nonlinear evolution of these sound waves. The isotropy of the microwave background places firm limits on the amplitude of the sound waves at the epoch of recombination. As a result we are able to rule out the hypothesis that the universe consists entirely of radiation and ordinary matter.

9:30

E2. Shock waves in astrophysics. Edmund Bertschinger (Department of Astronomy, University of California, Berkeley, CA 94720)

Gravitational forces acting on a large scale often generate supersonic velocities in cosmic gas leading to shock waves. Astrophysical shock waves range in size from the earth's bow shock in the solar wind to interstellar shock waves generated by supernova explosions, and perhaps to galaxy-size explosions in the early universe. Shock waves are important to astronomers and astrophysicists for a variety of reasons. Shocked gas emits radiation which serves as a useful diagnostic of the composition and state of the gas. Radiative shock waves, because they can greatly increase the gas density and hence gravitational binding energy, are also important in enhancing star formation. A review will be given of the causes, occurrence, and significance of astrophysical shock waves. The theoretical, observational, and computational methods used to study them will also be discussed.

10:00

E3. Physical mechanisms in stellar pulsations. Arthur N. Cox (Los Alamos National Laboratory, University of California, Los Alamos, NM 87545)

Stars evolve from their births to their deaths by converting their store of hydrogen to helium, and then much of this helium is fused to heavier elements such as carbon, oxygen, and up to iron. During this evolution, the stellar mass may decrease by a stellar wind mass loss, the radius usually greatly increases, and the radiation luminosity emitted at the surface grows until the stellar death results in a very small compact object. During this evolution, there are often several stages when the structure of a star is unstable against pulsations. These pulsations are observable and indicators of the internal details of its structure. Six of these self-excitation mechanisms, which produce limited amplitude pulsations, will be discussed and demonstrated. Three deep-seated ones are the modulated nuclear fusion reactions at the stellar centers, the possible Kelvin–Helmholtz instability at the surface of a rapidly rotating core of the star, and oscillation of convective eddies which has a restoring force due to a composition gradient in deep layers. Three mechanisms which operate in the outer layers are the oscillations of convective eddies restrained by a strong magnetic field, and the thermodynamic effects of blocking and hiding of the radiation luminosity due to the ionization of the abundant elements, hydrogen and helium.

10:30

E4. Coherent vortical features in a turbulent two-dimensional flow and the Great Red Spot of Jupiter. Philip S. Marcus (Division of Applied Sciences and Department of Astronomy, Harvard University, Cambridge, MA 02138)

We present the results of an initial-valve study of a nearly inviscid flow in a low aspect ratio, rapidly rotating, cylindrical annulus with a free upper surface and with a sloping bottom surface. In the limit of very rapid rotation, the equations and solutions of this flow are the same as those of a planetary atmosphere whose density decreases exponentially with height. We have found numerically that for a wide range of initial conditions the flow settles into a statistically steady state that consists of an isolated coherent spot of vorticity superposed on a turbulent zonal (statistically axisymmetric) flow whose time-averaged vorticity is linear in radius (or linear in latitude of a planetary atmosphere). The strength and sign of the vorticity in the zonal flow and in the spot, the shape and location of the spot, and the interaction of the spot with other features are quantitatively similar to the properties of the Red Spot of Jupiter and the zonal wind in which it is located. The time-averaged features of the zone and the spot are surprisingly insensitive to a number of different types of boundary conditions. We present examples of solutions where two or more spots (present as intial conditions) merge into one spot, and where a spot with the wrong sign of vorticity breaks up and reforms rotating with the correct sign. An analytic model is developed based on the numerical results that shows that under some conditions a spot must necessarily form, and that two or more spots must merge into a single spot. The model's predictions of the size, shape, strength, and location of the spot are in good agreement with the numerical results. We conclude by discussing the feasibility of reproducing this flow (i.e., a coherent spot in a turbulent background) in the laboratory.

11:00

E5. Gravitational waves: A new window for astronomy. Peter F. Michelson (Physics Department, Stanford University, Stanford, CA 94305)

Gravitational waves were predicted more than 50 years ago by Einstein as a consequence of the general theory of relativity. Because of the weakness of the gravitational interaction, efforts to directly detect gravitational waves have focused on astrophysical sources rather than terrestrial sources. In laboratories around the