SHOCKS

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Different forms of energy:

- Kinetic (macroscopic motions)

- Thermal (microscopic motions)

- Chemical

- Gravitational

- Electromagnetic
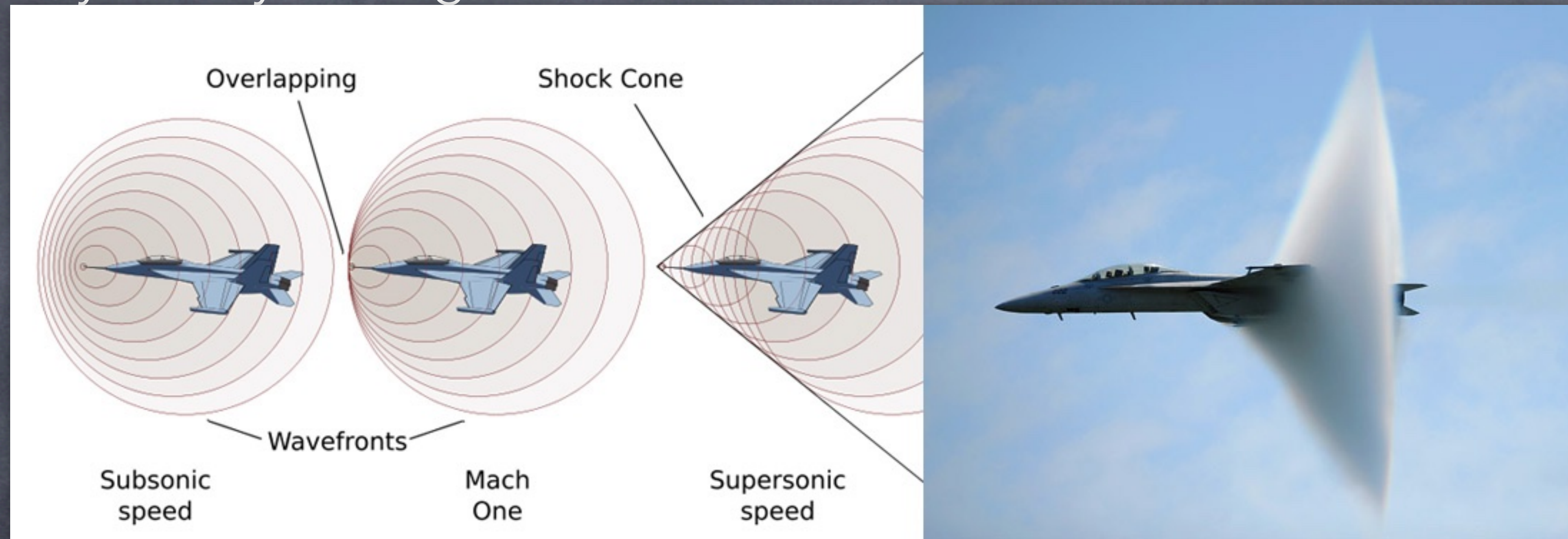
- Nuclear

- ⋯

- *Dark energy (ask a cosmologist!)*

Eugene Parker (with a model of the *Parker Solar Probe*)
  - theorized the existence of the solar wind
  - pioneered the study of magnetic reconnection
  - pioneered the study of cosmic ray transport

- "A sharp change of pressure *in a narrow region* traveling through a medium, caused by a body moving faster than sound"

- What is a *narrow region?* One collisional mean free path $\lambda \propto \dfrac{1}{n\sigma}$ $n = $ # density $\sigma = $ cross section

- In air $n \approx 10^{21} \text{cm}^{-3} \rightarrow \lambda \approx 7 \times 10^{-6} \text{cm}$; in space: $n \approx 1 \text{cm}^{-3} \rightarrow \lambda \approx 10^{15} \text{cm}$??

- Space/astro-plasmas are *collisionless*, i.e., not mediated by binary collisions but by EM

USS Iowa (1984)

