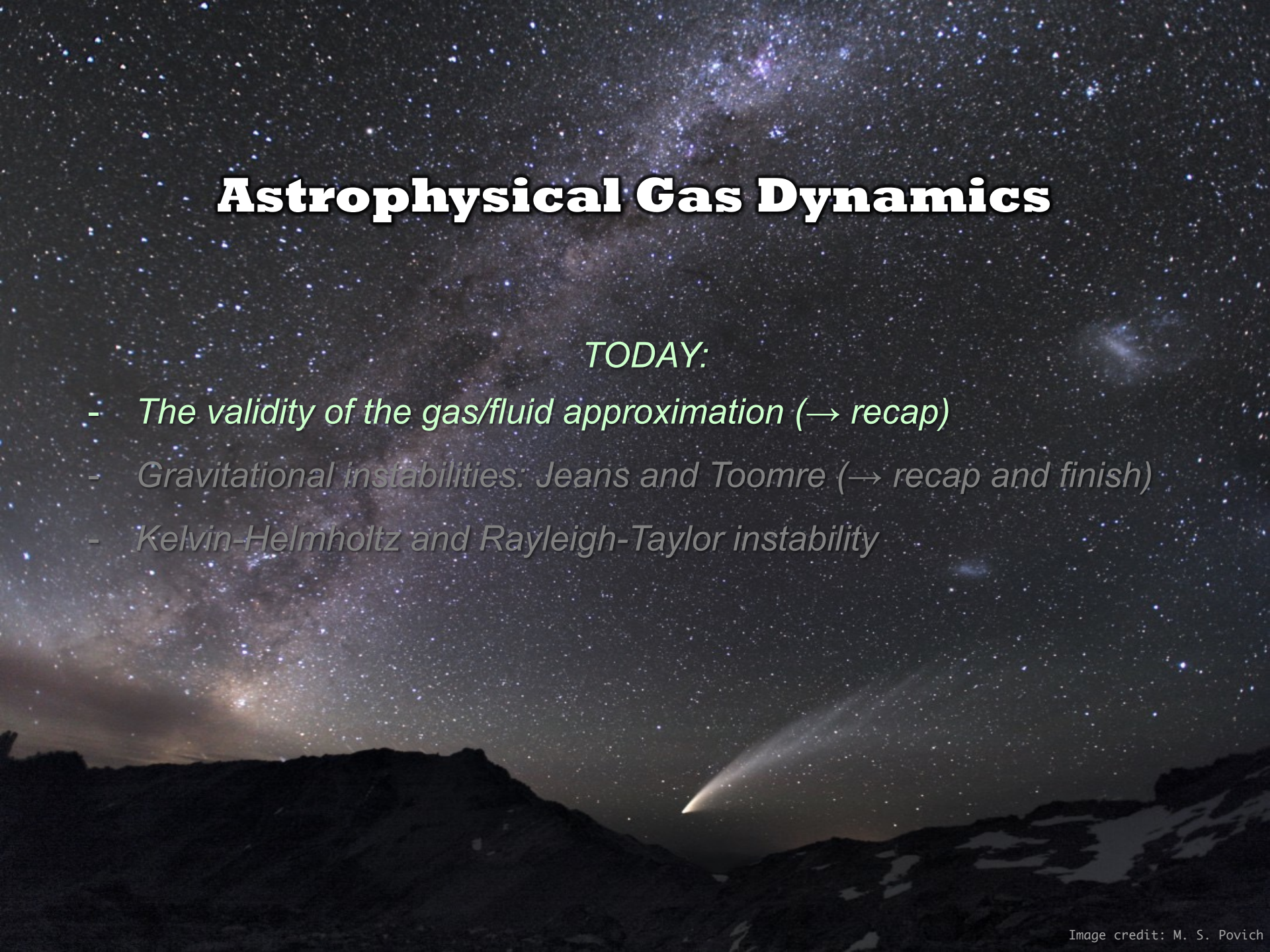

Image credit: M. S. Povich

Validity of the Gas/Fluid Approach

Gas/Fluid approximation only valid if particle mean free path much less than scales of interest

(particle collisions are sufficiently frequent on microscopic level)

Medium	Particle mean free path	Size scale
Water	9×10^{-9} cm	…
Air	5×10^{-6} cm	…
Solar core	2×10^{-8} cm	~ $R_{sol}/4$ ~ 2×10^{10} cm
Solar corona	1×10^{8} cm	~ R_{sol} ~ 7×10^{10} cm
Solar wind	1×10^{13} cm	~ AU ~ 1.5×10^{13} cm
Interstellar medium	$1 \times 10^{5-15}$ cm	~ pc ~ 3×10^{18} cm
Galaxy cluster (intracluster medium)	1×10^{23} cm	~ Mpc ~ 10^{24} cm

If the gas/fluid approximation breaks down, kinetic treatment is required.

