Astrophysics I: Stars and Stellar Evolution

AST 4001

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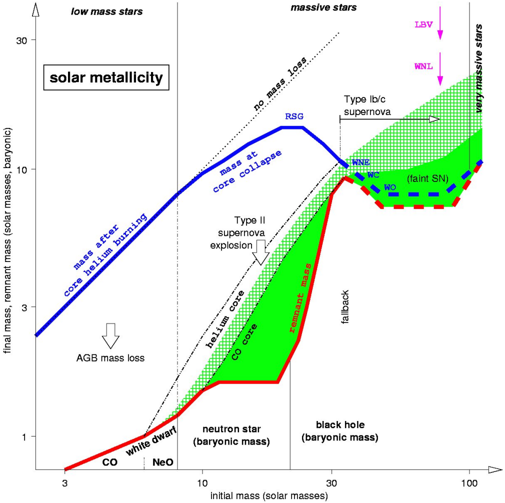
Stars and Stellar Evolution, Fall 2008

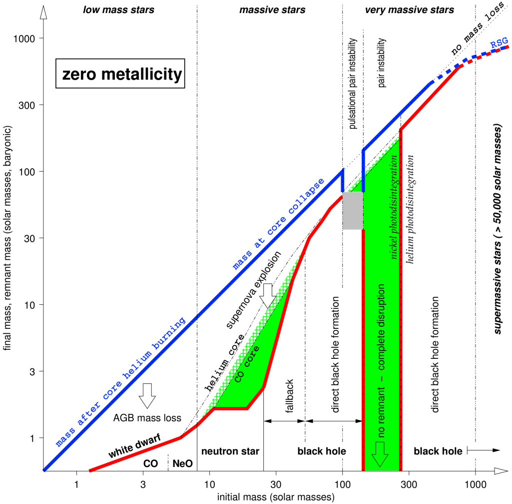
Overview

1. Recap
   - Remnants as a Function of Mass
   - Remnants and Supernovae – Mass and Metallicity
   - Binary Stars
2. Variable Stars
   - Variable Stars Overview
   - Variable Stars in the HRD
3. Magnitudes
   - The Magnitude
   - Filter and Colors
   - Absolute Magnitude and Distance Modulus

