ON STELLAR STRUCTURE AND STELLAR EVOLUTION

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Abstract

Current stellar astronomy maintains a close relationship between the observed structure of stars and their supposed evolutionary history. An attempt is made to distinguish between stellar structure observations and theoretical stellar evolution. The physical laws believed to govern the macroscopic structure of nondegenerate stars are reviewed. From these laws, scaling relationships between several properties are derived. These scaling relationships hold independent of the source of stellar power, allowing for both gravitational contraction and thermonuclear fusion sources. With additional observational information and physical approximation, a synthetic Hertzsprung-Russell (H-R) diagram is presented. The synthetic H-R diagram bears some similarity to observed H-R diagrams.

Introduction

As noted by Faulkner and DeYoung (1991) in their thought-provoking article, most creationist work in astronomy has focused on the small scale (astronomically speaking) such as the solar system, and on the large scale (cosmological). There does not exist even a rough framework for creationist astronomy because the middle scale has not been adequately addressed. The middle scale would be referred to as stellar evolution by general astronomical parlance. The theory of stellar evolution is briefly reviewed in the article, which concludes that stellar structure and stellar evolution are so closely related as to make it difficult to accept one without the other. Faulkner and DeYoung (1991) used stellar evolution to mean stellar aging, but for this paper stellar evolution will be used exclusively for the multi-billion year history depicted in evolutionary astronomy.

Before continuing, consider the framework of a creationist astronomy. According to Genesis 1-2, God created all things in the heavens and the earth, forming their structures and filling them over a period of six days. The earth was formed first (days 1-3) and the stellar heavens were filled on the fourth day. The stars were created fully functioning, fulfilling the Creator's expressed purpose to give light on the earth, and to distinguish days, seasons, and years. Following early history in Genesis 3-11 leads to the conclusion that the earth and the stellar heavens cannot be more than several thousand years old. A creationist astronomy must be faithful to this framework.

In contrast, stellar evolution explains the origin and development of stars in a naturalistic manner (Iben, 1991). Contrary to the biblical framework, stellar evolution accepts the presumed geological age (4.5 billion years) of the earth, and includes stellar models whose lifetimes are comparable to this age. It is rather easy to find numerous statements in stellar structure textbooks that power for stars must be thermonuclear, since this is the only known energy source capable of lasting for billions of years. For example, Chandrasekhar (1938, p. 455) stated:

> The order of the 'age' of the sun thus derived on the Helmholtz-Kelvin contraction hypothesis is found to conflict with other evidence which is essentially of a geological nature. . . . Hence, the geological evidence completely disproves the contraction hypothesis for the sun, and therefore also for the normal stars. We are thus led to seek a different origin for the source of stellar energy.

Also Clayton (1968, p. 43) explained:

> This time (solar gravitational contraction time of about 30 million years) is much too short for a maximum lifetime of the sun. It is known that the sun has existed over 100 times longer than this, because the age of the earth itself is about 4.6 billion years.

It can be concluded that stellar structure and stellar evolution are closely related because evolutionary astronomers have made them so.

Stellar evolution implies more than just the aging of stars. It has relation to the cosmic scale as well as to the small scale. Evolutionary astronomy believes that stars transform the basic material that originated in the Big Bang. Without nucleosynthesis of elements heavier than helium in earlier generation stars, there can be no solar system with planets (Wilt, 1983; Rigutti, 1984). The time scale for nuclear transformation is the time scale for the lifetime of stars; millions to several billion years. In summary, stellar evolution requires an old universe.