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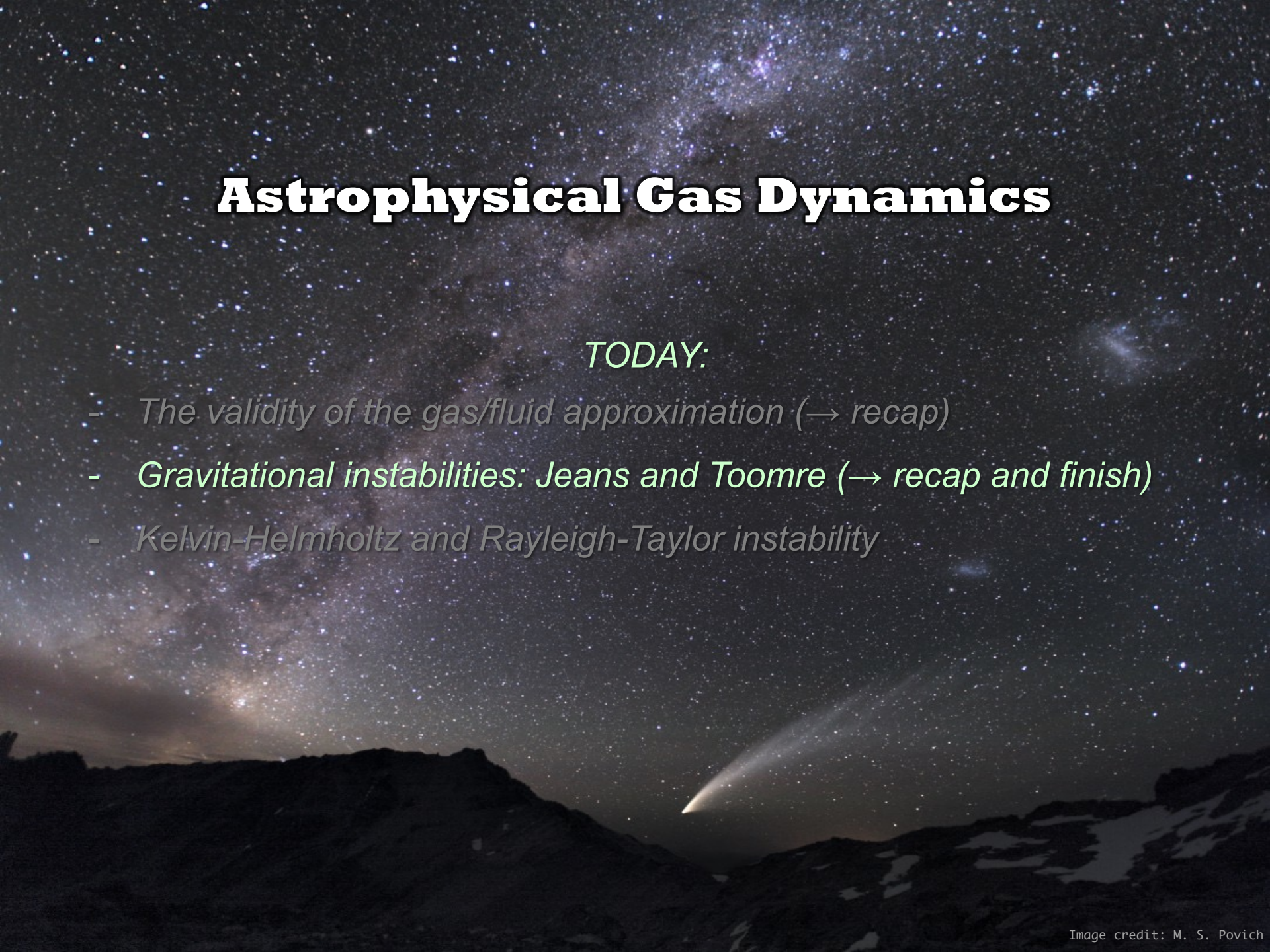
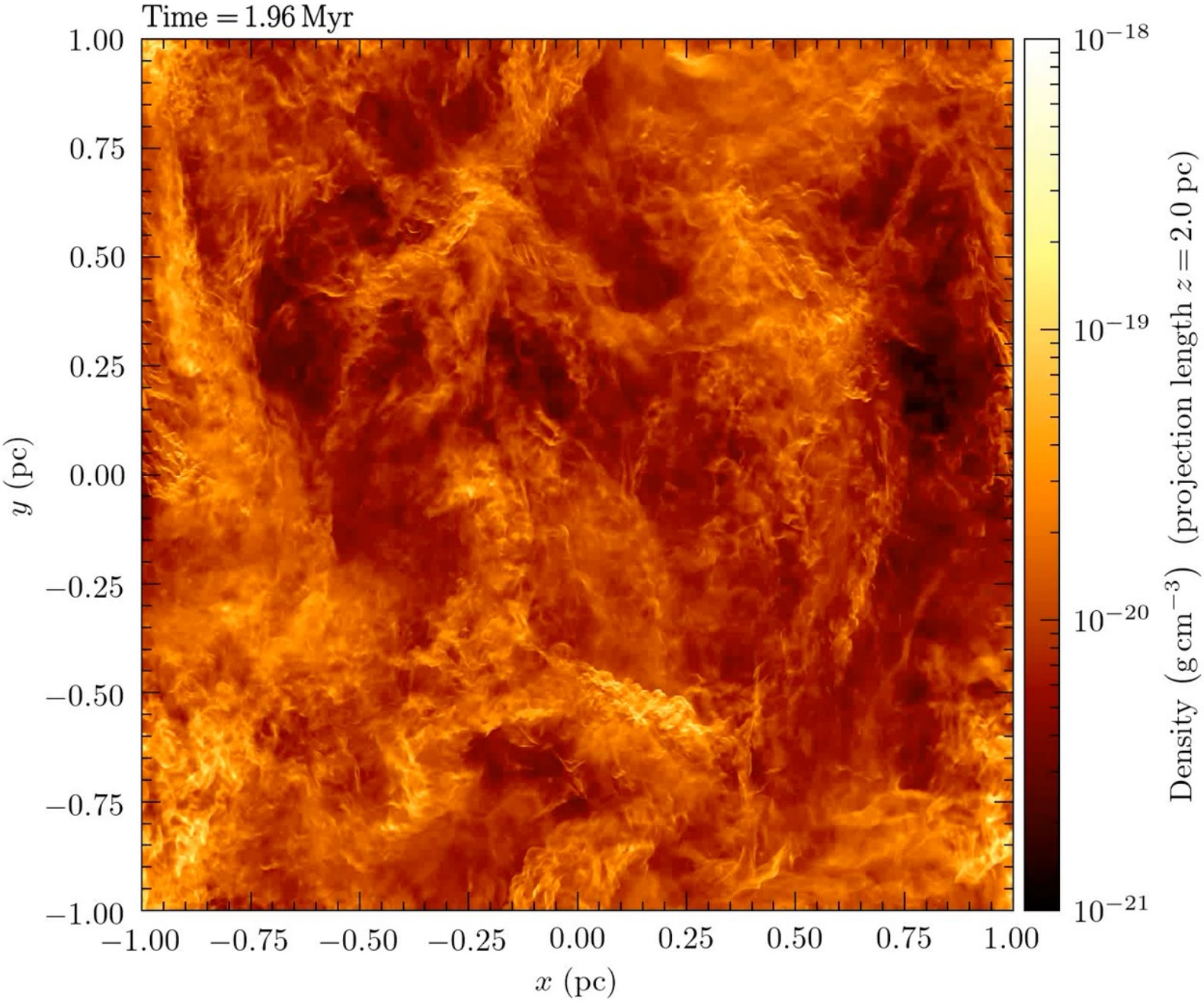


