**The 2nd International Olympiad on Astronomy and Astrophysics**

**Bandung, Indonesia**

Thursday, 21 August 2008

# Practical Competition: Data Analysis

***Please read this carefully:***

1. *Every student receives problem sheets in English and/or in his/her native language, answer sheets, millimeter block papers, and scratch sheets.*
2. *The time available is five hours for the data analysis and observation competitions. There are three data analysis problems, and two observation problems.*
3. *Use only the materials provided.*
4. *Fill in the boxes at the top of each sheet of paper with your country code and your student code.*
5. *Use only the front side of* ***answer sheets****. Write only inside the boxed area.*
6. *Begin answering each question on a separate sheet.*
7. *Numerical results should be written with as many digits as are appropriate.*
8. *Write on* ***the answer sheets and the millimeter block papers*** *whatever you consider is required for the solution of each question. Please express your answer primarily in term of equations, numbers, figures, and plots. If necessary provide your answers with concise text. Full credit will be given to correct answer with detailed steps for each question. Underline your final result.*
9. *At the end of the exam place the answer sheets and the millimeter block papers inside the envelope and leave everything on your desk.*

# Astronomical and Physical Constants

| Quantity | Value |
|---|---|
| Astronomical unit (AU) | 149,597,870.691 km |
| Light year (ly) | $9.4605 \times 10^{17}$ cm = 63,240 AU |
| Parsec (pc) | $3.0860 \times 10^{18}$ cm = 206,265 AU |
| Sidereal year | 365.2564 days |
| Tropical year | 365.2422 days |
| Gregorian year | 365.2425 days |
| Sidereal month | 27.3217 days |
| Synodic month | 29.5306 days |
| Mean sidereal day | $23^h56^m4^s.091$ of mean solar time |
| Mean solar day | $24^h3^m56^s.555$ of sidereal time |
| Mean distance, Earth to Moon | 384,399 km |
| Earth mass ($\mathcal{M}_\oplus$) | $5.9736 \times 10^{27}$ g |
| Earth's mean radius | 6,371.0 km |
| Earth's mean velocity in orbit | 29.783 km/s |
| Moon's mass ($\mathcal{M}_\leftmoon$) | $7.3490 \times 10^{25}$ g |
| Moon's mean radius | 1,738 km |
| Sun mass ($\mathcal{M}_\odot$) | $1.9891 \times 10^{33}$ g |
| Mean Earth radius | $6.3710 \times 10^{6}$ cm |
| Sun radius ($R_\odot$) | $6.96 \times 10^{10}$ cm |
| Sun luminosity ($L_\odot$) | $3.96 \times 10^{33}$ erg $s^{-1}$ |
| Sun effective temperature ($T_{eff_\odot}$) | 5 800 $^o$K |
| Sun apparent magnitude ($m_\odot$) | -26.8 |
| Sun bolometric magnitude ($m_{bol_\odot}$) | -26.79 |
| Sun absolute magnitude ($M_\odot$) | 4.82 |
| Sun absolute bolometric magnitude ($M_{bol_\odot}$) | 4.72 |
| Speed of light ($c$) | $2.9979 \times 10^{10}$ cm/s |
| Gravitational constant ($G$) | $6.6726\times 10^{-8}$ dyne $cm^2$ $g^{-2}$ |
| Boltzmann constant ($k$) | $1.3807 \times 10^{-16}$ erg. $K^{-1}$ |
| Stefan-Boltzmann constant ($\sigma$) | $5.6705\times 10^{-5}$ erg $cm^{-2}$ $K^{-4}$ $s^{-1}$ |
| Planck constant ($h$) | $6.6261 \times 10^{-27}$ erg s |
| Electron charge ($e$) | $1.602 \times 10^{-19}$ C = $4.803 \times 10^{-10}$ esu |
| Electron mass ($m_e$) | $5.48579903 \times 10^{-4}$ amu |