Despite elaborate modeling of stellar evolution theory, observational data is limited. According to Clayton (1968), the observable large scale properties of stellar structure are *luminosity* (total radiant power, inferred from measured radiance and distance), *effective surface temperature* (inferred from spectral observations), *mass* (inferred from binary star motions), *radius* (inferred from surface temperature and luminosity, as well as from eclipsing binaries and direct measurement), and *surface chemical composition* (also inferred from spectral line observations). The classical observational tool for summarizing stellar observations is known as the Hertzsprung-Russell (H-R) diagram (Clayton, 1968; Abell, 1969). This diagram shows the relationship between luminosity (L) and effective surface temperature (T_e) for observed stars, with luminosity (ordinate) increasing upwards and temperature (abscissa) increasing leftward. Clayton (1968) notes that about 90 percent of observed stars fall into a diagonal band from the upper left (high L, high T_e) to the lower right (low L, low T_e), known as the main sequence. Much smaller numbers of luminous stars are found in the giant and supergiant regions to the upper right (high L, generally lower T_e) region, while white

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dwarfs (comprising an estimated several percent of all stars) populate the lower left portion of the diagram (low L, high T_e). The H-R diagram summarizes a wide body of laboriously collected observational data in stellar astronomy, and must be the starting point for discussions of stellar structure.

Evolutionary astronomers have developed stellar evolution to explain H-R diagrams for various stellar systems. For example, most stars are found on the main sequence because stars spend much of their supposed million to several billion year lifetimes on the main sequence. Similar to evolutionary geologists, evolutionary astronomers have taken the observable data (H-R diagrams, or in the geologist's case, the geologic column with its embedded fossils) and theorized about purely naturalistic development of stellar systems over billions of years to explain these observations. The system of stellar evolution in astronomy is the exact analog of the system of biological evolution over geological ages in earth history.

To develop a more comprehensive creationist astronomy, the H-R diagram observations must be accepted, along with the usual physical principles believed to govern the structure of stars. The focus in this paper will be on nondegenerate stars, which includes main sequence stars along with giants and supergiants, but excludes white dwarfs and neutron stars. The physical laws that govern this group of stars can be expressed as a set of coupled equations. Rather than evaluate numerical solutions to these equations for model stars, a simpler approach is taken. These equations can be reduced to simple and well known scaling relationships between several important stellar properties (some observable). With further approximations these scaling equations can be reduced to luminosity-effective temperature (L/T_e) relationships which can be plotted on an H-R diagram, without any reference to stellar age or energy production mechanisms. It will be shown that the synthetic H-R diagram has some similarities to observed H-R diagrams. While scaling relationships do not constitute a full theory of stellar structure apart from stellar evolution, they do indicate the possibility of constructing an alternative theory of stellar structure for creationist astronomy without recourse to multi-billion year stellar evolution.

Physical Laws Governing Stellar Structure

The physical laws governing stellar structure are well known (see Chandrasekhar 1938; Clayton 1968; Kippenhahn and Weigart 1990). Stars are assumed to be spherically symmetric objects in quasi-static equilibrium (meaning that there is little change in structure over several thousand years). Let the mass density (mass of stellar material per unit volume) for radius r be r (r) and the total mass within a sphere of radius r be m(r). By mass conservation one derives:

$$\frac{dm}{dr} = 4\pi r^2 \rho \tag{1}$$

Direct integration of this equation yields the total mass M of the star:

$$M = \int_0^R 4\pi r^2 \rho \, dr$$

where M = m(R), and R is the radius of the star's surface.

Consistent with the assumption of quasi-static equilibrium, it is assumed that each small portion of the star is in local thermodynamic equilibrium. For nondegenerate stars the gas pressure p (force per unit area exerted by the stellar material), temperature T, and mean molecular weight μ (1 for pure neutral hydrogen), along with the mass density r, satisfy the ideal gas equation of state:

$$p = \frac{k}{m_H} \frac{\rho T}{\mu} \tag{2}$$

where k = Boltzmann's constant and m_H is the mass of a hydrogen atom. The mean molecular weight μ depends on the mass fractions of hydrogen, helium, and heavier elements, as well as on the degree of ionization of the stellar material. Radiation exerts pressure on stellar material, but except for very high temperatures ($T > 5 \times 10^6$ K), radiation pressure is orders of magnitude less than gas pressure.