Image credit: M. S. Povich

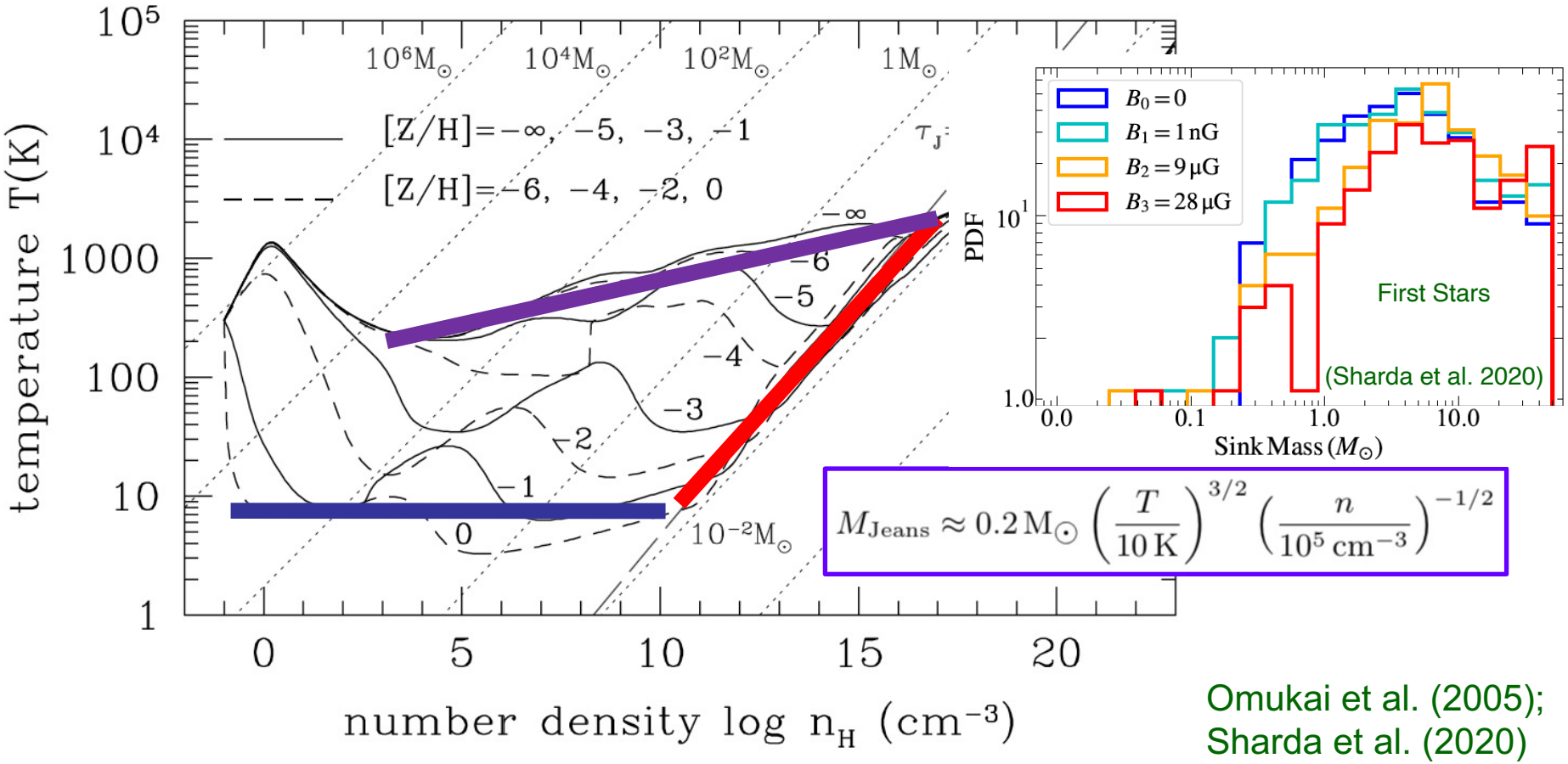
Jeans fragmentation

(Federrath 2015 MNRAS)



Equation of State – Chemistry / Heating / Cooling

Chemistry / Heating / Cooling: (Glover+2007, 2010, Micic+2012, Clark+2012)



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)

Toomre (gravitational disc) instability

Condition for disc instability

$$\frac{c_s \kappa}{\pi G \Sigma} < 1$$

c_s is the speed of sound

κ is the epicyclic frequency

Σ is the surface density

(Toomre 1964; Romeo et al. 2010)

For Jeans instability, we basically compare thermal pressure versus gravity.
For Toomre, we compare thermal pressure + rotation versus gravity.

Notes:

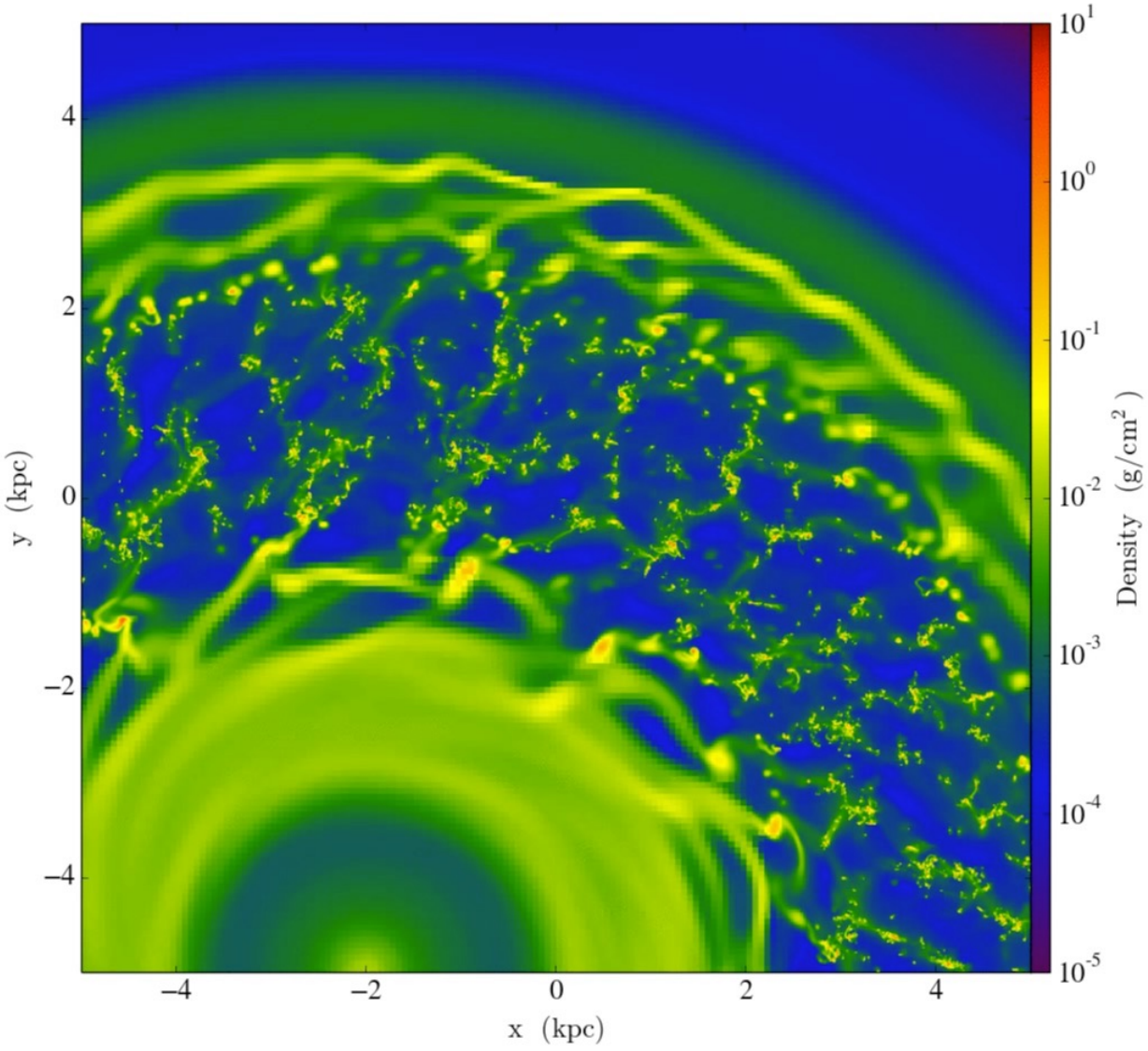
- Surface density can have gas and star contribution
- Sound speed could be modified to include turbulence and/or magnetic pressure (e.g., turbulent, magnetic Jeans length)