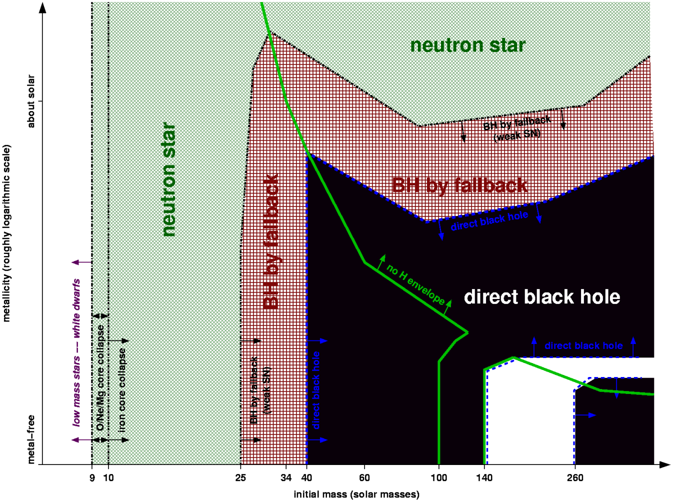
Stellar Mass Ranges - Solar Metallicity



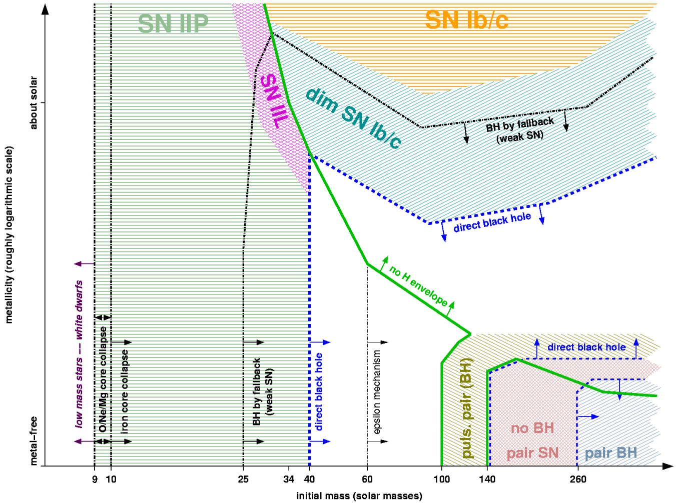
Stellar Mass Ranges - Population III Stars



Remnants - Mass and Metallicity



Supernovae - Mass and Metallicity



Binary Types

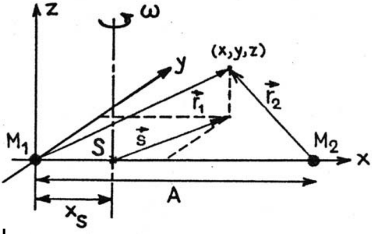
Binary Stars

about half of all massive stars are in binaries

close binary: interaction in lifetime of star
wide binary: no interaction

Observationally:
- **spectroscopic binaries**
- **eclipsing binaries**
- **resolved binaries**

Roche Model



$$\phi(x,y,z) = -\frac{GM_1}{|\vec{r}_1|} - \frac{GM_2}{|\vec{r}_2|} - \underbrace{\frac{1}{2}|\vec{s}|^2\omega^2}_{\text{centrifugal potential}}$$

centrifugal potential

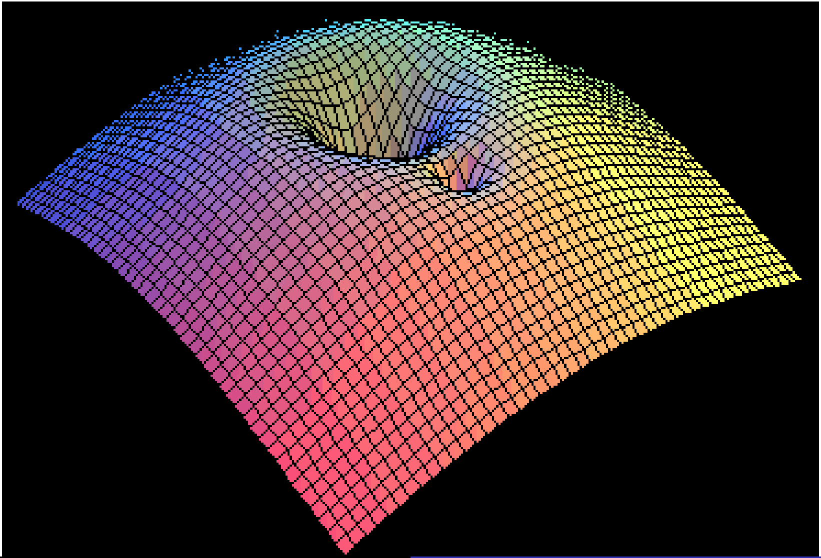
$$|\vec{r}_1| = (x^2+y^2+z^2)^{1/2} \quad , \quad |\vec{r}_2| = ((A-x)^2+y^2+z^2)^{1/2}$$

$$|\vec{s}| = ((x-x_s)^2+y^2)^{1/2} = \left[\left(x - \frac{M_2}{M_1+M_2}A\right)^2 + y^2\right]^{1/2}$$

