Lab #35: The HRD and Spectroscopic Parallax

PROCEDURE AND LAB REPORT

Date:_______ Your name: ___________Partner's name: ___________ Section: ___/___

Maximum two students may work together as partners!

This laboratory is taught only in the honors classes. The report must be printed out and the paper copy must be used.

Read:

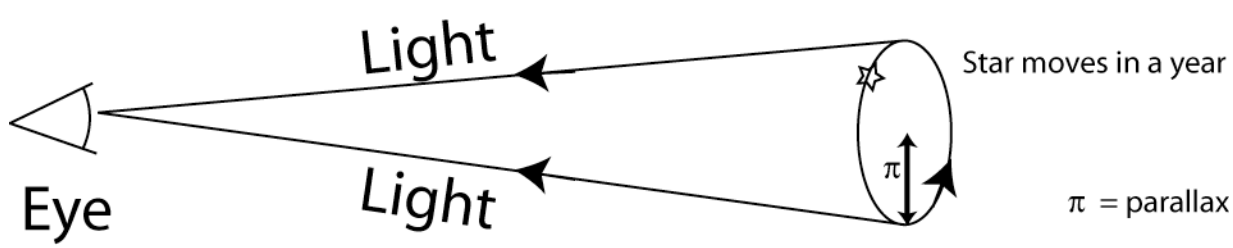
We assume that you are aware of the following facts:

(i) as the temperature increases, hot things glow in red, then in yellow, then in white and blue (this is called Wien's law).

(ii) a parsec [pc] is a unit of distance; 1 pc = 3.26 light years.

(iii) an arc second [as] is a small unit for the size of things as they appear in the sky; 3600 as = 1 degree.

The distance to the closest stars (up to about 100-200 pc) can be precisely determined by the parallax method. The motion of the star is measured in the sky relative to the far-away background stars during the year. The measured parallax directly tells the distance to the stars, according to the formula $D_{[pc]} = 1/\pi_{[as]}$.



Based on these distance determinations, two astronomers investigated the nearby stars in the early 1900's and made comparisons between their color and their brightness. Their result, the Hertzsprung-Russell diagram, proved to be an important tool in the study of stars.

In the first part of this lab we will set up this relationship ourselves; in the second part we will use it to determine distances to distant stars.

We will take for granted the distances to a few close-by stars and take them as measured by NASA's Hipparcos satellite with great precision; we will also accept the measurement of the brightness of these stars in two different colors that was done using images taken by the same satellite. The first table indicates these data (the first line has been filled out for you to help your understanding).

Table 1: Measured data of a few stars

Star name		*B* [mg]	*V* [mg]	π [as]	Dist. [pc]	*C* [mg]	Color	Spec-trum	T [K]	*Δ* [mg]	Mv [mg]
τ Scorpii		2.61	2.82	.0076	132	-0.21	b	B0	30,000	5.60	–2.78
α Leonis	Regulus	1.27	1.36	.0421							
α Lyrae	Vega	0.03	0.03	.1289							
μ Orionis		4.29	4.12	.0215							
α Aquilae	Altair	0.98	0.76	.1946							
ρ Geminorum		4.48	4.16	.0541							
β Virginis		4.11	3.59	.0917							
α^1 Centauri		0.70	-0.01	.7407							
α^2 Centauri		2.25	1.35	.7407							
61 Cygni		6.27	5.20	.2874							
α Centauri C	Proxima	12.82	11.01	.7692							
α Orionis	Betelgeuse	1.95	0.45	.0076							
α Scorpii	Antares	2.93	1.06	.0054							
β Orionis	Rigel	0.15	0.18	.0042							
α Canis Maioris A	Sirius A	-1.43	-1.44	.3792							
α Canis Maioris B	Sirius B	8.41	8.44	.3792							

The color of a star can be easily found by calculating the color index, $C = B - V$, the difference in brightness in blue (B) and yellow (V for "visual") color. For example, a hot blue star would be brighter in blue than in yellow, meaning that its *B* would be a smaller number (recall that a small magnitude means a bright star!), so its color index would come out small. The relationship among color index, the color impression the star gives, the surface temperature, and the official spectral class is shown in Table 2.

