

Martin Schwarzschild & The Structure and Evolution of Stars

The Great Andromeda Galaxy

18 June 2012

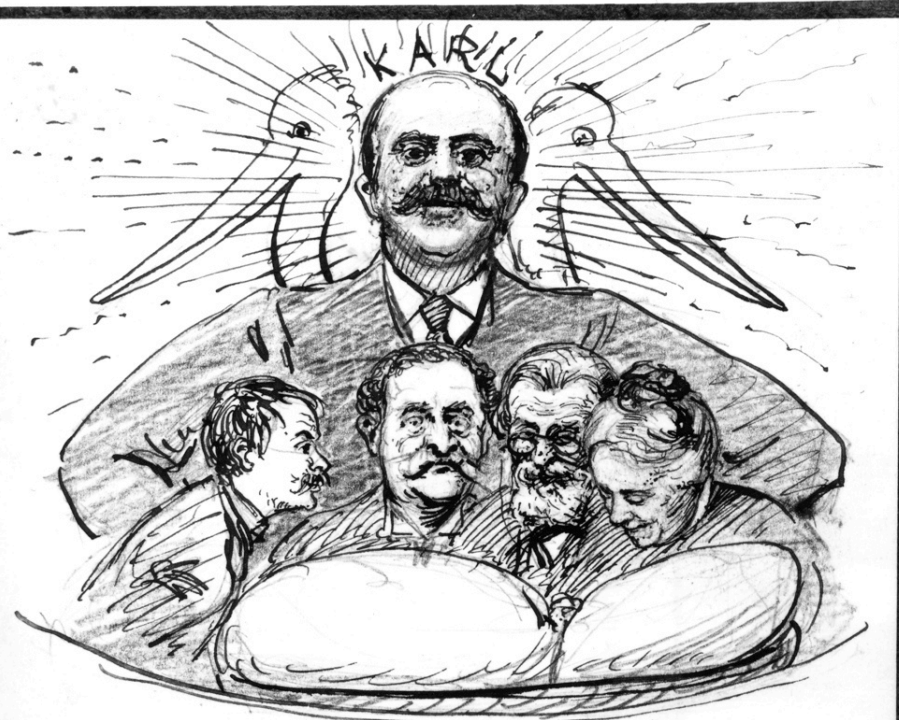
Princeton University



Mt. Wilson 1910



From left: Mr. McBrids, F.P. Brackett, J.C. Kapteyn, E.B. Frost, K. Schwarzschild (light suit), V.M. Slipher



Ina Gips sind sie alle da
 und wir sind fig, fig, fig, fig!
 Ganz der Jung, ganz der Mann!

Gut alpen.

For 31. May 1912

Eddington 1926

It is now generally agreed that the main source of a star's energy is subatomic. There appears to be no escape from this conclusion; but since the hypothesis presents many difficulties when we study the details it is incumbent upon us to examine the alternatives.

---The Internal Constitution of the Stars

1. Capella liberates 58 ergs per gram per second compared with 1.9 liberated by the sun.
2. The temperature of the sun at corresponding points is 4.3 times [that of] Capella.

....

Now it is generally believed that the liberation of subatomic energy, if it depends on temperature and density at all, will increase with temperature and density. Why then is there this decreased output in the sun in spite of the apparently more favourable conditions?

---Ibid

Öpik 1938

OBSERVATORY

PUBLICATIONS

DE

L'OBSERVATOIRE ASTRONOMIQUE DE L'UNIVERSITÉ DE TARTU
TOME XXX N° 3

STELLAR STRUCTURE, SOURCE OF ENERGY, AND EVOLUTION

BY

ERNST ÖPIK

A special giant source of energy which works at low temperatures and densities appears to be impossible; whatever assumptions as to the law of energy generation are made, if these assumptions are in harmony with general physical principles, they invariably lead to the conclusion that the central temperatures of the giants must be at least as high, or higher than the central temperatures of the main sequence stars; hence the giants must be differently built (with a greater concentration of mass towards the centre) as compared with the main sequence.