Bomb Detonation
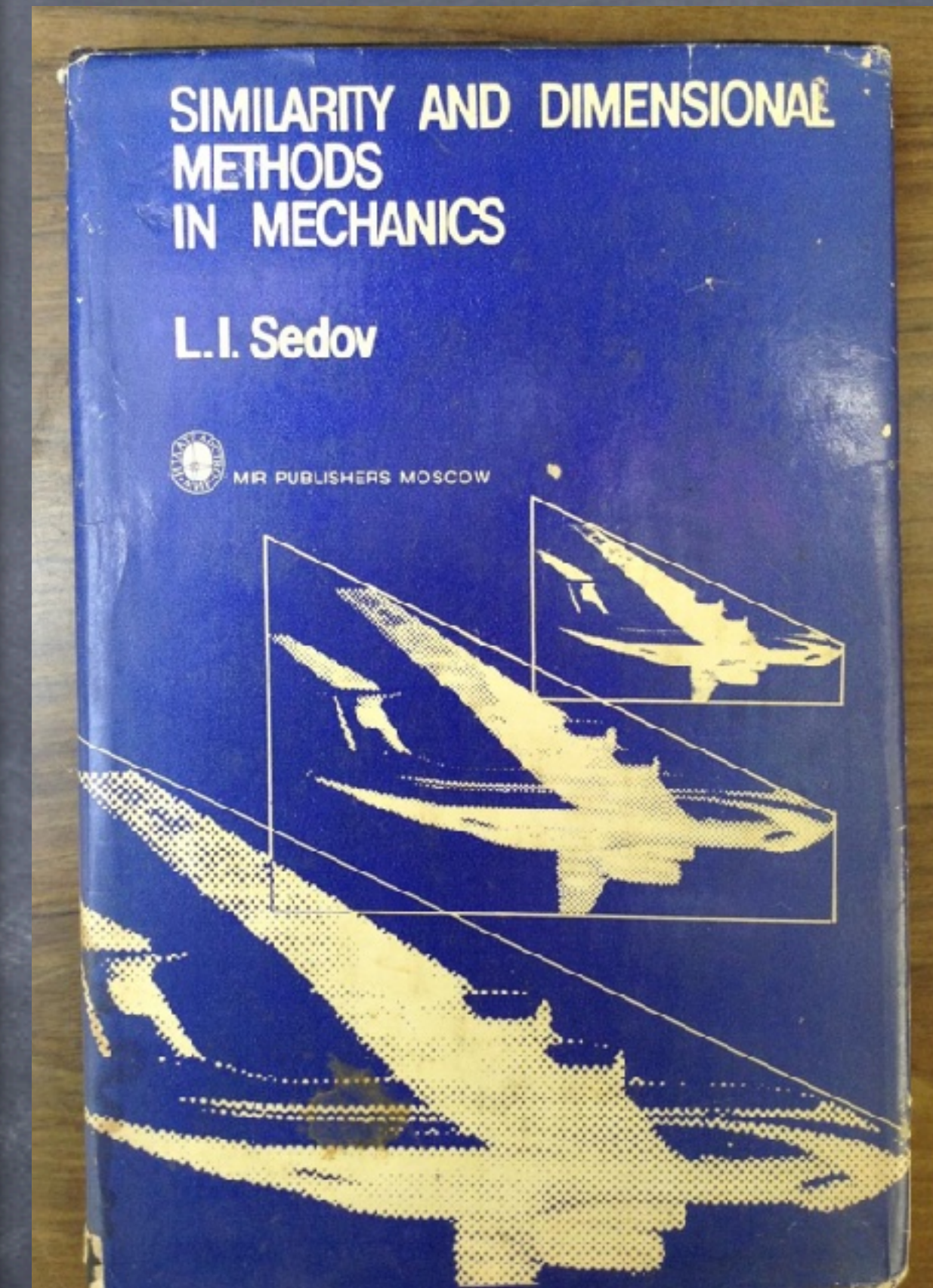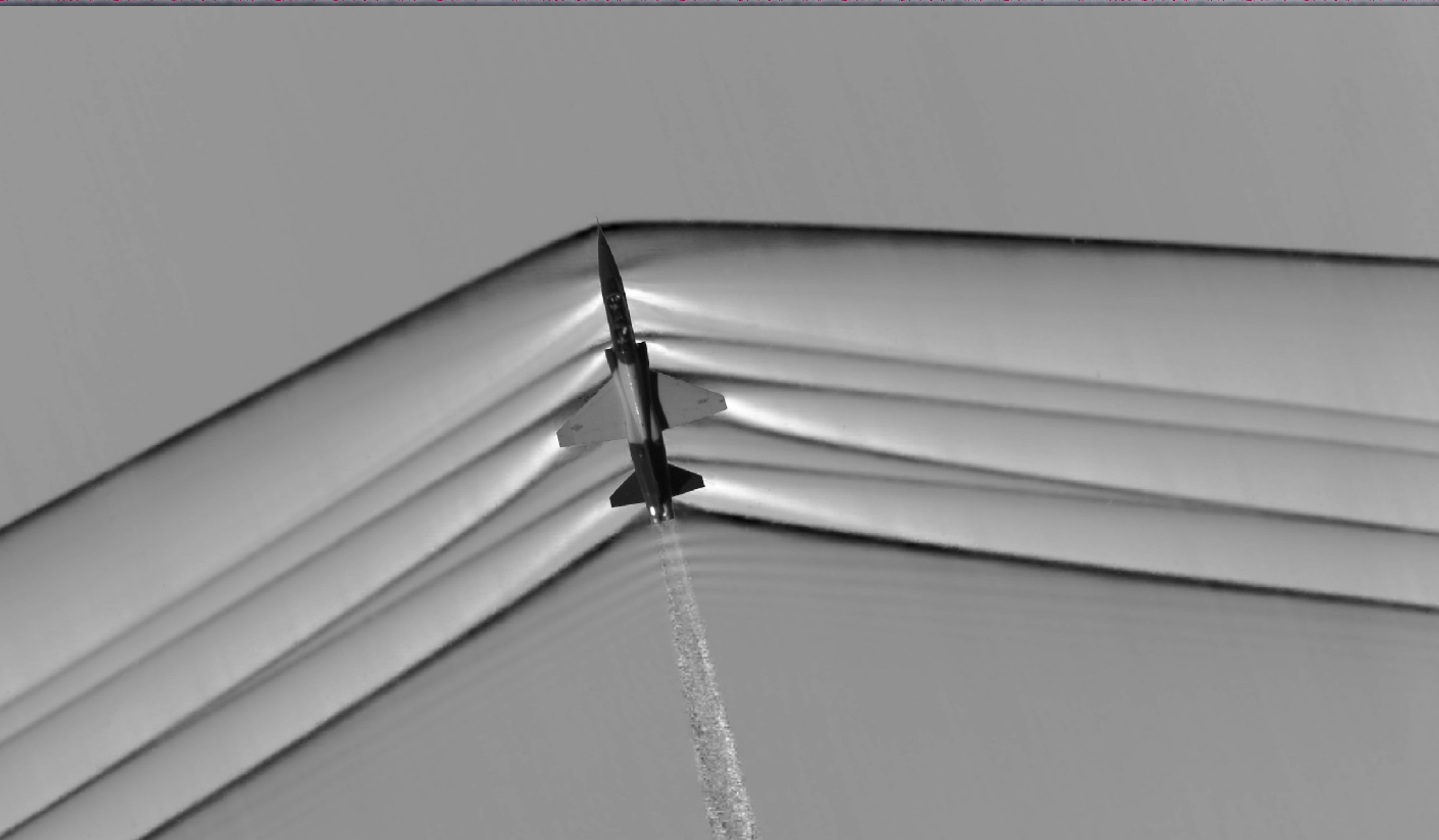