The star is assumed to be in a high degree of hydrostatic equilibrium, meaning that there must exist an outward radial pressure force that balances the inward gravitational force. This does not mean that the radial structure of the star cannot change; only that any accelerations accompanying such changes must be orders of magnitude less than the gravitational acceleration. If G is the gravitational constant, then the hydrostatic equilibrium condition can be represented by:

$$\frac{dp}{dr} = -\frac{Gm}{r^2} \rho \tag{3}$$

The existence of a radial pressure gradient implies radial gradients of mass density and temperature (from equation 2). Temperature gradients in turn imply energy transport, which in general can occur by radiation, convection (mass motions), or conduction (microscopic motions). At the surface of the star, where the opacity (resistance of stellar material to the propagation of radiation) becomes small, radiation can freely escape to space. If L is the luminosity (total power) of the star, and T_e is the effective surface temperature, then:

$$L = 4\pi R^2 \sigma T_e^4 \tag{4}$$

where σ is the Stefan-Boltzmann constant; the star is assumed to radiate to space at its radius R like a black body of effective temperature T_e.

The steady loss of power from the star implies slow quasi-static changes in stellar structure, which are governed by the first law of thermodynamics:

$$C_V \frac{dT}{dt} + p \frac{dV}{dt} = -\frac{1}{4\pi r^2} \frac{dL}{dr} + \rho\epsilon \tag{5}$$

where C_V is the heat capacity at constant volume, V is the volume, t is time, and ε is any internal energy generation (such as thermonuclear) per unit mass of stellar material. The first term on the left-hand-side is the change in thermal energy (proportional to T) of stellar material; the next term arises if any contraction or expansion occurs, and is the gravitational energy term; the first term on the right-hand-side is the energy transport term.

Equation 5 implies that the luminosity varies throughout the star from zero at the center up to the total luminosity L at the star's surface (equation 4). As noted previously, energy transport can be by radiation, convection, or conduction. Because of the relatively low opacity of stellar material, most of the energy transport is by radiation, and can be represented as a diffusion process:

$$L = -4\pi r^2 \frac{16\sigma T^3}{3\kappa\rho}\frac{dT}{dr} \quad (6)$$

where *k* is the Rosseland mean absorption coefficient of stellar material. The star is a large reservoir of radiant energy (radiation energy density is $4\sigma T^4/c$, where c is the speed of light), confined somewhat by the opacity of stellar material, which slowly diffuses to the surface to be emitted to space. The opacity *k* is a function of mass density, temperature, and composition, and depends on four competing processes: electron scattering, free-free absorption, bound-free absorption, and bound-bound absorption. For the highest temperatures and relatively low densities, electron scattering dominates, for which *k* is independent of *r* and T; for somewhat lower temperatures, free-free absorption dominates, which has a dependence of $\rho T^{-3.5}$ (termed Kramer's opacity); for lower T and *r* strong bound-free and bound-bound absorption occur. For extremely low *r* near the stellar surface, *k* typically becomes small again. (See Clayton, 1968 and Kippenhahn and Wiegert, 1990 for more complete discussion.)

For this paper, the energy transport will be assumed to be by radiation. If the opacity *k* is not large, the temperature gradient required to carry the luminosity is usually less than the adiabatic. That is,

$$\frac{dT}{dr} = \frac{\gamma - 1}{\gamma}\frac{T}{p}\frac{dp}{dr}$$

where *g* is the ratio of specific heats at constant pressure to that at constant volume. Regions with temperature gradients larger than the adiabatic are unstable to convective motions. This occurs around hydrogen and helium recombination zones (approximate temperatures of 5 x 10^4 and 10^5 K respectively). For these latter conditions, the actual temperature gradient follows the adiabatic one closely.