(Federrath & Klessen 2012)

Toomre (gravitational disc) instability

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

For example, simulations of disc galaxies:



(Jin et al. 2017)

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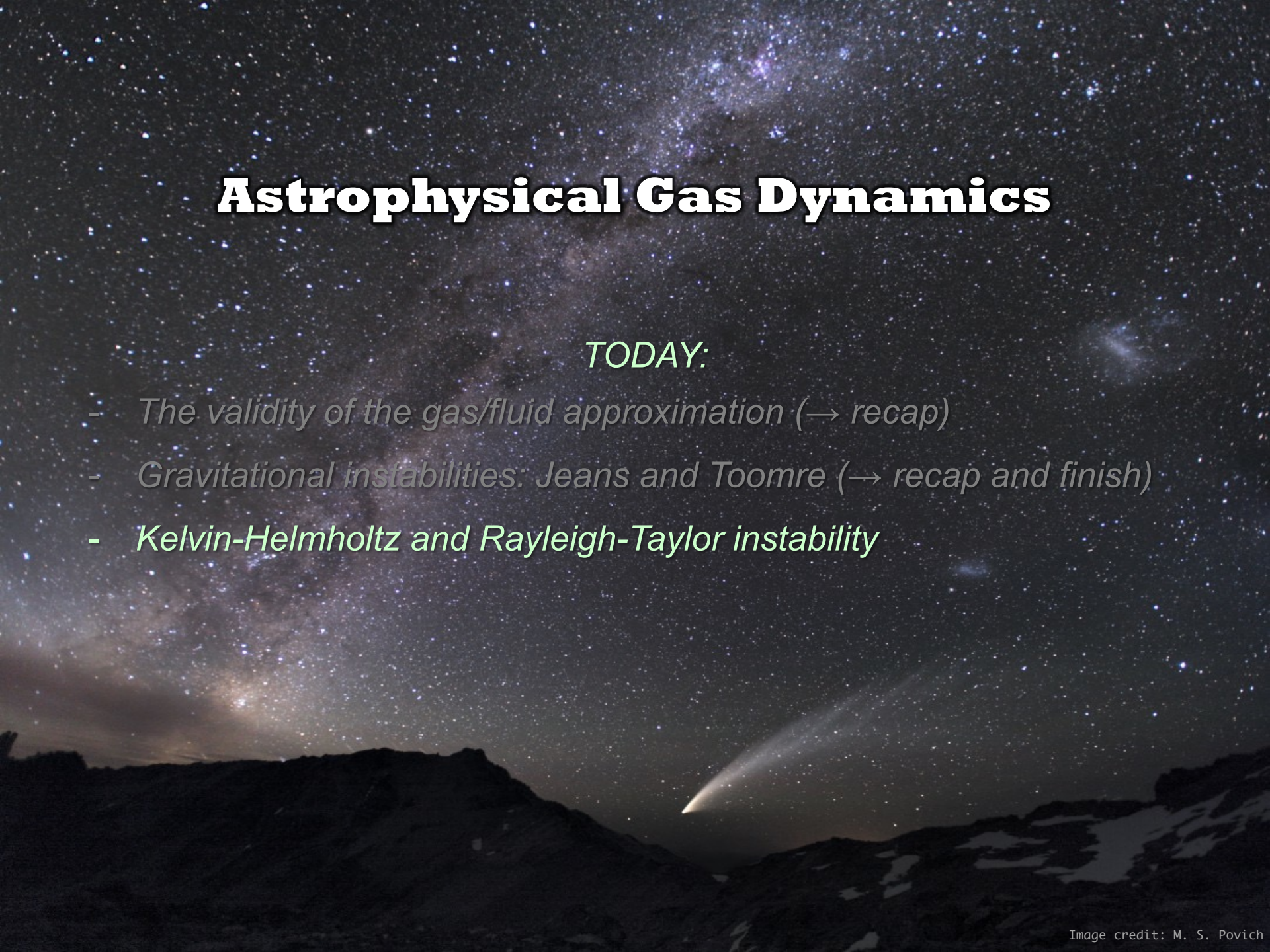
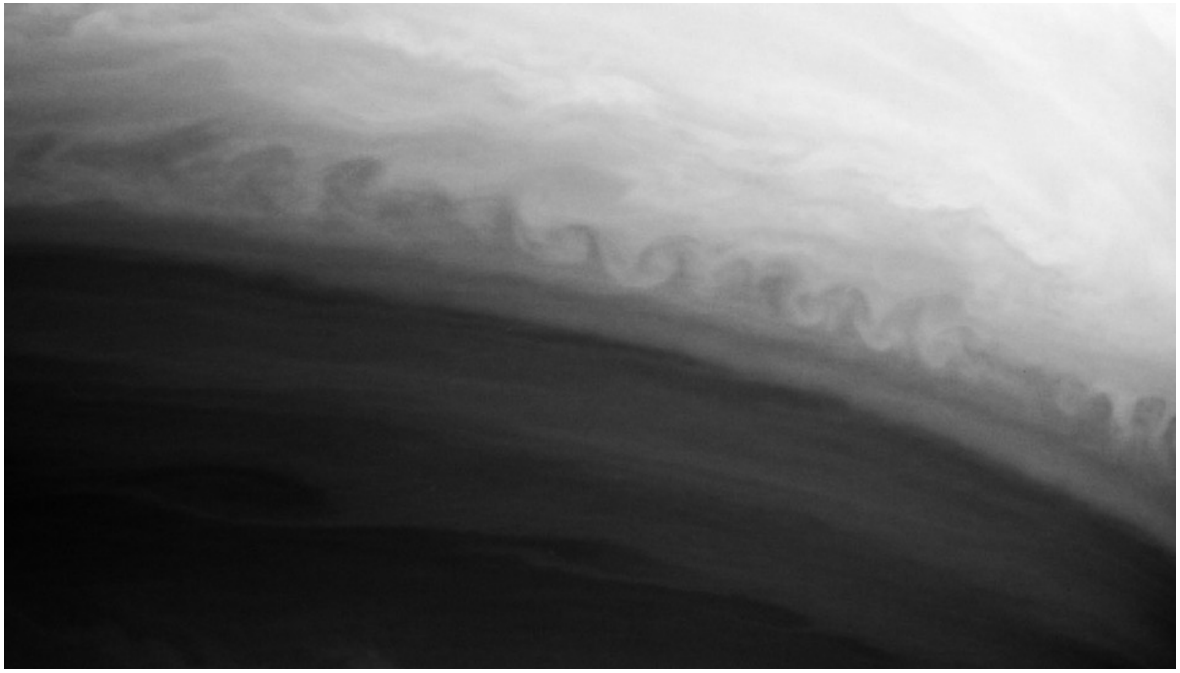