Krakatoa eruption, 1883
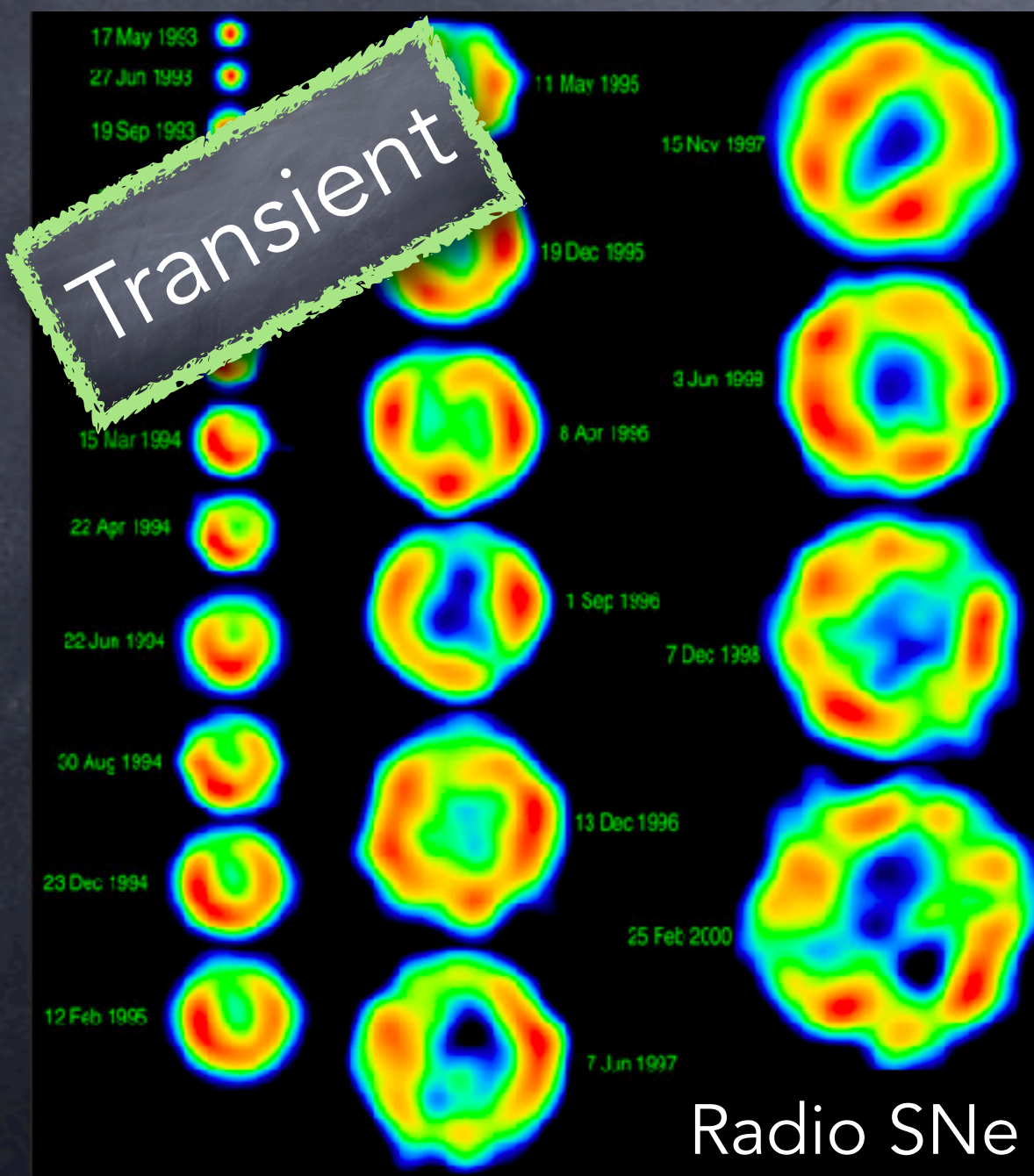