In summary, equations l-6 constitute a basic set of laws governing the macroscopic structure of nondegenerate stars. Given the microscopic structure specified by *{m, k, e}*, the macroscopic equilibrium structure of *{p, r, T, m, L}* as functions of r can be determined from equations 1-6, subject to the boundary conditions of m(r) = 0 at r = 0, m(r) = M at r = R, $r \to 0$ and $T \to T_e$ as $r \to$ R. Thus the macroscopic structure is uniquely determined by *m* and M in nuclear powered stars (Russell-Vogt theorem).

Scaling Relationships Between Major Properties

General scaling relationships can be derived from the governing equations presented in the previous section. For such relationships, all variables will be given in solar units (variables = 1 for the sun). This scaling analysis is well known in stellar structure theory (Clayton, 1968; Burrows, 1987; Kippenhahn and Wiegert, 1990).

The mass conservation equation (1) scales as:

$$\rho_c = \frac{M}{R^3} \quad (7)$$

where r_c refers to the mass density at stellar center. The equation of state (2) scales as:

$$p_c = \frac{\rho_c T_c}{\mu_c} \quad (8)$$

where again the subscript c refers to stellar center. The hydrostatic equation (3) scales as:

$$p_c = \frac{M\rho_c}{R} \quad (9)$$

The surface luminosity equation (4) scales as:

$$L = R^2 T_e^4 \quad (10)$$

while the interior energy transport equation (6) scales as:

$$L = \frac{RT_c^4}{\kappa\rho_c} \quad (11)$$

Using equations 8 and 9 gives an expression for the central temperature T_c:

$$T_c = \frac{\mu_c M}{R} \quad (12)$$

This important result states that the more massive the star, the higher the central temperature. If the composition is enriched with elements heavier than hydrogen (compared to the sun), the central temperature will increase also. Finally, any contraction of the star (decreasing R) implies an increase in the central temperature.

Using equations 11 and 12 and eliminating r_c with equation 7, the important result follows:

$$L = \frac{\mu_c^4 M^3}{\kappa} \quad (13)$$

which is the mass-luminosity relation. Other quantities being constant, this expression implies a strong mass dependence of the luminosity. In fact, the implication of this relation is that stellar luminosity is only incidentally dependent upon stellar energy sources. Given mass conservation, ideal gas equation of state, hydrostatic equilibrium, and radiant energy transfer, equation 13 results are independent of how radiant energy loss is replaced over time.

To proceed further, a relation between the mass M and radius R is needed. This cannot be obtained from scaling analysis. It is either obtained from detailed. stellar structure models, or from observation. This lack of closure in the scale analysis is equivalent to saying that over a wide range of densities, stellar structures described by the above scaling relations should be possible. An M-R scaling relationship can be obtained from observations of main sequence binary stars (Bohm-Vitense, 1989):

$$M = R^{4/3} \quad (14)$$

over the range of .20 to 23 solar masses. The use of this mass-radius relation has many interesting implications.

The central temperature (equation 12) can be written as:

$$T_c = \mu_c M^{1/4} \quad (15)$$

so that the central temperature slowly increases as M increases. The central density (equation 7) can be written as:

$$\rho_c = M^{-5/4} \quad (16)$$

so that the central density decreases with increasing M. The r_c, T_c scaling relations allow a crude estimate of the opacity dependence on mass. Using the opacity tables of Cox and Stewart (1970), for a reference central density and temperature and $10^2\ g\ cm^{-3}$ and 10^7 K respectively, and an approximately solar composition, one can write very roughly:

$$\kappa = M^{-1} \quad (17)$$

As mass increases, central density decreases while central temperature increases, resulting in a decreasing opacity (it approaches the electron scattering minimum). As the mass decreases, the central density increases while the temperature decreases, resulting in an increased opacity (free-free absorption strongly dominates). It must be kept in mind that equation 17 is only a rough approximation.

To summarize, several scaling relationships between macroscopic properties of stars have been found. The system could be reduced only by using an observed MR relationship for main sequence stars, but these relationships show that some stellar structure properties are independent of the precise source of stellar power. After a discussion of stellar power sources, the implications of these scaling relationships for H-R diagrams will be presented.