The starting reaction of the atomic synthesis is most probably the not yet observed direct synthesis of the deuteron from protons (with the expulsion of a positron). If this is a reaction of protons in their ground state, the observed rate of energy generation in the sun, together with the requirement of equilibrium with the rate of the known $\text{Li} + \text{H}$ reaction, sets for the probability of proton capture by a proton (after penetration has taken place) as low a limit as $q = 1,3 \cdot 10^{-19}$; in such a case there is no hope of detecting the reaction in the laboratory. The energy generation, ϵ , should have to vary then with about the sixth power of the temperature, $s = 6$. The correlation of radius and mass for stars of the main sequence leads, however, to $s = 19$ (from 15 to 25). Formal agreement in s can be obtained upon the



Evolutionary sequence

1912 May 31	M.S. born at Potsdam
1914 August	Father (Karl) volunteers for military service
1916 May	Karl dies of pemphigus; family returns to Göttingen
1931	M.S. matriculates at Göttingen
1932	Chadwick discovers the neutron
1935 December	M.S. completes PhD at Göttingen on stellar pulsations
1936-1937	Postdoc under Rosseland at Oslo
1937-1940	Littauer Fellow at Harvard; observes M3 variables
1939 March	Bethe article “Energy Production in Stars”
1940-1947	At Columbia. Stellar rotation, punched-card machines
1942-1945	Joins Army, becomes U.S. citizen
1945 August 24	Marries astronomer Barbara Cherry
1946 May	Article on helium content of Sun
1947	M.S. and Lyman Spitzer come to Princeton



1948 (ApJ 107, 1)	ON NOISE ARISING FROM SOLAR GRANULATION
1948 (ApJ 108, 373)	Richardson & Schwarzschild: A STELLAR MODEL FOR RED GIANTS OF HIGH CENTRAL TEMPERATURE
1949 (MNRAS 109, 631)	Hen Li & Schwarzschild: RED GIANT MODELS WITH CHEMICAL INHOMOGENEITIES
1950 (ApJ 112, 248)	Martin & Barbara Schwarzschild: A SPECTROSCOPIC COMPARISON BETWEEN HIGH AND LOW-VELOCITY F DWARFS
1950	von Neumann offer MS access to MANIAC at IAS
1952 (ApJ 115, 326)	Salpeter's article on triple-alpha process
1952 (ApJ 116, 317)	Oke & Schw.: INHOMOGENEOUS MODELS I. MODELS WITH A CONVECTIVE CORE AND A DISCONTINUITY IN CHEMICAL COMPOSITION
1952 (ApJ 116, 453)	Sandage & Schw.: INHOMOGENEOUS MODELS II. MODELS WITH EXHAUSTED CORES IN GRAVITATIONAL CONTRACTION
1953 (The Obs. 73, 77)	Schw. & Spitzer: ON THE EVOLUTION OF STARS AND CHEMICAL ELEMENTS IN THE EARLY PHASES OF A GALAXY
1953 (ApJ 118, 326)	Schw., Rabinowitz, & Härm: INHOMOGENEOUS MODELS III. MODELS WITH PARTIALLY DEGENERATE ISOTHERMAL CORES
1955 (ApJS 2, 1)	Hoyle & Schw.: ON THE EVOLUTION OF TYPE II STARS
1957 (ApJ 125, 123)	M. & B. Schw., Searle, & Meltzer: A SPECTROSCOPIC COMPARISON BETWEEN HIGH AND LOW-VELOCITY K GIANTS
1957 (ApJ 125, 233)	Schw., Howard, & Härm: A SOLAR MODEL WITH A CONVECTIVE ENVELOPE AND AN INHOMOGENEOUS INTERIOR
1958 (Princeton Univ. Pr.)	Schw.: THE STRUCTURE AND EVOLUTION OF THE STARS