| | |
|---|---|
| Proton mass ($m_p$) | 1.007276470 amu |
| Neutron mass ($m_n$) | 1.008664904 amu |
| Deuterium nucleus mass ($m_d$) | 2.013553214 amu |
| Hydrogen mass | 1.00794 amu |
| Helium mass | 4.002603 amu |
| Carbon mass | 12.01070 amu |

| Conversion table | |
|---|---|
| 1 Å | 0.1 nm |
| 1 barn | $10^{-28}$ m$^2$ |
| 1 G | $10^{-4}$ T |
| 1 erg | $10^{-7}$ J = 1 dyne cm |
| 1 esu | $3.3356 \times 10^{-10}$ C |
| 1 amu (atomic mass unit) | $1.6606 \times 10^{-24}$ g |
| 1 atm (atmosphere) | 101,325 Pa = 1.01325 bar |
| 1 dyne | $10^{-5}$ N |

## II. Determination of stellar masses in a visual binary system

The star α-Centauri (Rigel Kentaurus) is a triple star which consists of two main-sequence stars α-Centauri A and α-Centauri B representing visual binary system, and the third star, called Proxima Centauri, which is smaller and fainter than the other two stars. The angular distance between α-Centauri A and α-Centauri B is 17.59". The binary system has an orbital period of 79.24 years. The visual magnitudes of α-Centauri A and α-Centauri B are -0.01 and 1.34 respectively. Their color indices are 0.65 and 0.85 respectively. Use the data below to answer the following questions.

Data for main-sequence stars

| $(B-V)_0$ | $T_{\text{eff}}$ | $BC$ |
|---|---|---|
| -0.25 | 24500 | 2.30 |
| -0.23 | 21000 | 2.15 |
| -0.20 | 17700 | 1.80 |
| -0.15 | 14000 | 1.20 |
| -0.10 | 11800 | 0.61 |
| -0.05 | 10500 | 0.33 |
| 0.00 | 9480 | 0.15 |
| 0.10 | 8530 | 0.04 |
| 0.20 | 7910 | 0 |
| 0.30 | 7450 | 0 |
| 0.40 | 6800 | 0 |
| 0.50 | 6310 | 0.03 |
| 0.60 | 5910 | 0.07 |
| 0.70 | 5540 | 0.12 |
| 0.80 | 5330 | 0.19 |
| 0.90 | 5090 | 0.28 |
| 1.00 | 4840 | 0.40 |
| 1.20 | 4350 | 0.75 |

$BC$=Bolometric Correction, $(B\text{-}V)_0$=Intrinsic Color

Questions:

1. Plot the curve $BC$ versus $(B\text{-}V)_0$.

2. Determine the apparent bolometric magnitudes of α-Centauri A and α-Centauri B using the corresponding curve.
3. Calculate the mass of each star.

*Notes*:

1. **Bolometric correction** (BC) is a correction that must be made to the apparent magnitude of an object in order to convert an object's visible magnitude to its bolometric magnitude:

$$BC = m_v - m_{bol} \text{ or } \quad BC = M_v - M_{bol}$$

2. **Luminosity mass relation** : $M_{bol} = -10.2 \log\left(\frac{M}{M_\odot}\right) + 4.9$

## III. The Age of Meteorite

The basic equation of radioactive decay can be expressed as:

$$N(t) = N_0 \exp(-\lambda t)$$

where $N(t)$ and $N_0$ are the number of remaining atoms of the radioactive isotope (or parent isotope) at time $t$ and its initial number at $t = 0$, respectively, while λ is the decay constant. The decay of the parent produces daughter nuclides $D(t)$, or radiogenics, which is defined as

$$D(t) = N_0 - N(t) \ .$$

Based on those ideas, a group of astronomers investigates a number of meteorite samples to determine their ages. They have two kinds of samples: allende chondrite (A) and basaltic achondrite (B). From the samples, they measure the abundance of $^{87}$Rb and $^{87}$Sr, where it is assumed that $^{87}$Sr is entirely produced by the decay of $^{87}$Rb. The value of λ is $1.42 \times 10^{-11}$ per year for this isotopic decay. In addition, non-radiogenic element $^{86}$Sr is also measured. Results of measurement are given in the table below, expressed in ppm (part per million).