Stellar Power Sources

Stars are continuously emitting radiant energy. This radiant energy derives from the thermal motions of stellar material in the surface regions of a star. Such emission of radiant energy should cause local cooling in the star's surface layers, and to be sustained for any appreciable length of time, must be replenished. It is taken for granted by evolutionary astronomers that the power source of most stars is thermonuclear. Nuclear reactions in the central regions of the star produce surplus thermal energy. This thermal energy is presumed to diffuse towards the surface by radiative and/or convective transport processes. As noted in the introduction, the reason for choosing this power source is because it appears to be the only one that could power stars for hundreds of millions to billions of years. The other major power source is gravitational, but this is rejected by all evolutionary astronomers (except in the presumed approach to the main sequence in stellar birth), because this power source would be exhausted after an order of 30 million years, too short for the evolutionists.

The problem with the thermonuclear power theory is that it is apparently impossible to observationally verify in all stars except perhaps for the sun. Elusive subatomic particles known as neutrinos would be emitted from the presumed nuclear reactions occurring in virtually all stars, but the fluxes of neutrinos from these stars would not be easily detected on the earth (with the exception of extremely rare events such as supernovas). Only from the sun might it be possible to observed neutrinos emitted during luminosity sustaining nuclear reactions. Both the quantity and energy distribution of the neutrinos would give clues concerning the composition and temperature in the sun's core, although it is not clear that a unique combination of μ_c, and T_c (see equation 12) would be associated with a unique neutrino flux. According to stellar evolution, the sun began 4.5 billion years ago with presumably cosmological composition (enriched somewhat in helium but especially in heavier elements left over from previous short lived stars). Burning hydrogen in the core would increase μ_c slowly, increasing the central temperature (equation 12) and also the luminosity (equation 13). The deficit of observed neutrinos (about 1/3 of expected; see Bahcall, 1990; Smith, 1990; and Peterson, 1991) points out a potential problem with the evolutionary model of the sun, and therefore also with the evolutionary models of all thermonuclear burning stars.

A serious consequence of the solar evolutionary model is the increase in luminosity implied by equation 13. According to Newman and Rood (1977), over the supposed 4.5 billion year history of the sun its luminosity has increased about 25 percent. Present climate models are admittedly crude, but none (without significant modification) could sustain a 25 percent decrease in solar luminosity without leading to an ice-covered earth. This problem is called the faint young sun paradox, and contrasts sharply with the warmth of much of the presumed geological history of the earth (Crowley, 1983). Incredible enhancements of greenhouse effects are necessary to counter the faint young sun (Kiehl and Dickinson, 1987). All of these problems with evolutionary theories disappear if one accepts a young earth, which does not require exclusive thermonuclear power sources.

If thermonuclear power is not exclusively powering stars, they must be slowly contracting. Noting that in a hydrostatic ideal gas atmosphere the thermal energy is related to the gravitational potential energy by the virial theorem (Swihart, 1968), equation 5 can be written for the entire star as:

$$L = -\frac{KG\,M^2}{R^2}\frac{dR}{dt} + Q_n \quad (18)$$

where K is a dimensionless parameter of order unity (whose precise numerical value depends on the mass distribution), and where Q_n is the possible heat source by thermonuclear reactions. Evolutionary astronomers assume that for main sequence stars dR/dt = 0, and solve for stellar structure assuming $L = Q_n$. Assuming known composition μ and mass M allows a unique solution for structure (Russell-Vogt theorem) including L, R, and T_e. Stellar evolution models trace presumed tracks on the H-R diagram by adjusting μ_c (to account for nuclear produced composition changes after a specified time), and recomputing the structure. However, as noted by DeYoung and Rush (1989), if $Q_n = 0$ the value of dR/dt obtained for the sun is so small as to be presently unobservable. Therefore, it cannot be conclusively stated that the sun is not partly powered by slow gravitational contraction (and by inference neither for other stars as well).