1958 (AJ 63, 313)	Schw., Rogerson, & Evans: SOLAR PHOTOGRAPHS FROM 80,000 FEET
1958 (ApJ 128, 348)	Schw & Härm: EVOLUTION OF VERY MASSIVE STARS
1959 (ApJ 129, 637)	S & H: ON THE MAXIMUM MASS OF STABLE STARS
1961 (ApJ 134, 1)	S: CONVECTION IN STARS
1961 (ApJ 134, 337)	Bahng & S: LIFETIME OF SOLAR GRANULES
1962 (ApJ 136, 150)	S & Selberg: RED GIANTS OF POPULATION II. I (MANIAC)
1962 (ApJ 136, 158)	S & H: RED GIANTS OF POPULATION II. II (IBM 370; He flash)
1964 (ApJ 139, 594)	S & H: RED GIANTS OF POPULATION II. III (Henyey method)
1965 (ApJ 142, 855)	S & H: THERMAL INSTABILITY IN NONDEGENERATE STARS (He shell instability)
1968 (ApJ 151, 389)	Hartwick, H, & S: ON THE BLUE END OF THE HORIZONTAL BRANCH...
1971 (L'Astr. 85, 277)	S: "Points noirs dans la théorie de l'évolution stellaire"
1975 (ApJ 200, 324)	H & S: TRANSITION FROM A RED GIANT TO A BLUE NUCLEUS AFTER EJECTION OF A PLANETARY NEBULA
1977 (ApJ 216, 138)	Bhavsar & Härm: THE NEUTRINO FLUX OF INHOMOGENOUS SOLAR MODELS

Schwarzschild, Rabinowitz, & Härm 1953

1953ApJ...118...

INHOMOGENEOUS STELLAR MODELS. III. MODELS WITH PARTIALLY DEGENERATE ISOTHERMAL CORES*

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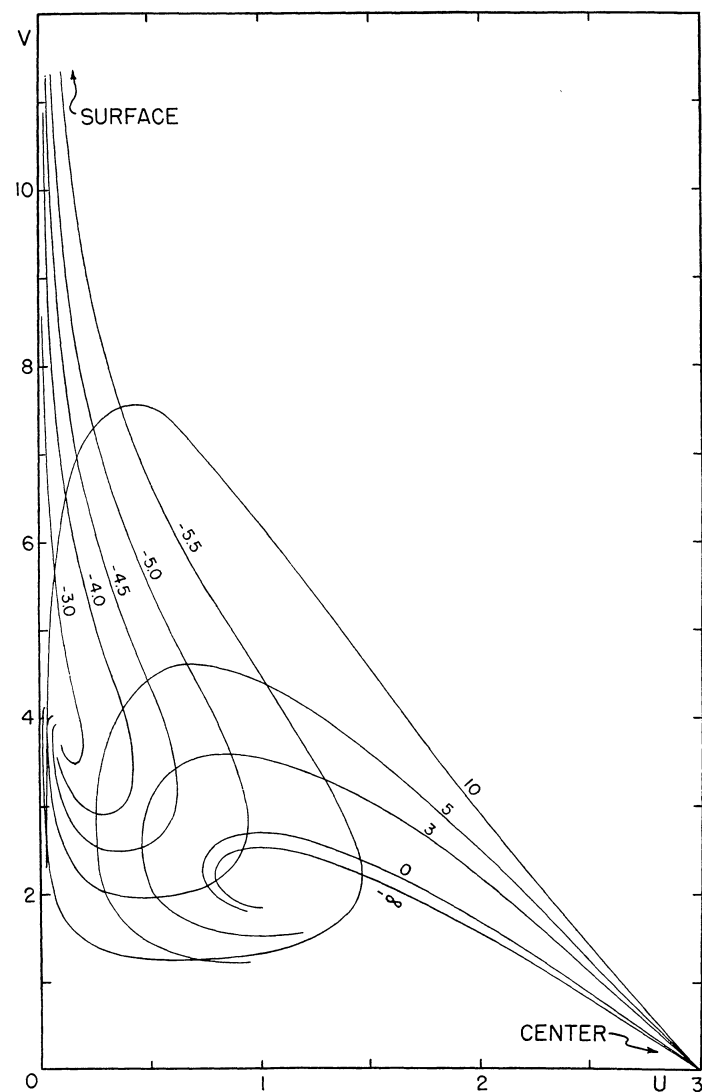
Received March 30, 1953

ABSTRACT

A search was made for conditions under which models with partially degenerate isothermal cores could give radii as large as those of red giants. Special conditions were found for which detailed computations gave, indeed, models fitting well the red giants in radius and luminosity. But it has not been investigated whether the special conditions are likely to be realized in the evolution of a star.

