eccentricity of the Earth's orbit may play an important role in determining whether an external perturbation of the terrestrial climate would result in ice sheet growth or recession. Presently the solar constant varies from a maximum of about 3.4% above its mean value at perihelion (closest approach to the Sun) on January 1 to about 3.4% below average at aphelion on July 1. Thus presently with perihelion occurring close to the winter solstice the Northern Hemisphere is having cool summers and mild winters, ideal conditions for the initiation of ice sheet growth. However, due to the precession of the equinoxes and other minor orbital effects the longitude of the perihelion changes through 360° over a period ranging from 20,000 – 25,000 years. Over the past cycle this period of variation has been close to 22,000 years. Using Berger's data (1977) to follow the variation of the longitude of the perihelion back in time, it is found that about 11,500 years BP perihelion coincided with the summer solstice, giving maximally hot summers and maximally cold winters in the Northern Hemisphere, ideal conditions for glacial retreat. Going further back in time, conditions would have been optimal for glacial growth around 22,000 years BP and for glacial recession around 33,000 years BP.

In summary, the following general model is proposed to account for the glacial-interglacial oscillations characteristic of the Pleistocene climate. The initiators of the abrupt climatic changes are ultimately astronomical in nature — superwaves that transport nebular material into the solar system. These particles of dust and ice would in turn cause changes in the Sun's continuum spectrum, in the intensity of solar radiation transmitted to the Earth, and in the Earth's atmospheric albedo. These external perturbations of the Earth's climate would occur in a random fashion, but they would have differing effects depending on the particular phase of planetary precession. Thus the regular variation of the longitude of the perihelion would introduce a cyclic character to the resulting climatic response, ice sheet growth being more probable during winter perihelion epochs and ice sheet recession being more probable during summer perihelion epochs. Following each brief destabilizing event, the Earth's climate would tend to enter a period of stabilization, the particular climatic state adopted being dependent on the extent of the glacial ice cover. If the supply of cometary debris residing near the heliopause were to gradually diminish, the amount of cosmic dust periodically injected into the solar system by passing superwaves would also diminish as would the severity of the induced climatic changes. Eventually, a point would be reached where superwaves of moderate intensity would be able to pass the Earth without producing significant climatic changes. However, even with dust-free conditions there is always the possibility that a superwave of high intensity could pass by and cause a major climatic perturbation.

3.3.5 Biological Effects

There are several ways in which the passage of a Galactic superwave could have affected living organisms, as seen in Figure 3.26. Consider first the direct effect of the superwave cosmic ray electrons. In Subsection 3.3.1 it was determined that at the superwave's peak intensity the sea level radiation intensity would have increased about 80 fold from its normal steady state level. Given that the current background flux of ionizing radiation measured at sea level at the geomagnetic equator is ~0.05 roentgens/year (r/yr) (Harrison, 1968), during peak superwave intensity a flux of ~4 r/yr would be present. Chronic exposure to such levels would not have serious consequences. This dosage rate is comparable to the maximum acceptable occupational dose rate for human beings (~100 mr/wk), although it is about 5 times the maximum acceptable occupational dose rate for pregnant women. At this exposure rate, a human being would accumulate about 100 r over the course of one generation, resulting in a doubling of the mutation rate (cf. Harrison, 1968; after Kato, Schull, and Neel, 1966; Glasstone, 1964).