It should be noted that the Russell-Vogt theorem is not valid unless the luminosity is generated exclusively by thermonuclear power. The theorem states that a star's structure is determined uniquely by its mass and composition (and indirectly its age) if powered by thermonuclear reactions. If stars are contracting, the theorem is no longer valid, and a star's structure is no longer uniquely defined by its mass and composition.

In conclusion, the source of stellar power cannot be determined by observations. Solar neutrino measurements are inconclusive. That solar neutrinos are observed at all suggests that some nuclear reactions are occurring in the sun's core, but these measurements do not agree with the predictions of evolutionary models. This suggests that these models are in error. Contraction rates necessary to power the sun are so small as to be unobservable. It is possible that stars are powered by *both* thermonuclear and gravitational sources in varying degrees, and exist in various states of contraction consistent with the governing equations of stellar structure.

Synthetic H-R Diagram

The luminosity relation of equation 13, combined with the opacity relation of equation 17, yields a mass-luminosity expression independent of the radius:

$$L = \mu_c^4 M^4 \tag{19}$$

If Q_n is much smaller than L in equation 18, any radius R is possible within wide limits for a given luminosity, as the rate of contraction dR/dt will adjust accordingly. Let us modify the mass-radius relation of equation 14 to include a dimensionless scaling parameter (s) that determines the state of contraction of the star. This parameter will be termed the size parameter; it takes a value of one for the main sequence. Thus equation 14 becomes

$$R = sM^{3/4} \tag{20}$$

Using the mass-luminosity relation of equation 19, along with the surface luminosity relation of equation 10, allows the derivation of a general H-R diagram (M - T_e) relationship:

$$T_e = \mu_c \frac{M^{5/8}}{s^{1/2}} \tag{21}$$

Thus different values of the size parameter s give rise to different curves on the H-R diagram.

These results are summarized in Figure 1 which shows a synthetic H-R diagram. The mass-luminosity relation equation 19 specifies L for a given M and equation 21 specifies T_e for a given M and s, where $\mu_c = 1$ is assumed. For s = 1 a solid diagonal line from high L, high T_e to low L, low T_e is shown; masses from 25 to .05 are given at several points along the line. Effective temperatures range from about 42000 K to 1200 K over this mass range (using 6000 K for the sun), corresponding roughly to the spectral range from O to M main sequence stars. For various size parameter values (s > 1), equivalent lines run diagonally across the upper right portion of the diagram; dashed diagonal lines are lines of constant radius. There is no upper limit to R from any of the scaling relations, but dynamical instabilities would probably limit R for very large stars.

The synthetic H-R diagram suggests that the main sequence could be stars of solar type contraction states

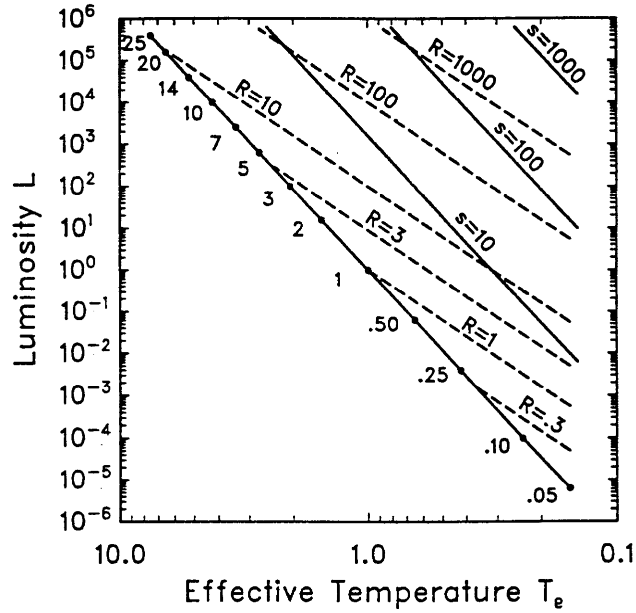

Figure 1. Synthetic Hertzsprung-Russell (H-R) diagram, based on scaling relationships for nondegenerate stars, in solar units. R is radius, s is size parameter, and stellar masses are shown for various points on the main sequence diagonal.