$$U \equiv \frac{d \ln M_r}{d \ln r} = \frac{4\pi r^2 \rho}{M_r} \rightarrow \frac{4\pi r^2}{M_r} \frac{P m_H}{k_B T} \mu$$

$$V \equiv -\frac{d \ln P}{d \ln r} = \frac{GM_r}{r} \frac{\rho}{P} \rightarrow \frac{GM_r}{r} \frac{m_H}{k_B T} \mu$$



Hoyle & Schwarzschild 1955

ON THE EVOLUTION OF TYPE II STARS

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Received February 4, 1955

ABSTRACT

The evolution of the stars in globular clusters has been followed from the main sequence to the top of the red giant branch. In the initial phases the relevant models consist of partially degenerate isothermal helium cores and radiative hydrogen envelopes. These models show the well-known turnoff from the main sequence in the Hertzsprung-Russell diagram of globular clusters. The helium core steadily increases in mass because of the hydrogen-burning. When the core has reached approximately 20 per cent of the total stellar mass, the envelope has reached an appreciable extent, and it is found necessary to take into account explicitly the photospheric boundary condition and the hydrogen convection zone. During the subsequent phases this convection zone steadily deepens while the luminosity increases; the star evolves in the Hertzsprung-Russell diagram along the observed red giant sequence. During these phases the internal temperature steadily rises so that the carbon cycle can keep in balance with the increasing luminosity. At the top of the red giant sequence the temperature in the hydrogen-burning shell at the edge of the core reaches about 40,000,000°, while the helium core reaches approximately 50 per cent of the stellar mass.

Energy production in thin shell at x_1 , from (11), (12), (13), and (14):

For thin shell, from equations (17) and (18),

$$P \approx P_1 \left(\frac{r}{r_1} \right)^{-V_{1e}}, \quad T \approx T_1 \left(\frac{r}{r_1} \right)^{-V_{1e}/(n+1)_{1e}}.$$

Hence, for the proton-proton chain,

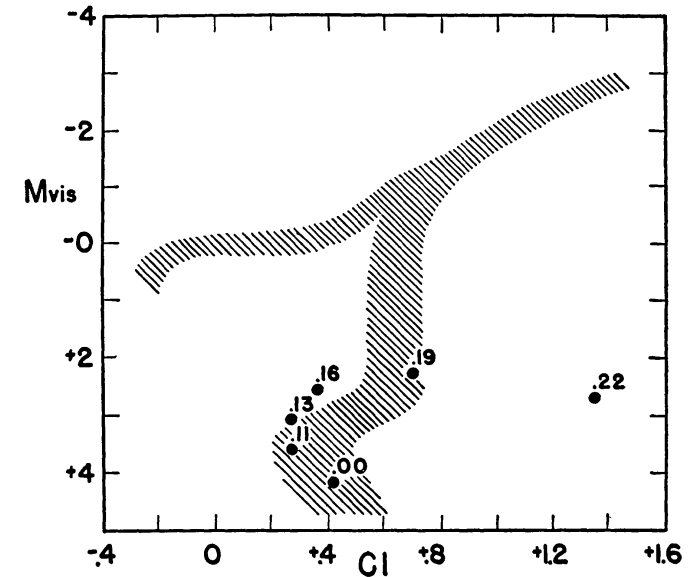
$$L_{pp} \approx 0.5 X^2 \rho_{1e}^2 \left(\frac{T_1}{15 \times 10^6} \right)^4 \frac{4\pi r_1^3}{V_{1e} [2 + 2/(n+1)_{1e}] - 3}, \quad (43)$$