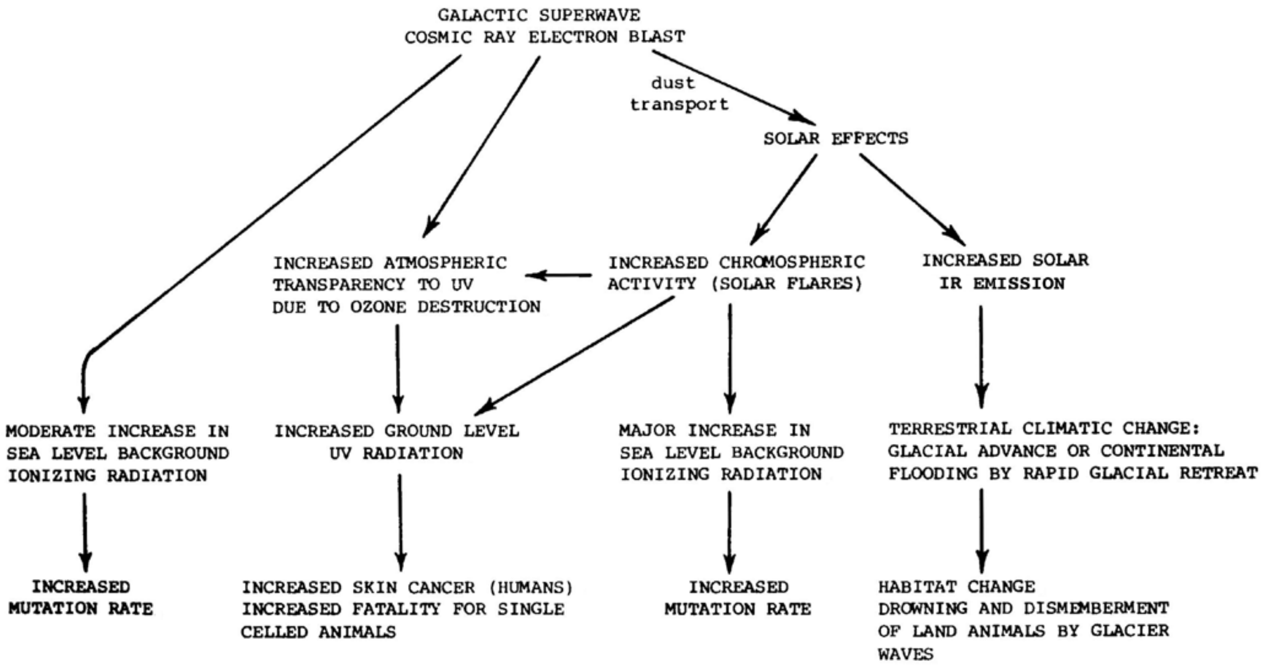

Figure 3.26. Ways in which a Galactic superwave could affect living organisms.

It is possible that at other times in geologic history there may have been superwaves having a much higher cosmic ray intensity than the levels postulated here for the 14,200 years BP event (perhaps even up to 1000 times higher), in which case the mutational and health effects would have been much more serious. However, radiation levels very much higher than the quoted level can be ruled out for the 14,200 years BP event, since higher cosmic ray intensities would have caused an excessive elevation in C-14 concentration in the terrestrial carbon reservoir.

The heliopause sheath would also have posed a substantial threat to planetary life. As was discussed in Subsection 3.3.2, the heliopause could have contained cosmic ray energy densities of the order of 10^{-4} – 10^{-3} ergs/cm^3, or about 10^9 – 10^{10} fold greater than the current cosmic ray background levels. If the heliopause happened to contact the Earth during a period of peak superwave intensity, radiation levels on the order of 100 to 1000 r/min would have occurred at the Earth's surface. At these rates most unprotected life forms, both plants and animals, and surface dwelling sea creatures would have received the lethal dose within a matter of minutes. The planet would have become practically barren of life except for the lucky few which at the appointed time happened to be sheltered under a sufficient thickness of rock, soil, or water. However, for the 14,200 years BP superwave, exposure times longer than a few minutes at these high radiation rates can be ruled out on the basis of the Earth's C-14 record.

An increase in the cosmic ray electron background would also have affected life forms in an *indirect* manner. For example, the atmospheric photo-electron cascade produced by cosmic rays generates a considerable amount of atmospheric ionizations which in turn produces nitrous oxides (and other compounds) which in turn catalytically destroy atmospheric ozone. The ozone layer, which is found at an altitude of ~30 kilometers in the Earth's stratosphere is effective in screening out harmful solar UV radiation. Thus increased cosmic ray electron levels, by being involved in the destruction of the ozone layer, as a side effect would induce an increase in the level of UV radiation reaching the ground.

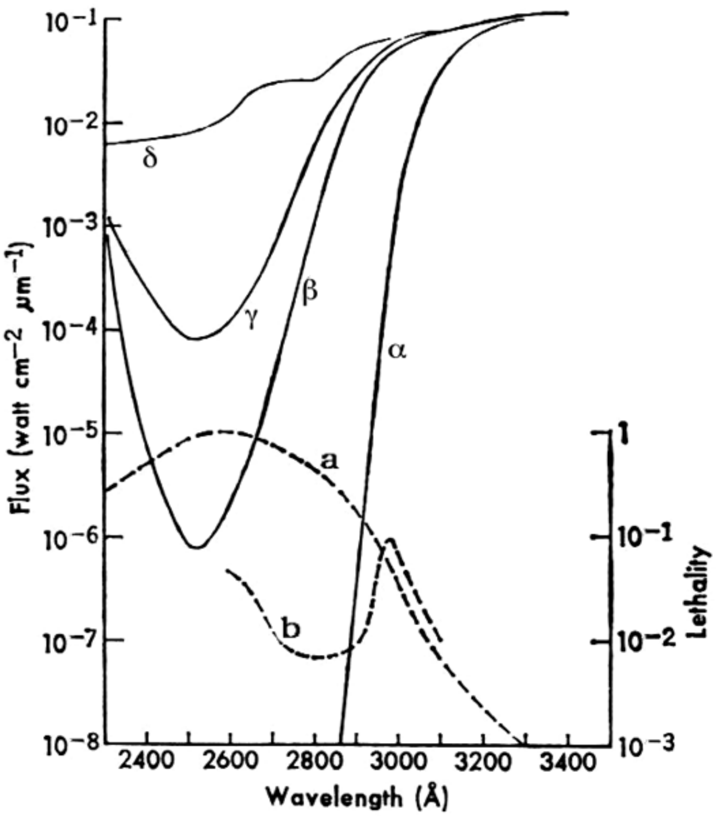

Figure 3.27. Solar ultraviolet flux on the Earth (vertical incidence): Curve α, after passing through a typical stratospheric ozone layer, Curve β, after passing through an O_3 layer depleted to 10% of its present concentration, Curve γ, after passing through a layer depleted to 6% of the present O_3 concentration, Curve δ, flux at the top of the atmosphere. Curve a, relative effectiveness of ultraviolet flux at various wavelengths in killing bacterial cells. Curve b, relative effectiveness of ultraviolet flux in producing erythema (sunburn) (reproduced from Ruderman, 1974).