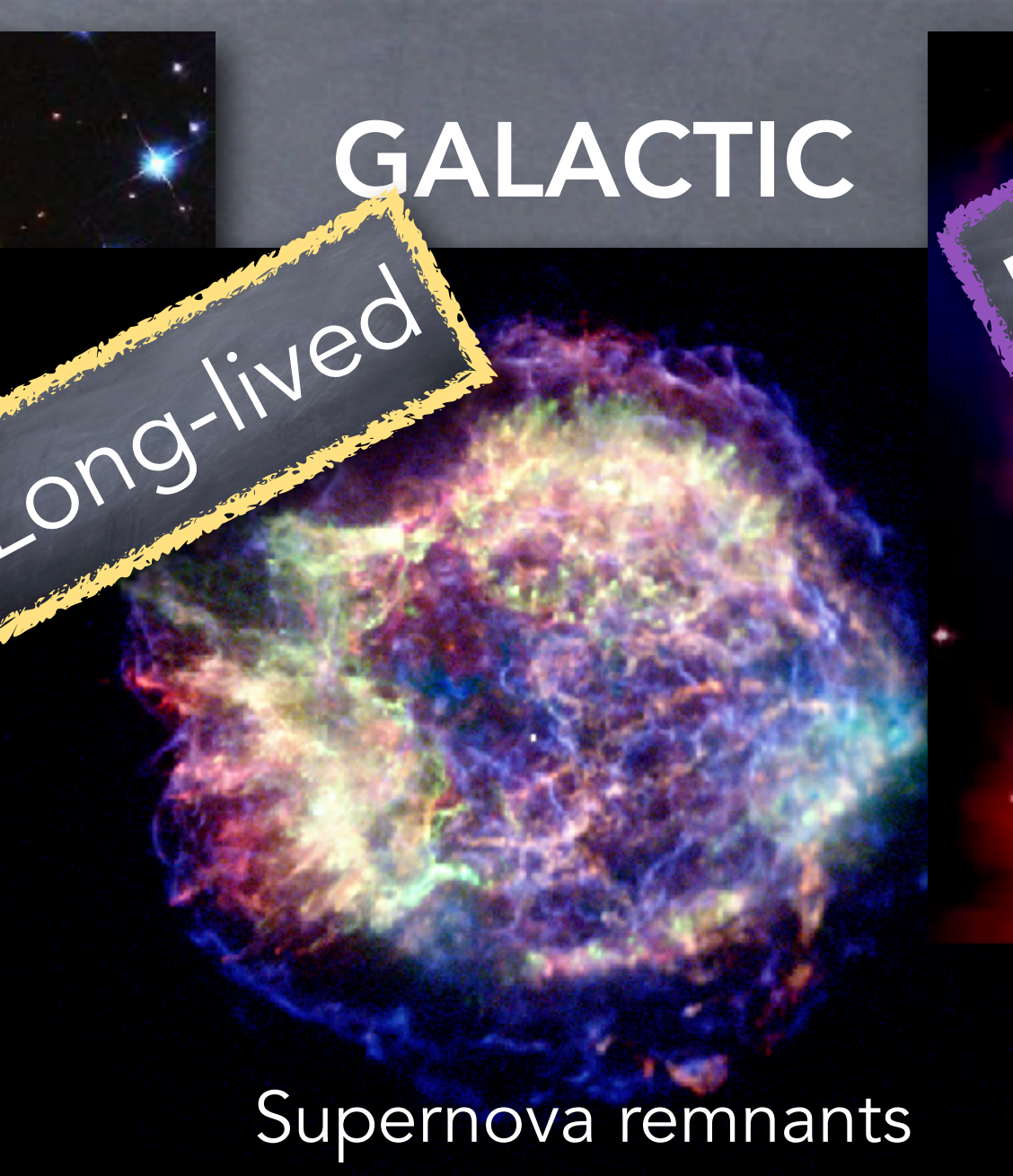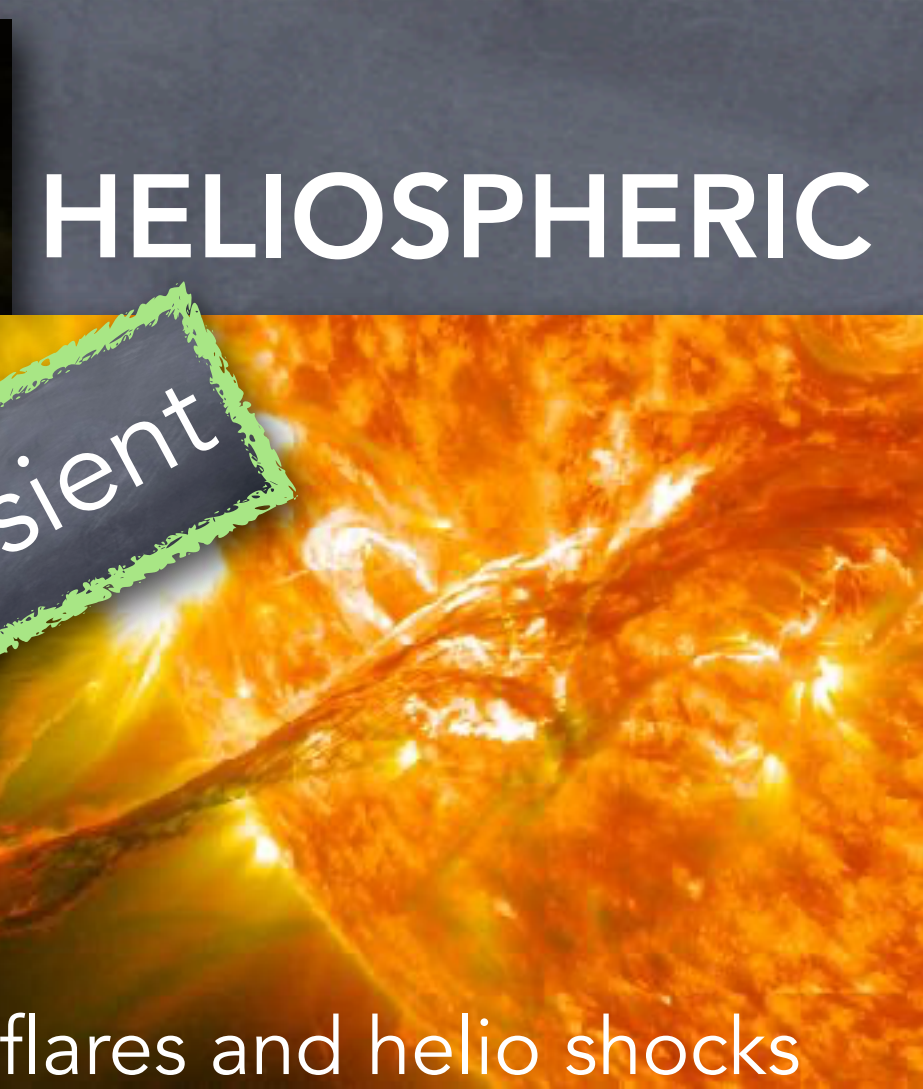