Image credit: M. S. Povich

Kelvin-Helmholtz instability

(clouds)



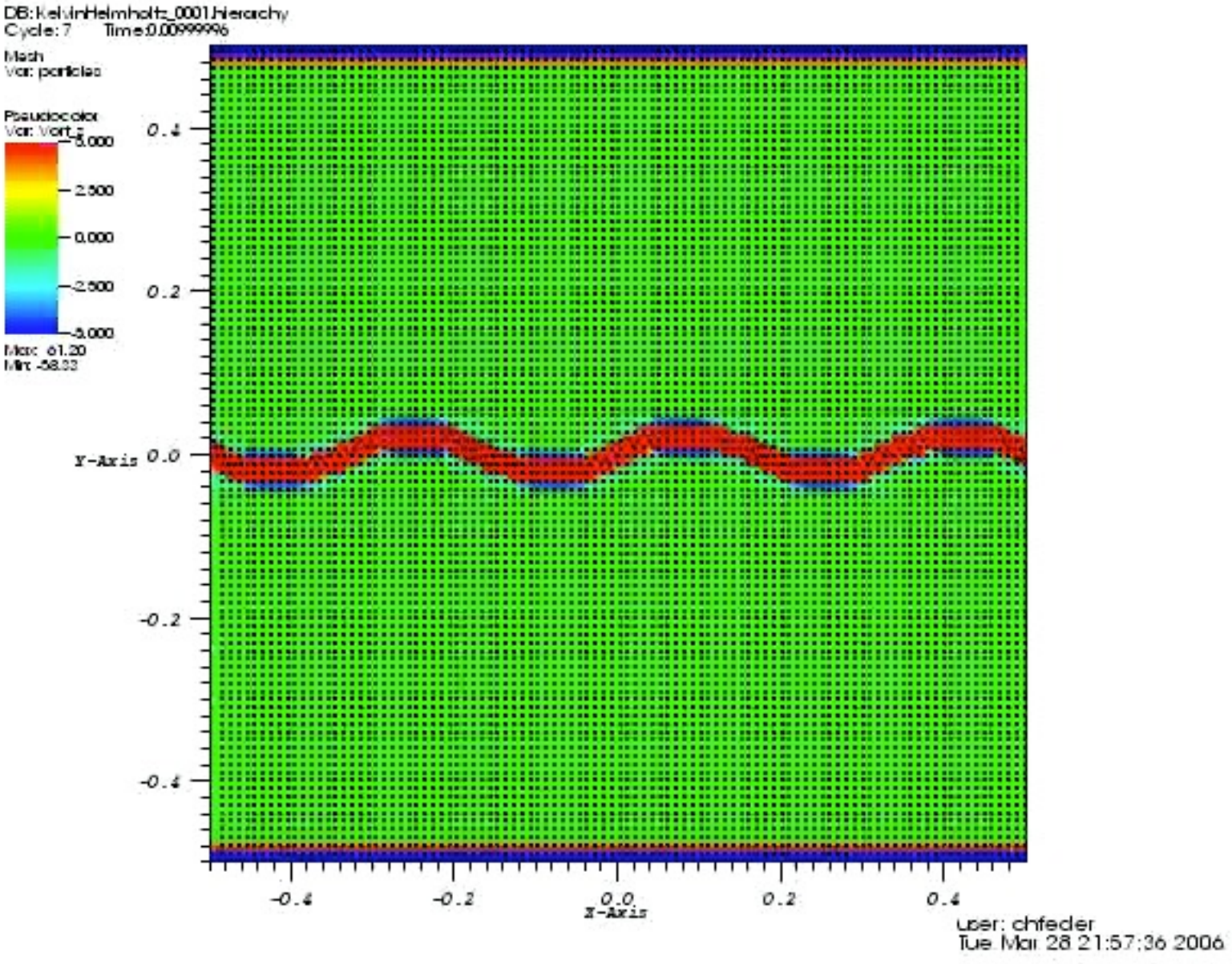
(Saturn)

Kelvin-Helmholtz instability

- Derivation of the KH instability
- Simulation movies of KH instability
- Relation to Rayleigh-Taylor instability