Ruderman (1974) estimates that a supernova explosion producing a hundredfold increase in cosmic ray intensity at the top of the atmosphere would cause a 2 – 50 fold increase in NO_x concentration, which in turn would produce a decrease in ozone concentration to a level that would be between 60 and 3 percent of its former value. These same figures would be equally applicable to the proposed superwave cosmic ray electron blast. At the hypothesized intensity the 14,200 years BP superwave would produce about a 75 fold increase in the cosmic ray flux reaching the top of the atmosphere.

Figure 3.27 (Ruderman, 1974) illustrates how varying degrees of ozone reduction would affect the level of UV radiation reaching sea level. Note that a 10 fold decrease in ozone (to 10% of its former level, curve) would have drastic effects. At 3000 Å, the wavelength most effective in producing sunburn, there would be a hundredfold increase in UV intensity. However, at 2500 Å, the wavelength most harmful to single celled organisms, there would be a 10^{36} fold increase! At this wavelength the stratospheric ozone layer normally allows only 1 out of about 10^{40} photons to penetrate (Coulson, 1975, p. 144). A major increase in 2500 Å radiation could have serious consequences for phytoplankton which dwell near the ocean surface. Water is not a very good shield for UV radiation. It takes 5 meters of pure water to attenuate 2900 Å wavelength radiation to 3% of its former intensity (Ruderman). For humans the main worry would be skin cancer, wavelengths in the 2000 – 3000 Å range being most biologically active (Coulson, p. 147). However, this would not be a problem for most mature land animals, since feathers, fur, or hide would offer suitable protection. But young animals would have to be sheltered.

There would have been several biologically significant effects arising as a result of the activation of the solar chromosphere. For example, if solar flare activity had become 10^3 times more intense as a result of nebular material falling into the Sun, cosmic ray proton intensities striking the Earth's atmosphere could have averaged 100 times higher than present background levels (i.e., assuming that solar cosmic rays currently contribute about 10% of the cosmic ray flux above 10 Gev). This would have produced an acceleration of the mutation rate comparable to that caused by the superwave cosmic ray electron flux. In addition, the UV flux from the Sun would have risen considerably. UV radiation would have been produced both from the ever-present solar flares and from heating of the solar chromosphere by infalling material; cf. Subsection 3.3.2. As an extreme example, if the Sun were to enter a T Tauri phase of activity and were to adopt a continuum similar to the star R W Aurigae, its UV emission in the 2500 Å band could conceivably increase 10 fold. However, at this wavelength a more dramatic change in the ground level UV flux would have come about as a result of deterioration of the stratospheric ozone layer.

Sudden climatic changes brought about as a result of a shifting of the solar spectrum to the infrared and changes of the solar constant would also have made a significant impact. Consequent increases in the amount of radiant energy absorbed by the Earth could have caused a considerable increase in the temperature of the Earth's atmosphere (and surface), particularly in low latitudes. This in turn could have induced death through hyperthermia, especially in the case of land animals. A very intense, but brief, heating episode associated with a major nova-like solar outburst (such as is considered in Section 4.7.3) could also have produced fatal results. In addition, glacier waves, forming as a result of accelerated glacial melting at high latitudes, would have been particularly hazardous through their ability to dismember and drown land animals; see Chapter 10, **p. 277**. Perhaps the greater portion of the Terminal Pleistocene fossil record owes its creation to the agency of such continental flooding episodes; see Chapter 10.

In general, the Galactic Explosion Hypothesis predicts that at the end of the Wisconsin Ice Age period (14,000 – 10,000 years BP) there would have been a greater chance for mass extinction. Large land mammals would have been at a particular disadvantage since they would have had greater difficulty in seeking shelter from the hazards of glacier waves and elevated levels of ionizing radiation. As is discussed in Chapter 10, a major extinction of large land animals, the worst of the Pleistocene, occurred between 14,500 and 12,700 calendar years BP, most likely in connection with a major episode of continental flooding of global extent.

If Galactic superwaves (and possibly associated solar effects) periodically produce very high radiation levels on the Earth, then the history of evolution should indicate the presence of periodic evolutionary spurts. That is, the reduction in population sizes brought about by the hazardous environmental conditions would have led to the formation of isolated animal communities. This isolation, together with the resulting acceleration in mutation rate, would have tended to foster speciation, i.e., the evolution of a parent species into a variety of daughter species. Thus over the space of a few centuries or less, a cosmic ray barrage could have terminated some species, while at the same time inducing the remainder to branch into a plurality of novel forms. As is discussed in Chapter 11, Section 11.1, the paleontological record indicates that, indeed, there appears to be a quantum, step-like character to evolution.