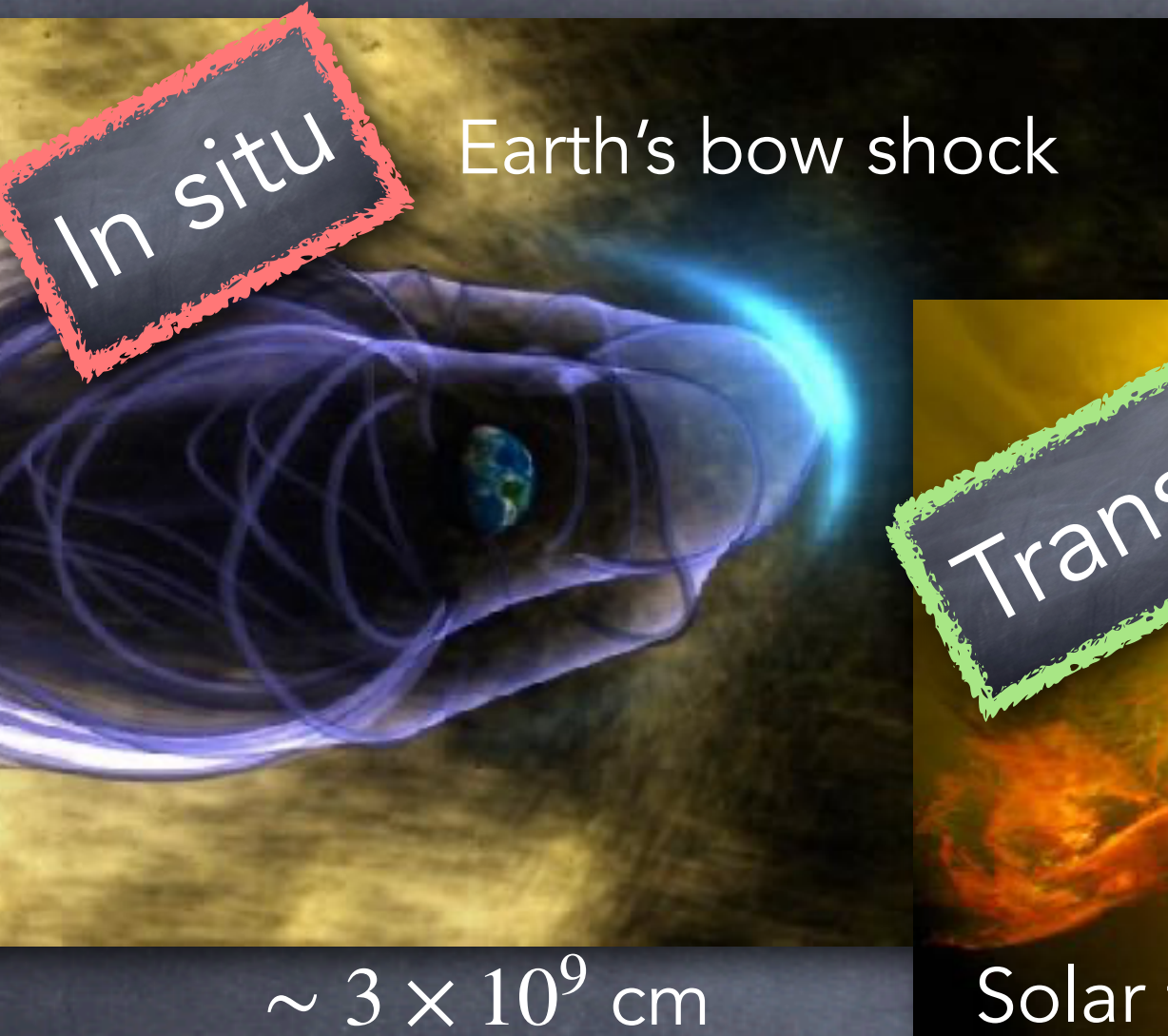(~310db, cannon-like ~5000km away)