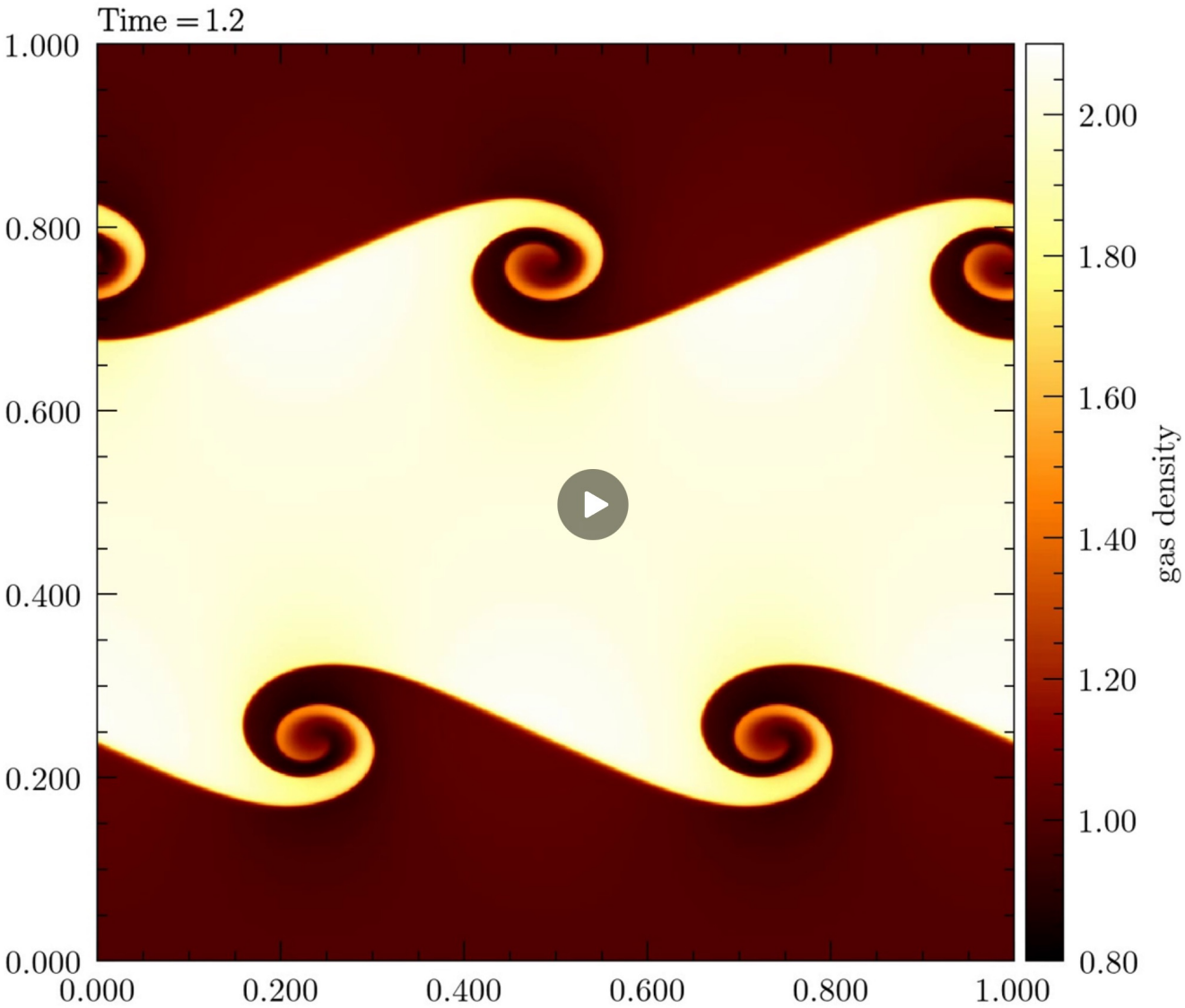
Kelvin-Helmholtz instability

Movies available: http://www.mso.anu.edu.au/~chfeder/movies/tracer_particles/tracer_particle_movies.html