(partly, but not exclusively powered by thermonuclear reactions), of solar type composition with varying masses. Giants and supergiants in the upper portion of the H-R diagram would be stars much larger than their main sequence companions of the same mass, but with cooler effective temperatures. Equation 18 shows that if stars are contracting, giants and supergiants (large M, large R) would be contracting relatively quickly compared to their main sequence companions of the same mass. It should be noted that stellar evolution theory postulates that giants have degenerate helium cores remaining from millions of years of thermonuclear fission. However, it is impossible to observationally distinguish such stars from those of uniform solar-like composition which are contracting towards the main sequence.

It should be noted that states of contraction for s < 1 were not plotted in Figure 1. Using equation 20 for the mass-radius relation (with size parameter included), along with equations 7 and 12 for the central density and temperature respectively, yields:

$$\rho_c = \frac{M^{-5/4}}{s^3} \tag{22}$$

$$T_c = \frac{\mu_c M^{1/4}}{s} \tag{23}$$

The size parameter s cannot be made arbitrarily small, since the increase in central density and temperature would inevitably lead to intense thermonuclear reactions. The theorized reaction rates for the proton-proton cycle (Gibson, 1973) are proportional to the density and strongly temperature dependent. As s decreases below 1, the central temperature and density will rise dramatically, strongly suggesting that the leftmost edge of the main sequence could be a contraction limit maintained by thermonuclear reactions. This contraction limit is termed the zero age main sequence (ZAMS) in stellar evolution. Whether some stars are at the limit where $dR/dt = 0$ in equation 18 cannot be determined observationally. The thickness of the main sequence band is interpreted by evolutionary astronomers as a result of aging of stars away from the ZAMS, but it could just as easily be interpreted as stars of either variable internal composition at creation (μ_c variable), or stars which are not yet at the contraction limit for which $L = Q_n$ in equation 18.

To summarize, the synthetic H-R diagram bears some similarity with observed H-R diagrams. The strong mass-luminosity relation is independent of power source. The radius of the star for a given mass effectively determines its position on the diagram through its effective temperature. Most nondegenerate stars fall into the main sequence diagonal band with giants and supergiants to the upper right. Limits to central density and temperature due to thermonuclear processes limit the diagram to the diagonal and right of the diagonal.

Conclusion

Present stellar structure theory is closely related to stellar evolution theory by the requirement of an old universe, and a naturalistic origin of stellar systems. Stellar evolution theory interprets the observational data (in particular the H-R diagram) in terms of multi-billion year histories of stars. Yet observational data does not require an old universe. Given all the observational data it is not known for certain how old stars are. In a fashion analogous in earth history, evolutionary astronomers have interpreted the observational data consistently with the philosophical view of slow, naturalistic origins of stellar systems.

Using the basic physical laws believed to govern the structure of nondegenerate stars, simple scaling equations relating stellar properties were derived. It was shown that these scaling relations suggest, although they do not conclusively demonstrate, that the broad features of H-R diagrams can be explained by these physical laws, without recourse to accepting old ages of stars and the necessary evolutionary histories. Several issues discussed by Faulkner and DeYoung (1991) were not raised in this paper: H-R diagrams for star clusters, planetary nebulae, white dwarfs, neutron stars and pulsars. Only further study and numerical work using the approach of this paper can demonstrate whether detailed creationist stellar models can more completely explain observed H-R diagrams.

Acknowledgments

It is hoped that this paper has contributed to the discussion desired by Faulkner and DeYoung (1991). If it has in any way given honor to the One who knows every star by name, then the author is pleased.