Lithography, 1888

Sedov's book (1959)

Shock waves produced by a T-38 Talon (schlieren photography)

SHOCKS: From Helio to Cosmological Scales

In situ — Earth's bow shock

$\sim 3 \times 10^9$ cm

HELIOSPHERIC

Transient — Solar flares and helio shocks

$\sim 10^{15}$ cm

Transient — Novae

GALACTIC

Long-lived — Supernova remnants

$\sim 3 \times 10^{18}$ cm

Flaring — Pulsars and PWNe

Transient — Radio SNe

EXTRA-GALACTIC

Flaring — AGN jets/lobes

Long-lived — AGN Winds

$\sim 3 \times 10^{21}$ cm

Long-lived — Galaxy clusters

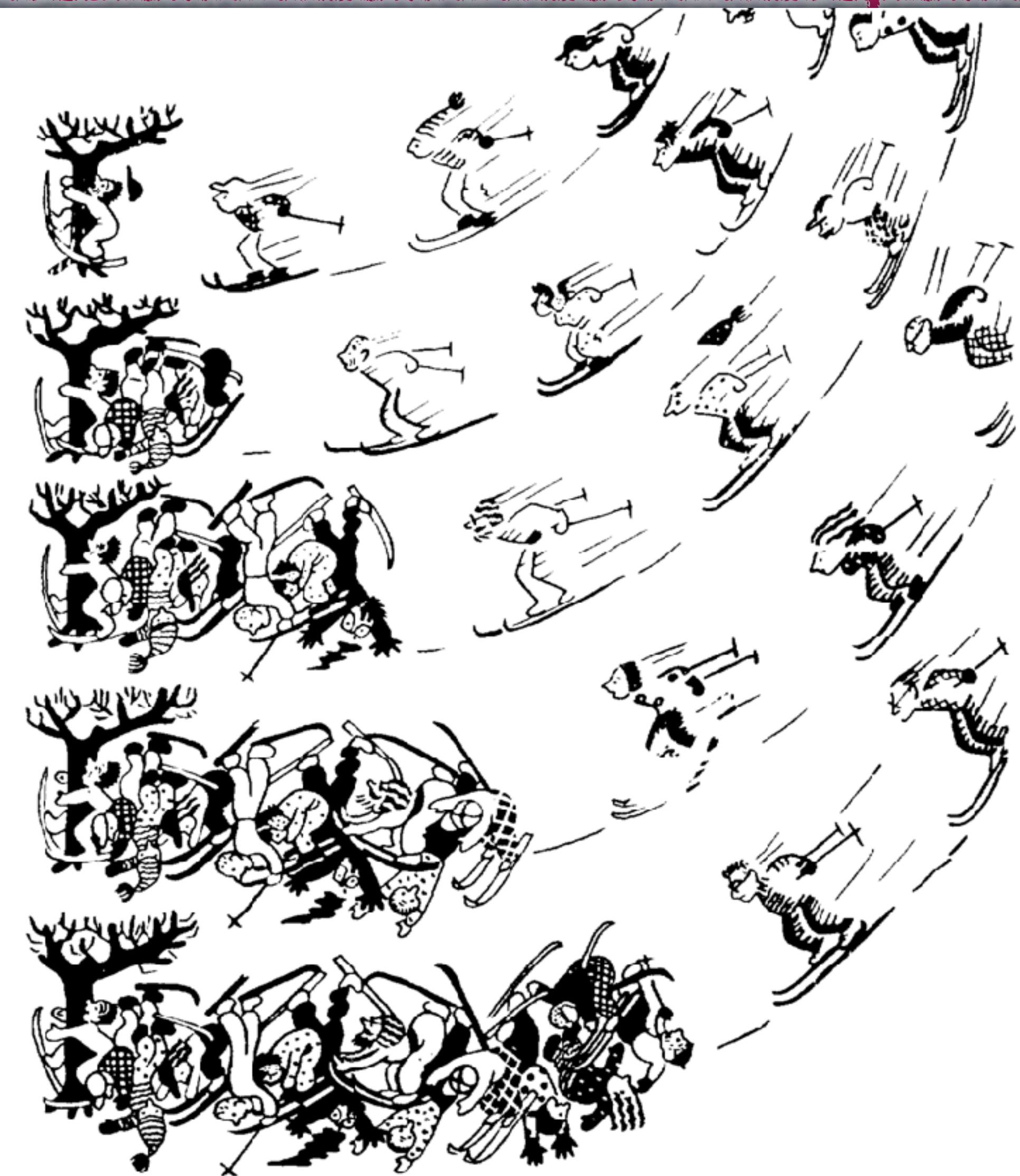$\sim 6 \times 10^{24}$ cm
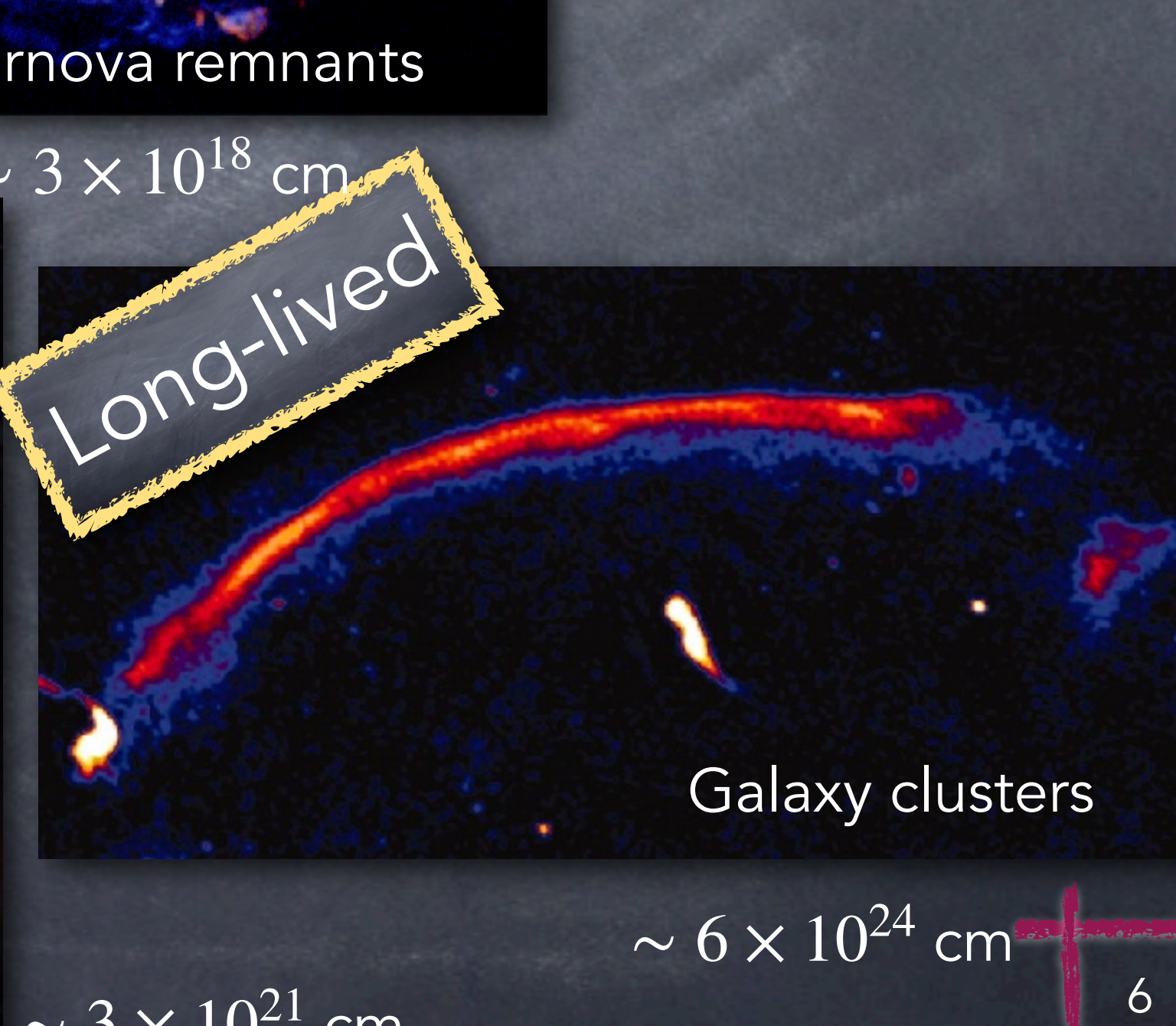
- Steepening of supersonic signal
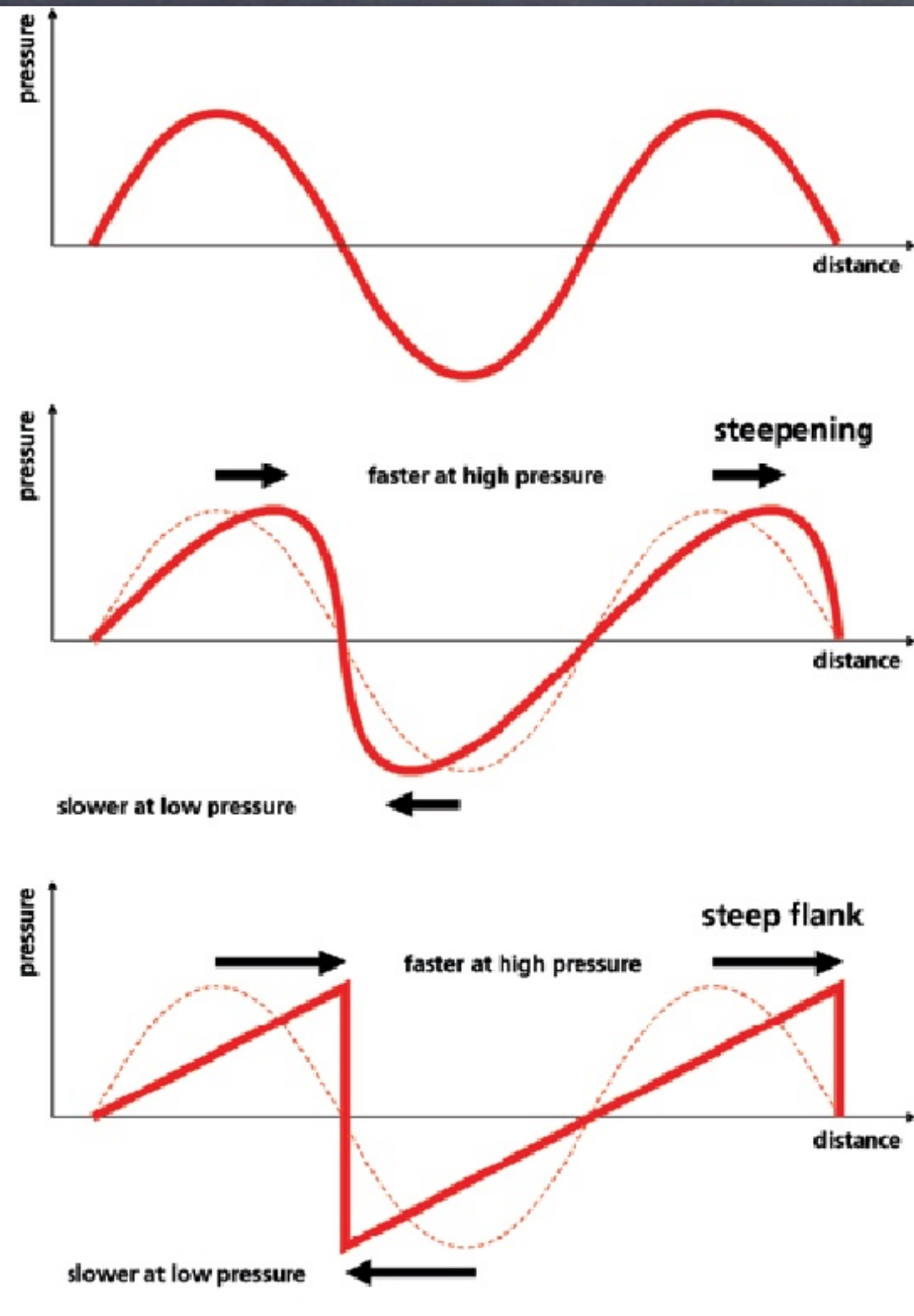
Why *supersonic*?
Because otherwise
sound waves would
smooth
any gradient out