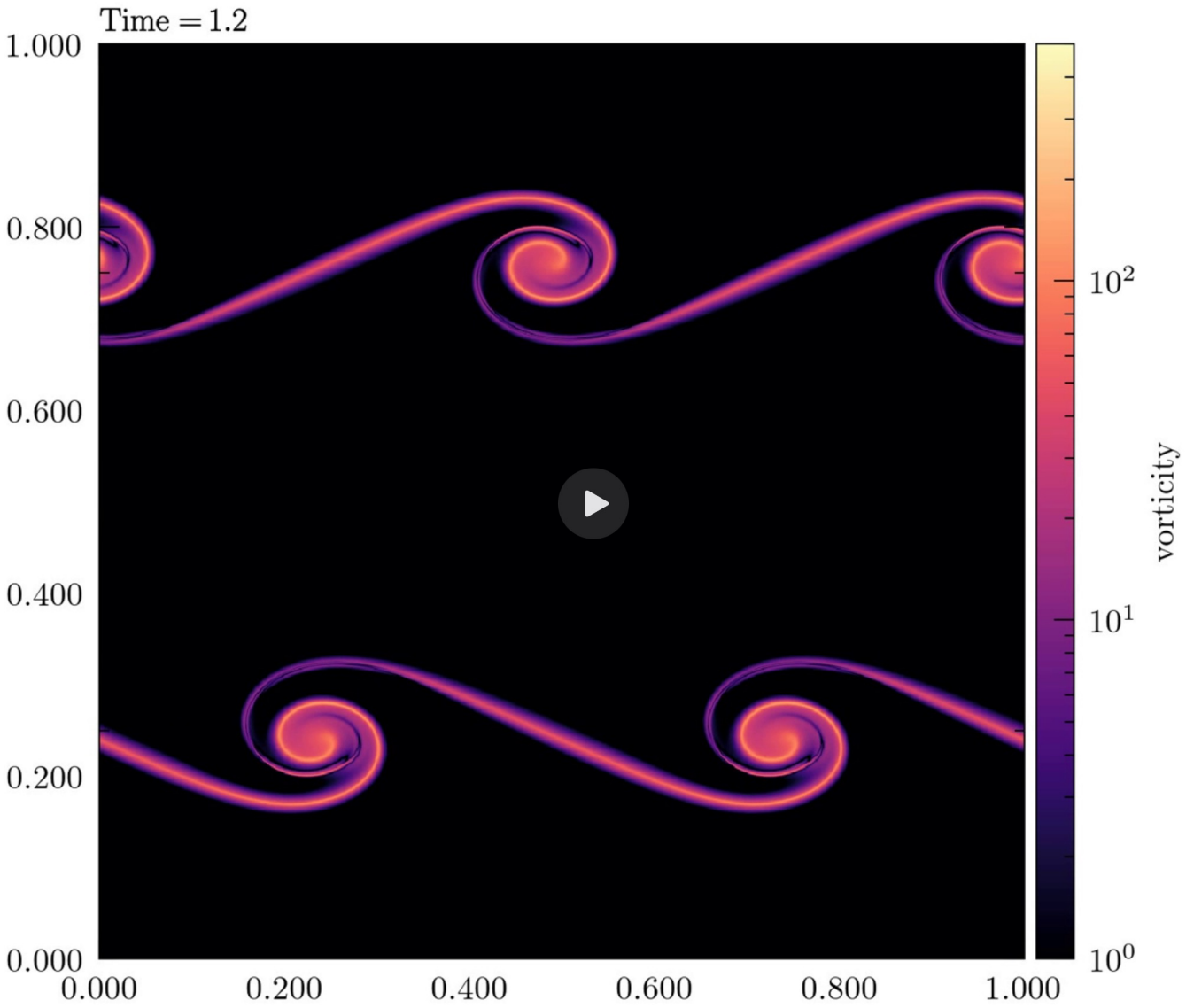
Kelvin-Helmholtz instability

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

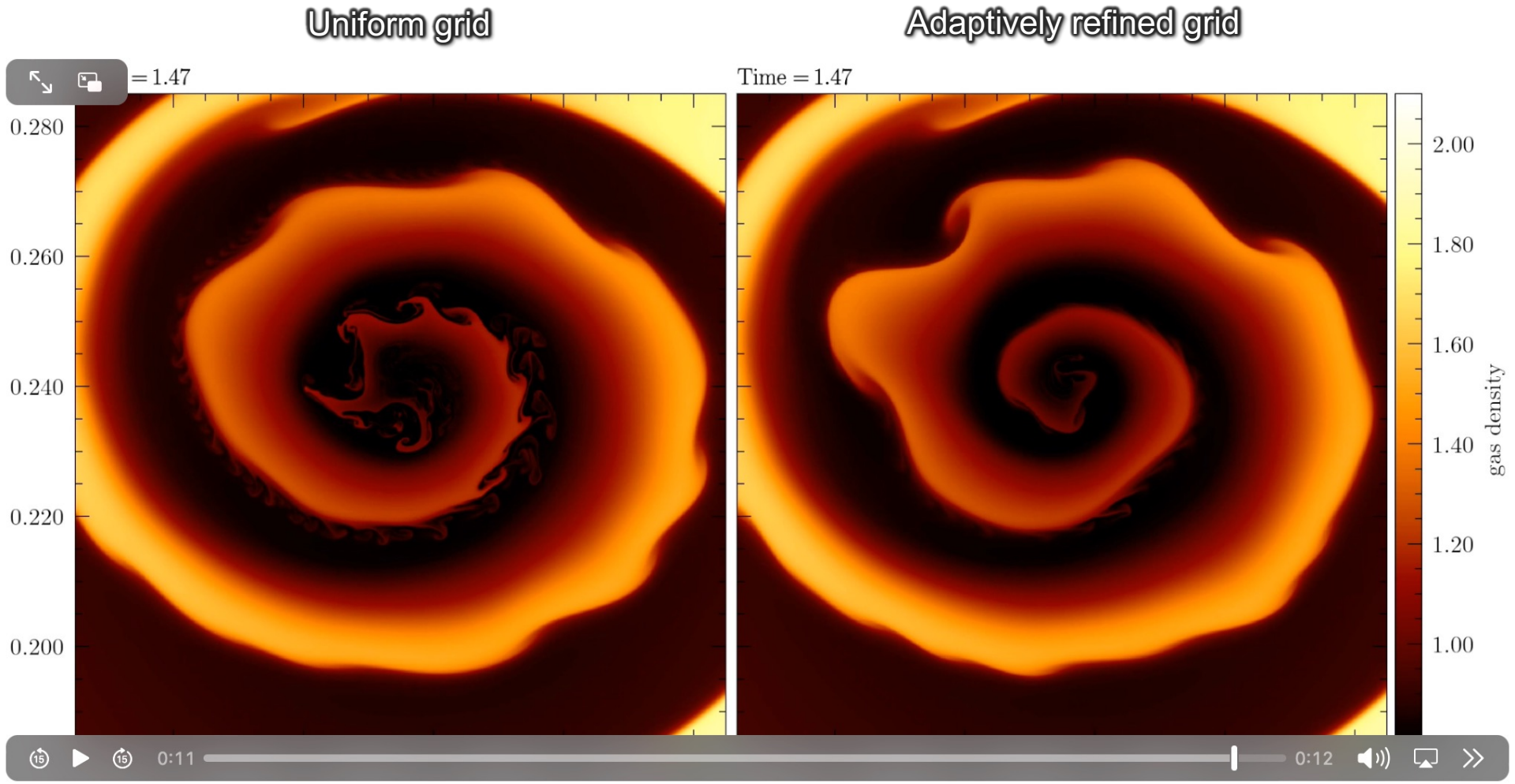


Kelvin-Helmholtz instability

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



Kelvin-Helmholtz instability



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

Rayleigh-Taylor instability

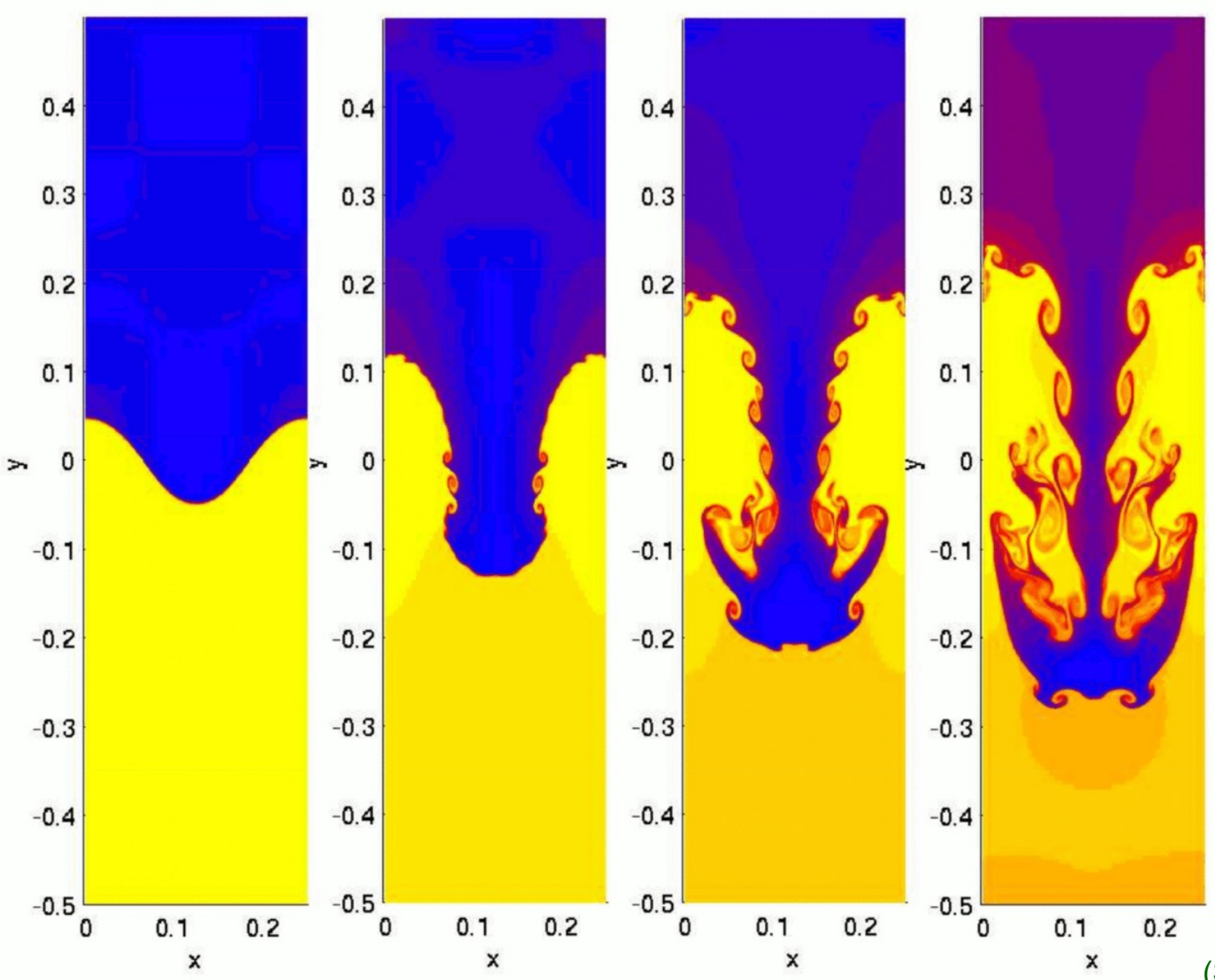
Denser fluid (red) mixes with less dense fluid (transparent)

Time