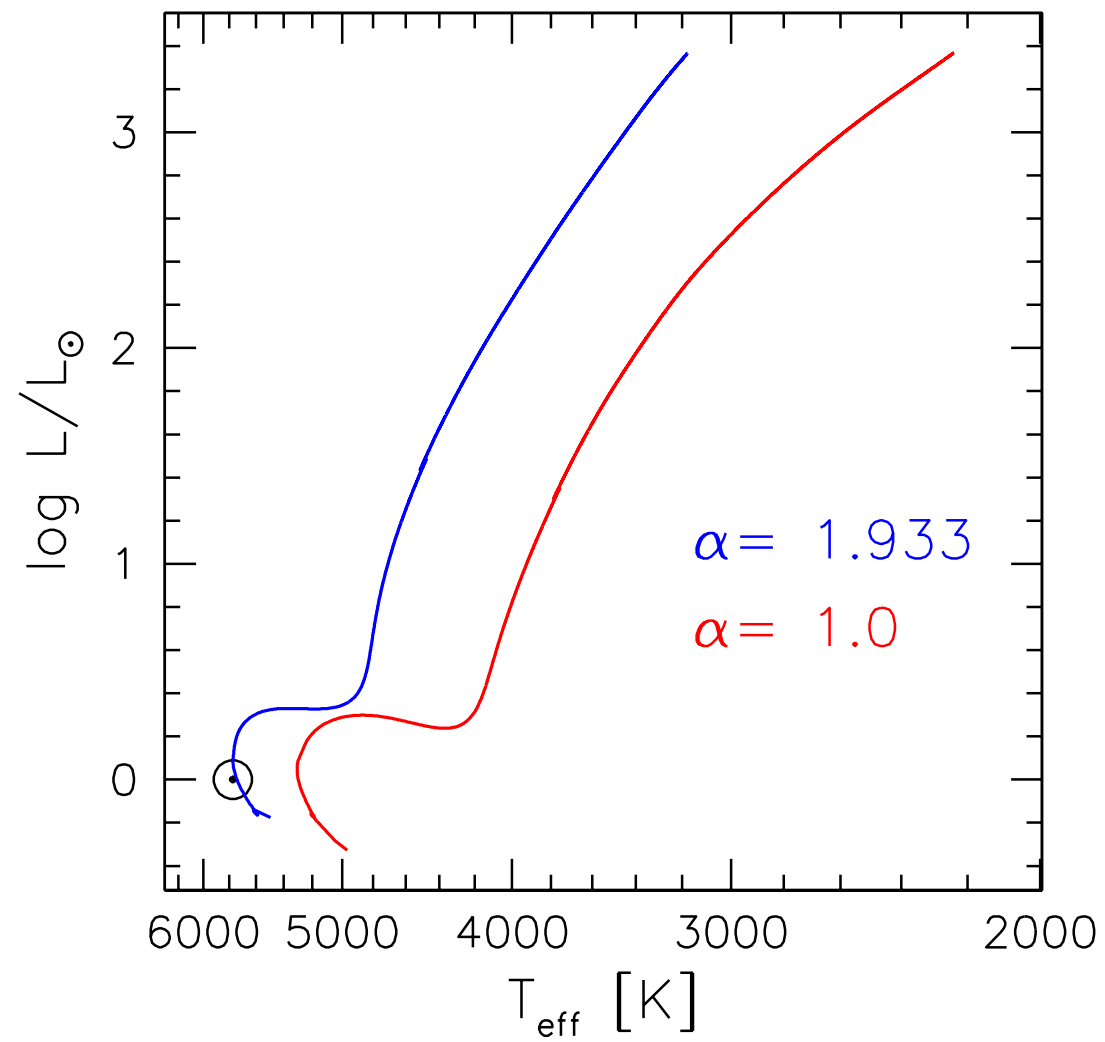
and, for carbon cycle,

$$L_{CN} \approx 600 X \frac{X_{CN}}{0.01} \rho_{1e}^2 \left(\frac{T_1}{20 \times 10^6} \right)^{15} \frac{4\pi r_1^3}{V_{1e} [2 + 13/(n+1)_{1e}] - 3}. \quad (44)$$

Total luminosity:

$$L = L_{pp} + L_{CN}. \quad (45)$$





MESA models for $M = 1.0 M_{\odot}$, $Z = 0.02$



References

http://adsabs.harvard.edu/cgi-bin/nph-abs_connect?library&libname=MartinS&libid=4984e8f67c

AIP Oral History interviews with M.S.: http://www.aip.org/history/ohilist/4870_1.html