Fluid Phenomena: Some Examples
1. Stellar Physics
Ordinary Star:

Self-gravitating, rotating, gaseous sphere

Radius changes on time scales of $10^{10}$ years

Collapse in $10^3$ s in absence of gas pressure

Solar granulation: 5 minute time scale
Figure 2. The Sun's luminosity (energy output), temperature, pressure, and composition all vary with depth in its interior. At the Sun's center, the pressure is 233 billion times that of the Earth's atmosphere at sea level.
Figure 16. Internal rotation rates of the Sun at latitudes of $0^\circ$, $30^\circ$, and $60^\circ$ have been inferred using data from the Michelson Doppler Imager (MDI) aboard the SOHO spacecraft. Just below the convection zone, the rotational speed changes markedly. Shearing motions along this interface may be the source of the Sun’s magnetism.
Figure 17. A surprising variety of large-scale flows occur in the Sun’s interior. Red corresponds to faster-than-average flows, yellow to slower than average, and blue to slower yet. For example, on the left side, deeply rooted zones (yellow bands), analogous to the Earth’s trade winds, travel slightly faster than their surroundings (blue regions). Sunspots may tend to form at the edges of these zones. Polar “jet streams” (dark blue ovals) move approximately 10 percent faster than their surroundings (light blue). There is slow movement poleward from the equator shown by the streamlines in the right-hand cutaway (the return flow below it is inferred).
Granular convection and sunspots as seen at 304 Angstroms
Sun, as seen in the far ultraviolet (195 Angstroms)
Prominences:
Magnetohydrodynamically controlled
Solar disturbances and coronal looping, as seen by a soft X-ray satellite-borne telescope
Solar corona as seen during a solar eclipse
No generally accepted theory for short term variations in solar luminosity

Figure 22. Complementary observations from several satellites show that the Sun’s output fluctuates during each 11-year cycle (dips in curves), with a maximum coinciding with the peak in sunspot and magnetic activity. Some researchers believe the satellite data also suggest that the Sun was slightly brighter in 1996 than during the previous solar minimum (dashed lines). However, this interpretation is considered controversial, and a longer baseline of observations is needed.
Figure 24. Billions of years from now the Sun will grow enormously in size and luminosity. Note the different time scales, expanded near the end of the Sun’s life to show relatively rapid changes. The orbits of the planets enlarge due to mass loss from the Sun. By the time our star becomes a white dwarf, it will have only 0.51 to 0.58 of its present mass.
Supernovae: Absorption of neutrinos produces shock wave that blows off envelope of gas. Shock wave stops at finite radius...envelope should then collapse but does not.....
2. Mantle Convection
Mantle Convection Simulation by
Walter Kiefer (LPI) and Louise Kellogg (Univ. California)
3. Climate Dynamics
Heat Transport by Oceans and Atmosphere
Ocean Thermohaline Circulation
A hot plate is brought in contact with the left half of the surface of a swimming pool of cold water. Heat diffuses downward and the warm water begins to rise. The strength of the circulation is controlled in part by the rate of heat diffusion. In the real world, this rate is very, very small.
Adding a stirring rod to this picture greatly enhances the circulation by mixing the warm water to greater depth and bringing more cold water in contact with the plate. The strength of the lateral heat flux is proportional to the \( \frac{2}{3} \) power of the power put into the stirring, and the \( \frac{2}{3} \) power of the temperature of the plate.

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\text{Heat Flux} \sim P^{\frac{2}{3}} B^{\frac{2}{3}}
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h \sim P^{\frac{1}{3}} B^{-\frac{2}{3}}
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Figure 4.1. Modern (solid line) and estimated early Eocene (dashed lines) zonal sea surface temperatures. Modern (diagonal hatch) and estimated early Eocene (vertical hatch) water temperatures at bottom depths between 1000 m and 5000 m. Modern data are from the World Ocean Atlas data set (Levitus and Boyer, 1994). The cooler Eocene SST profile is based on Zachos et al. (1994); the warmer SST profile is based on Crowley and Zachos (Chapter 3, this volume).