References

CRSQ—Creation Research Society Quarterly.

Abell, George. 1969. Exploration of the universe. Holt, Rinehart and Winston. New York.

Bahcall, J. N. 1990. The solar neutrino problem. *Scientific American.* 262(5):54-61.

Bohm-Vitense, Erika. 1989. Introduction to stellar astrophysics. Volume 1. Basic stellar observations and data. Cambridge University Press. New York.

Burrows. A. 1987. The birth of neutron stars and black holes. *Physics Today*. 40:28-37.

Chandrasekhar, S. 1938. An introduction to the study of stellar structure. Dover. New York.

Clayton, Donald D. 1968. Principles of stellar evolution and nucleosynthesis. McGraw-Hill. New York.

Crowley. Thomas J. 1983. The geologic record of climate change. *Reviews of Geophysics and Space-Physics.* 21:828-877.

Cox, A. N. and J. N. Stewart. 1970. Rosseland opacity tables for population I compositions. *Astrophysical Journal (Supplement).* 19(174):243-259.

DeYoung, Don B. and D. E. Rush. 1989. Is the sun an age indicator? *CRSQ* 26:49-53.

Faulkner, Danny R. and Don B. DeYoung. 1991. Toward a creationist astronomy. *CRSQ* 28:87-92.

Gibson, Edward G. 1973. The quiet sun. National Aeronautics and Space Administration. Washington, D.C.

Iben, Icko. 1991. Single and binary star evolution. *Astrophysical Journal (Supplement).* 76:55-114.

Kiehl, J. T. and R. E. Dickinson. 1987. A study of radiative effects of enhanced atmospheric CO2 and CH4 on early earth surface temperatures. *Journal* of *Geophysical Research.* 92:2991-2998.

Kippenhahn, R. and A. Weigert. 1990. Stellar structure and evolution. Springer-Verlag. Berlin.

Newman, M. J. and R. T. Rood. 1977. Implications of solar evolution for the earth's early atmosphere. *Science.* 198:1035-1037.

Peterson, I. 1991. *Science News.* 140:406.

Rigutti, Mario. 1984. A hundred billion stars. MIT Press. Cambridge MA.

Smith. D. H. 1990. The solar-neutrino mystery deepens. *Sky and Telescope.* 80:375.

Swihart, Thomas L. 1968. Astrophysics and stellar astronomy. John Wiley. New York.

Wilt, Paul. 1983. Nucleosynthesis, in Mulfinger, George, Jr. (Editor). Design and origins in astronomy. Creation Research Society Books. Kansas City, MO.

Quote

It was once common to explain the lack of ancestors of many taxa by assuming that they had lived in areas that happened to be unknown. The deep-sea and the higher mountain environments are not well represented by fossils, for example, and if novel taxa had first evolved in such places their primitive members might never be found. However it is now clear, from studies of the adaptive significance of the characteristic features of taxa, that many of them evolved in some of the best-known ancient environments, such as on shallow seafloor. The "unknown environment" explanation cannot be applied generally.

Certainly, many early members of novel lineages may have been rare; the adaptive zone model certainly suggests that pioneering populations could be small. However, if it is assumed these early novel lineages evolved at the same rates as have lineages for which the fossil record is well known, then it would take many hundreds of millions of years to develop the great degrees of morphological difference that they exhibit. It is not reasonable to expect these lineages to have small population sizes (and certainly not to be poorly adapted) for such a long time. Furthermore, even a rare lineage, if skeletonized, should appear in the fossil record sooner or later if it persisted for such a long period. *We are forced to the conclusion that most of the really novel taxa that appear suddenly in the fossil record did in fact originate suddenly.* [Italics added.]

Ayala, F. J. and J. W. Valentine. 1979. Evolving, the theory and processes of organic evolution. Benjamin/ Cummings. Menlo Park, CA. pp. 266, 267.