Structure and Evolution of Stars
Paul Hewett, Michaelmas 2015

SOHO image of the Sun in far-UV light
Schedules

2) Stellar Structure (cont.)
• Hydrostatic equilibrium, Virial Theorem, Pressure
• Stellar properties as a function of mass, homology
• Degeneracy: Chandrasekar limit

3) Stellar Evolution and the Hertzsprung-Russell diagram
• Pre-main sequence evolution, Hayashi and Henyey tracks
• Post-main sequence evolution: massive stars, supernovae, neutron stars, black holes
• Post-main sequence evolution: low-mass stars, planetary nebulae, white dwarfs, Type Ia supernovae
• Initial mass function
Schedules (continued)

4) Observational Tests and Constraints
   • The mass-luminosity relationship
   • Stellar abundances
   • The most massive stars and stellar winds
   • Supernovae
Recommended Text Books

  – Best overall match to course

  – Quite excellent on the physics of the course

• Green, S. & Jones, M., An Introduction to the Sun and Stars, Cambridge University Press, 2004
  – Gentle modern introduction to the observational aspects of the course. Very good figures
Recommended Text Books

  – North American and fairly voluminous but some very good parts

• Tayler, R.J., The Stars: Their Structure and Evolution, Cambridge University Press, 1994
  – Low-level overview but quite sound

Sun

Mass $= 2 \times 10^{30}$kg
Radius $= 7 \times 10^8$ m
Lum $= 3.9 \times 10^{26}$W
Temp $= 5800$K

SOHO image at 304A

Distance is essential
Blackbody curves for different $T$
Figure 3.18 Black-body spectra at different temperatures. Each source is of the same size, and at the same distance from the detector that measures the flux density. Note that the vertical scale for the set of spectra in (a) is greatly elongated compared with that for the set in (b).
Figure 3.19 The photometric method of obtaining photospheric temperatures. The ratio of the amount of energy measured in two different wavelength regions (shaded) is uniquely defined by the temperature if the object emits like a black body.
Wide-field view of the Milky Way
Pre-Collapse Black Cloud B68 (comparison)
(VLT ANTU + FORS 1 - NTT + SOFI)

ESO PR Photo 02c/01 (10 January 2001)

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Figure 1.28 A black and white image of the solar spectrum. Note that for convenience of display, the spectrum has been cut into sections and consecutive sections have been stacked vertically in sequence. (The horizontal streaks on the spectra are artefacts.) (Kitt Peak National Observatory)
Figure 3.26 The stellar absorption spectra given in Figure 3.25 are more usually presented as graphs of relative flux density versus wavelength for ease of identification of the prominent absorption lines. The spectra have been plotted without spectral flux density scales and displaced vertically for clarity. (Kaufmann and Freedman, 1998)
Star clusters with size $<<$ distance allow some progress. Also evidence that $\Delta t_{\text{form}} << \text{age}$, so stars coeval.
Figure 7.3 (a) The predicted path of a $1 M_\odot$ star, plotted on the same scale with the same labels as Figure 7.2, (A) hydrogen core fusion; (B) onset of hydrogen shell fusion; (C) hydrogen shell fusion continues; (D) helium core fusion starts; (E) helium core fusion continues; (F) helium shell fusion starts. (b) The H–R diagram of a globular cluster which illustrates how stars tend to concentrate in these regions.
HIPPARCOS satellite data showing Hertzsprung-Russell diagram for stars within 150pc of the Sun
Figure 7.7 The mass–luminosity relation. (Data from Popper, *Annu. Rev. Astron. Astrophys.*, 18, 115, 1980.)
Figure 9.1 The positions of central stars associated with planetary nebulae (dots) and of white dwarfs (open circles) on the H–R diagram. Also shown (solid line) is the evolutionary track that would be followed by a star of constant radius as it cools and (dashed line) a schematic evolutionary track between the regions occupied by AGB stars (Section 8.2.1) and by the central stars of planetary nebulae.
Globular Cluster M4
Location of white dwarf companion to pulsar B1620-26

Hubble Space Telescope • WFPC2
NASA and H. Richer (University of British Columbia)
STScI-PRC03-19b
Cat's Eye Nebula • NGC 6543

NASA, ESA, HEIC and The Hubble Heritage Team (STScI/AURA)
Hubble Space Telescope ACS • STScI-PRC04-27

Structure & Evolution of Stars
Nebula Around the Hot Binary Star AB7 in the SMC
(VLT MELIPAL + FORS 1)

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Arches cluster

Cavity excavated by heavy stars

Quintuplet cluster

Milky Way centre

HST/Spitzer composite: NASA, ESA, D.Q. Wang (UMass), JPL, S. Stolovy (Spitzer Science Center)
Star Clusters Near the Center of the Galaxy

PRC99-30 • STScI OPO • D. Figer (STScI) and NASA

Arches Cluster

Quintuplet Cluster

1 light year

2 light years

HST • NICMOS
Spiral Galaxy NGC 6118
(VLT MELIPAL + VIMOS)
Spiral Galaxy NGC 6118 and SN 2004dk
(VLT MELIPAL + VIMOS)
The Crab Nebula in Taurus  (VLT KUEYEN + FORS2)

ESO PR Photo 4099 (17 November 1999)

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Structure & Evolution of Stars
Time Sequence of Crab Pulsar  (VLT KUEYEN + FORS2 + FIERA)

ESO PR Photo 40h:99 (17 November 1999)
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SN1987A in the LMC
Environment of SN1987A post explosion
The Tarantula Nebula in the LMC
(MPG/ESO 2.2-m + WFI)

ESO PR Photo 14a/02 (7 June 2002)
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