- Interaction of a supersonic flow with an obstacle

Copyright, 1948,
by Gabriele Waxow

An example of a receding shock wave. From Supersonic Flow and Shock Waves by
R. Courant and K. O. Friedrichs (New York:Interscience Publishers, Inc., 1948)

- At a shock, entropy increases (see Landau Lifshitz, vol 6., sec IX)

- Distinguish subcritical and supercritical shocks (depends on Θ_{Bn} and sonic and Alfvènic Mach numbers: $M_s = V_{sh}/c_s$ and $M_A = V_{sh}/v_A$)
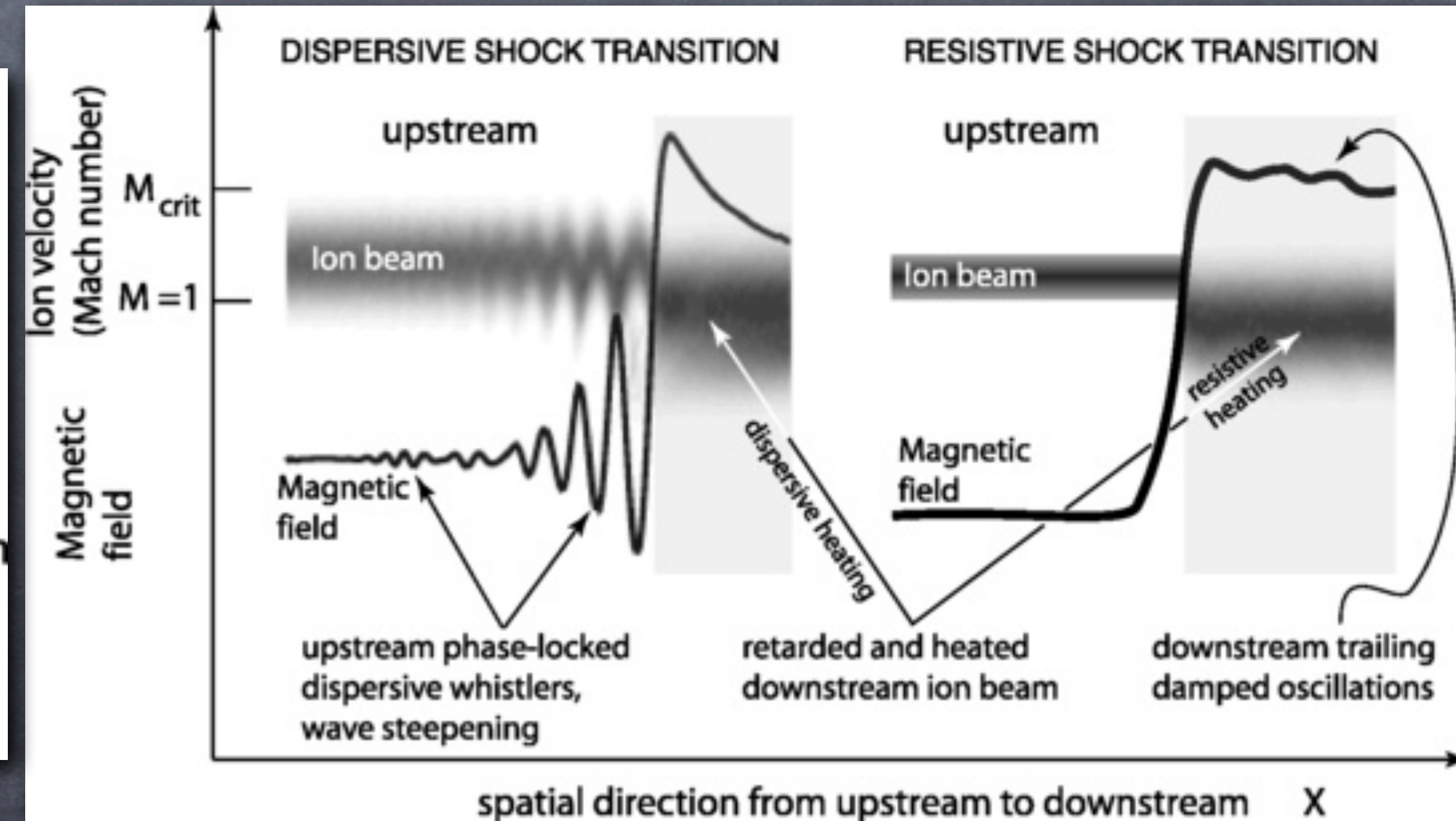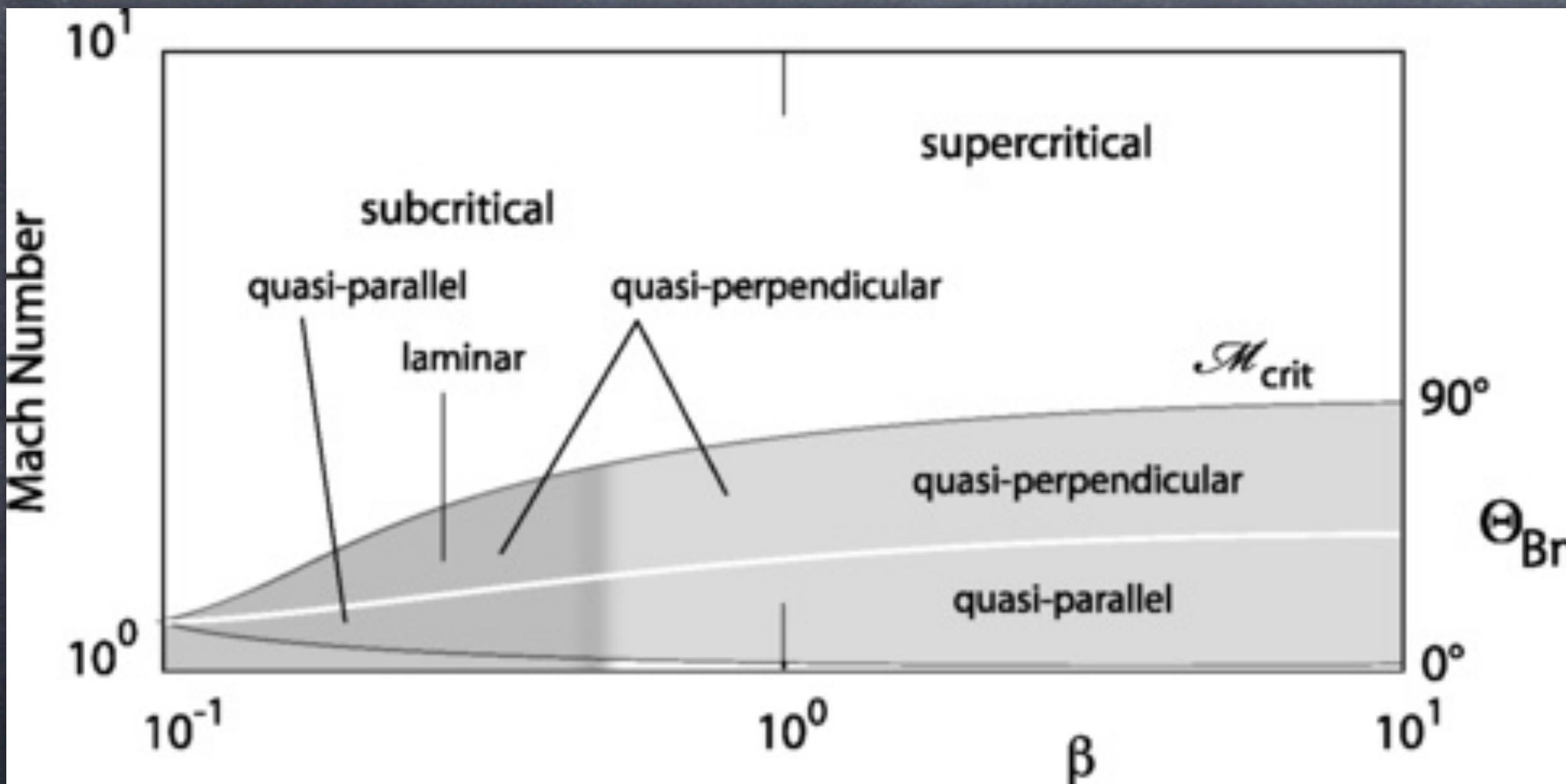
- The vast majority of space/astro shocks are *supercritical* (and reflect particles!)

References

- Books:

  - **M. Vietri**: Foundations of High-Energy Astrophysics

  - **M. Longair**: High-energy Astrophysics

- Lecture Notes:

  - **R. Fitzpatrick**: https://farside.ph.utexas.edu/teaching/plasma/lectures/node79.html

  - **G. Bicknell**: https://www.mso.anu.edu.au/~geoff/AGD/Shock_Waves.pdf (MHD shocks)

    https://www.mso.anu.edu.au/~geoff/AGD/Relativistic_Gases.pdf (relativistic shocks)

  - **N. Murphy**: https://lweb.cfa.harvard.edu/~namurphy/Lectures/Ay253_2016_08_Shocks.pdf

- Reviews on shocks (including space data and simulations)

  - **Balogh & Treumann 2013**

  - **Treumann 2009**

- With Cosmic Rays

  - **Drury 1983; Jones & Ellison 1991**