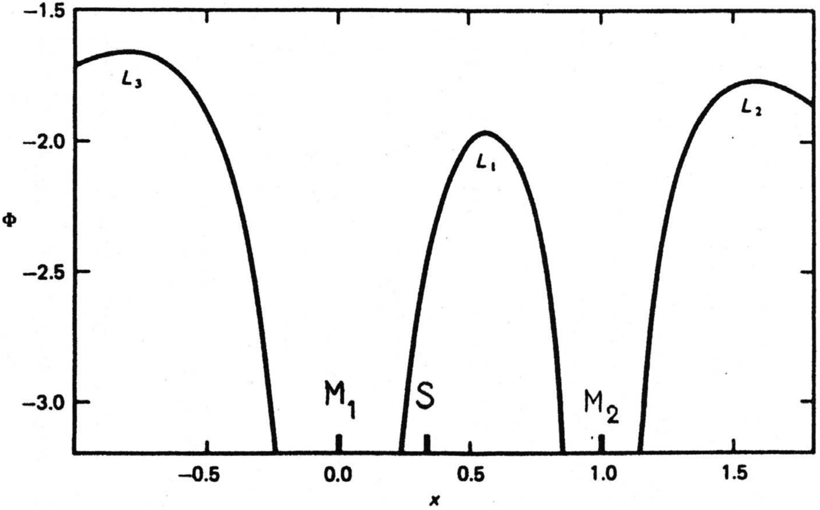
$$\omega^2 = \frac{G(M_1+M_2)}{A^3}$$: **3rd Kepler's Law**

Introduce dimensionless variables: $\xi = \frac{x}{A}\ ;\ \eta = \frac{y}{A}\ ;\ \zeta = \frac{z}{A}\ ;\ q = \frac{M_1}{M_2}$

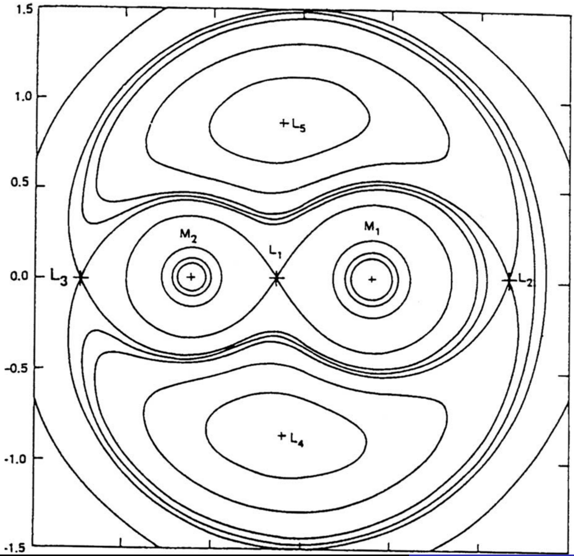
Roche Potential



Roche Potential



Lagrange Points

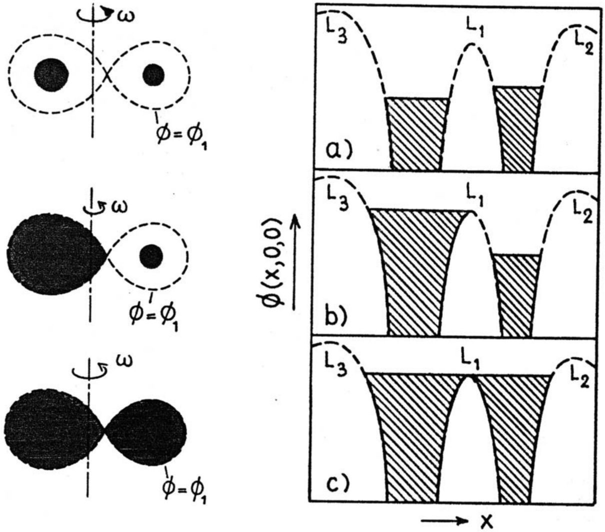


Five Lagrange points:

L1, L2, L3: unstable

L4,L5: stable

Contact Binaries



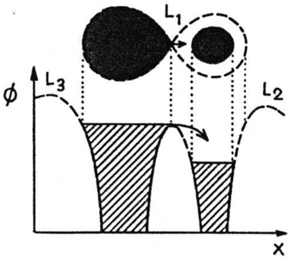
detached

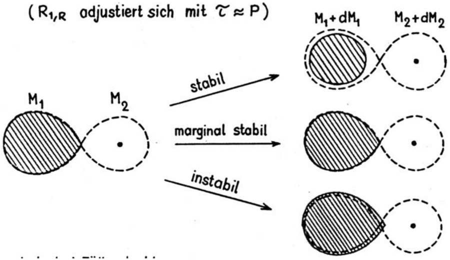
semi-detached

contact

Binary Mass Transfer

Stability of mass transfer depends on reaction of donor and receiving star





Compact Binary Types

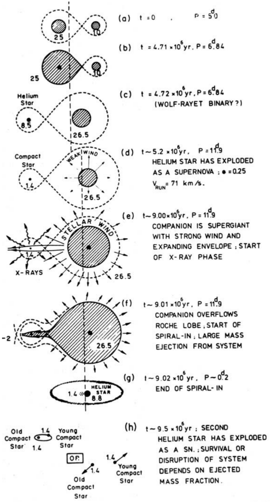
Star + compact remnant + Roche-Lobe overflow: X-ray binaries

WD + companion:
Novae, Dwarf Novae, Type Ia supernovae

NS + companion:
X-ray bursts, millisecond pulsars, …

NS+NS: Binary pulsars

Binary Pulsar Production



Supernovae from Binaries

Binaries

initial mass $M_\odot$	binary mass transfer			single star
	Case A	Case B	Case C	
~8…13	WD	WD	SN Ib, NS	SN IIp, NS
~13…16	WD	SN Ib/c, NS	SN Ib, NS	SN IIp, NS
~16…25	SN Ic, NS	SN Ib, NS	SN Ib, NS	SN IIp, NS
~25…35	SN Ic, NS	SN Ic, NS	SN Ib, BH	SN IIL, BH
>35	SN Ic, NS/BH	SN Ic, NS/BH	SN Ib, NS/BH	SN Ic, NS/BH

Overview

Variable Stars Classification

recurrence:

- regular
- irregular
- non-repetitive

oscillation type:

- radial
- non-radial

driving mechanism:

- nuclear
- opacity
- equation of state
- ...

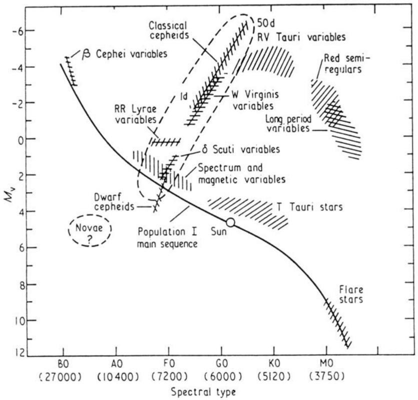
Variable Stars Overview

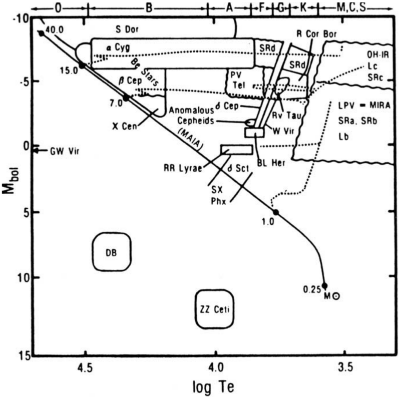
TABLE 2.4. Intrinsically variable stars

Kind of Variable	Period	Pop	Spec	M_V	R or NR
RR Lyrae	1.5–24 h	II	A2–F2	$\langle M_V \rangle \approx 0.6$	radial
Classical Cepheids	1–50 d	I	F6–K2	−6 to −0.5	radial
W Virginis	2–45 d	II	F2–G6	−3 to 0	radial
RV Tauri	20–150 d	II	G–K	~ -3	radial
Red Semiregular	100–200 d	I and II	M,N,R,S	−3 to −1	radial
Long period, Miras	100–700 d	I and II	M,N,R,S	−2 to +1	radial
The sun	5–10 min	I	G2	+4.83	nonradial
β-Cepheids (β CMa)	3–6 h	I	B1–B2	−4.5 to −3.5	both(?)
53 Per variables	0.5–2 d	I	O9–B5	−5 to −4	nonradial
ζ Oph	hours	I	O	−6 to −5	nonradial
Rapid Ap	5–15 min	I	$\sim$A5	+2 to +2.5	nonradial
δ-Sct (Dwarf Cepheid)	0.5–5 h	I	A5–F5	+2 to +3	nonradial
DO, DB, DA WDV's	100–1000 s	I(?),II	O,B2,A0	+2,+7,+8	nonradial