Gravity

https://images.slideplayer.com/14/4208308/slides/slide_21.jpg

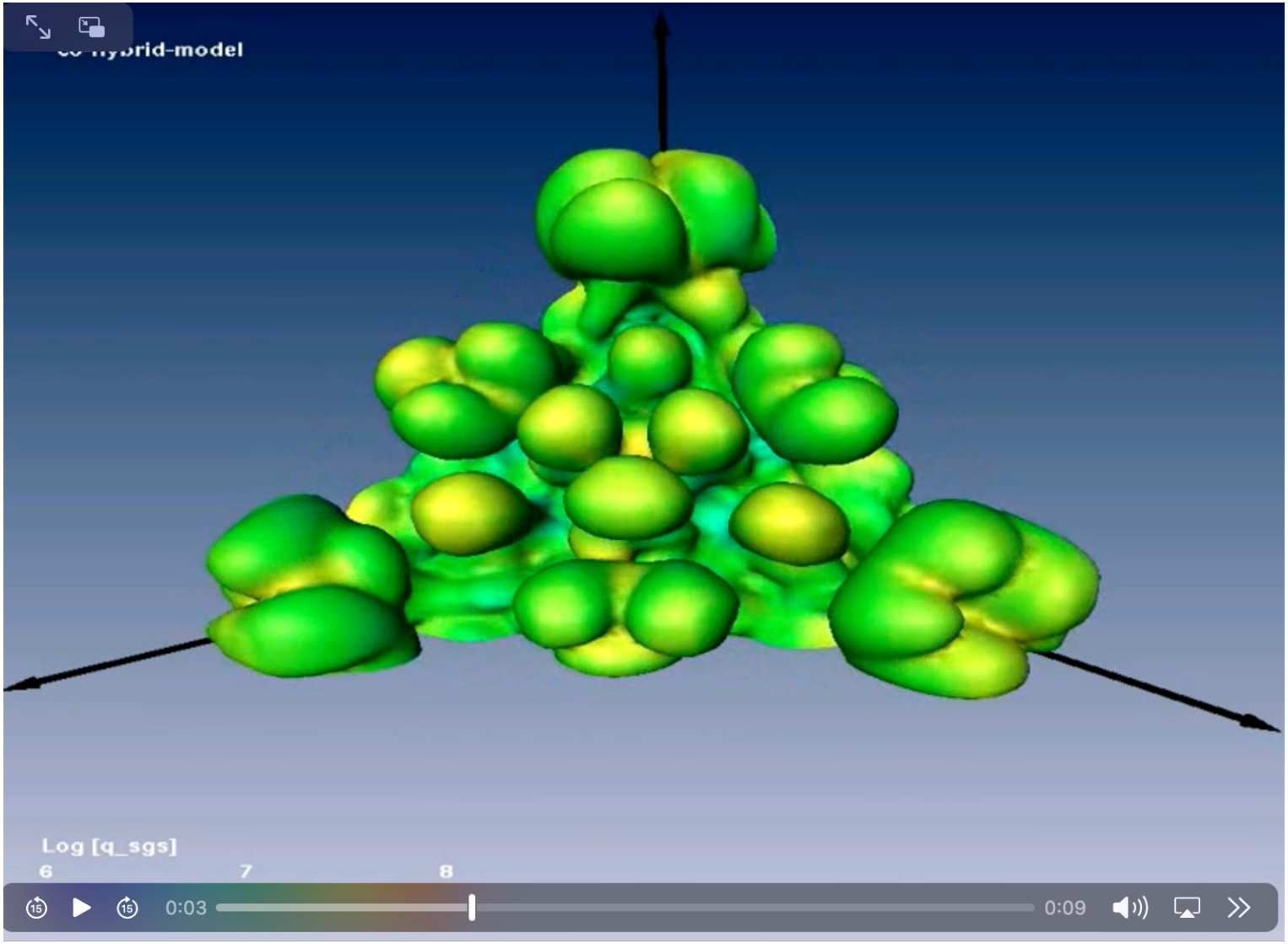
Rayleigh-Taylor instability



(Shengtai Li, Hui Li)

Rayleigh-Taylor instability

Movies available: http://www.mso.anu.edu.au/~chfeder/movies/supernova/supernova_movies.html



(Simulation of Type Ia Supernova explosion)

Astrophysical Gas Dynamics

NEXT TIME:

- *Spherically symmetric stationary flows (stellar winds and accretion)*

Image credit: M. S. Povich