R or NR refers to Radial or Nonradial, Spec is Spectral type.

Variable Stars in the HRD





Overview

Introducing - The Magnitude

- Basic definition of magnitude from relative brightness of stars.
- The difference in magnitude between two stars, **1** and **2**, with apparent brightnesses (as we see/observe) them in the sky, s_1 and s_2, is given by

$$m_1 - m_2 = -2.5 \log \left(\frac{s_1}{s_2} \right)$$

- If a star at distance r has a surface luminosity of L_λ in wavelength λ a radiation flow of

$$f_\lambda = \frac{L_\lambda}{4\pi r^2}$$

reaches us.

The Magnitude

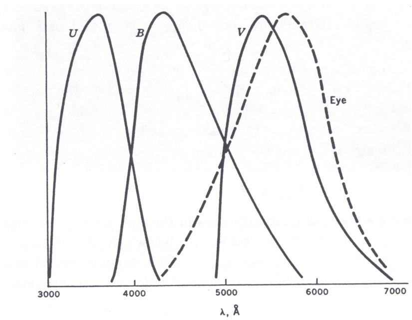
- If our instrument, filer, or eye has a response function E_λ we obtain

$$s = \frac{1}{4\pi r^2} \int_0^\infty L_\lambda E_\lambda \mathrm{d}\lambda$$

- The magnitude is then given, up to a constant, by

$$m = -2.5 \log \frac{1}{4\pi r^2} \int_0^\infty L_\lambda E_\lambda \mathrm{d}\lambda \quad + \mathrm{const.}$$

Filters, Color Index



Filter Functions, arbitrary units (should be normalized to 1)

- We define a color index by $m_x - m_y$ for filters x and y by

$$\text{color index} = m_x - m_y$$

- x, y is, e.g., "U", "B", "V" for ultraviolet, blue, and visible.
- They have centers at $\lambda_\mathrm{U} = 365\,\mathrm{nm}$, $\lambda_\mathrm{B} = 440\,\mathrm{nm}$, and $\lambda_\mathrm{V} = 584\,\mathrm{nm}$.

Absolute Magnitude, Distance Modulus

- We often define
  $U = m_{\mathrm{B}}$, $B = m_{\mathrm{B}}$, and $V = m_{\mathrm{B}}$, etc.
- We define the absolute magnitude M of a star by its apparent magnitude if it were at a distance of 10 pc
  (1 pc = 3.26 light years)
- With this definition we obtain the distance modulus by

$$m - M = 5 \log \left(\frac{r}{10\,\mathrm{pc}} \right)$$

- The bolometric luminosity is the total luminosity of a star through its entire spectrum, i.e., $E_\lambda = 1$.

Absolute Bolometric Magnitude

- The apparent bolometric luminosity of the sun is $m_{\mathrm{bol},\odot} = -26.83\,\mathrm{Mag}$
- The bolometric correction, B.C., is defined by $\mathrm{B.C.} = m_\mathrm{B} - m_\mathrm{bol}$
- The absolute magnitude of the sun is $M_{\mathrm{bol},\odot} = 4.74\,\mathrm{Mag}$
- The absolute bolometric magnitude of a star is hence given by

$$M_\mathrm{bol} = 4.74 - 2.5\log\left(\frac{L}{\mathrm{L}_\odot}\right) \quad [\mathrm{Mag}]$$