Table 2: The color index – temperature – spectral class relationship

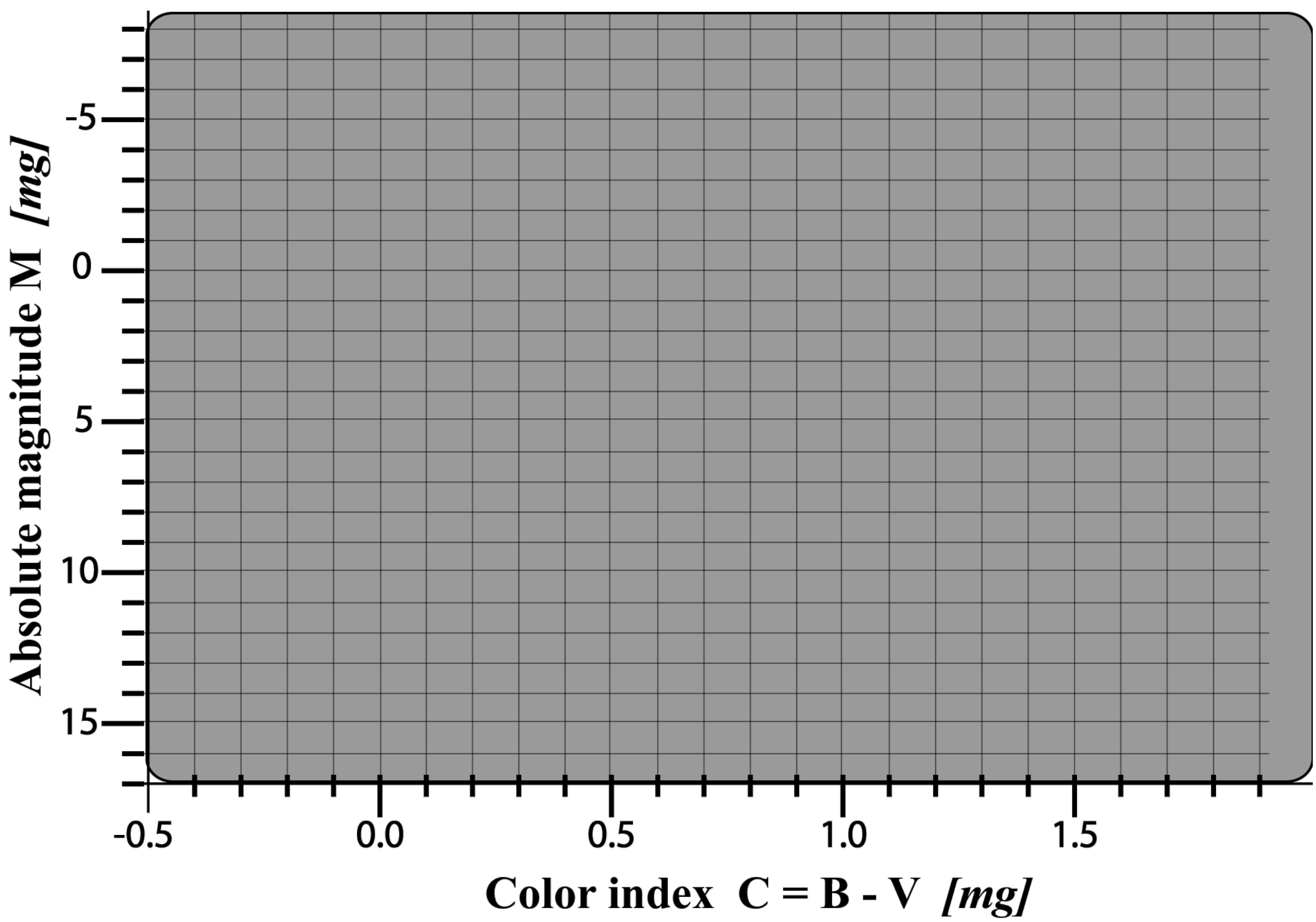
C [mg]	color	T [K]	Spectrum
-0.33	blue	44,500	O5
-0.17	whitish blue	15,400	B5
+0.15	white	8,200	A5
+0.44	whitish yellow	6,440	F5
+0.68	yellow	5,770	G5
+1.15	orange	4,350	K5
+1.64	red	3,240	M5

Spectral classes are divided into sub-classes from 0 to 9; for example,
A0, A1,…, A9.

The true brightness (called absolute magnitude, M) of a star is what it would look like from a distance of $10\ pc$. Stars are of course not at $10\ pc$ from us, but are at various distances. For example, a far-away star looks fainter than its M, and a close-by star looks brighter than its M. The difference is due to distance, and it is called the distance modulus: $\Delta = m - M$. Obviously, the distance modulus of a star that is at $10\ pc$ from us is $\Delta = 0$, a star that is closer than $10\ pc$ to us has a negative Δ (because $m<M$), and a far-away star has a positive Δ (because $m>M$). The distance modulus is related to the distance to the star as $\Delta = 5 \times lg(D) - 5$, where D is the distance to the star in parsecs. [Here, lg means 10-based logarithm.]

For the stars in Table 1 we have all the information to calculate the distance moduli, then the absolute magnitudes.

The Herzsprung-Russell Diagram



Step 1: Establish the HRD

- Fill out Table 1. Estimate the color, the spectral class, and the temperature; calculate the rest. Use the yellow magnitude ($V \rightarrow m$) to calculate the absolute magnitude.
- Plot the stars on the blank Hertzsprung-Russel diagram below, using a color pencil to indicate the color impression the star gives. Mark each star's name on the plot.
- Connect the stars with a reasonably smooth line, allowing for some measurement inaccuracy. The line you find is called the *main sequence*, because the normal hydrogen-burning stars are located on or around it.

Notice that a few stars are above the main sequence. These are helium-burning giants.

Read:

You have actually established the result that made Hertzsprung and Russel famous: that most stars follow the main sequence of the HRD!

We cannot do this, however, for stars that are much farther than *100 pc*, because the geometric method of determining the distance to these stars breaks down (these stars would have an immeasurably tiny parallax). But by now you have established a relationship between a star's color (i.e. temperature) and absolute magnitude (M), and you could use this method *backwards* for far-away stars and determine their otherwise unmeasurable distances. Table 3 includes a list of stars together with their measured brightness in blue and yellow color. (In order to keep things simple, we chose only main sequence stars for this list. Off-main-sequence stars are usually easy to notice due to their excess infrared and/or ultraviolet radiation.) Now you have enough information, without knowing how far these stars might be, to determine their color index, to plot them on your HRD, and to read off their absolute brightness. This will help you to find the stars' distance moduli, which lets you know their distance. (The distance calculated this way lets you know the parallax of a star without directly measuring it, and it is called *spectroscopic parallax*.)

Table 3: Use your HRD to determine distances

Name	*B* [mg]	*V* [mg]	D [pc]	π [as]	*C* [mg]	Color	Spec-trum	T [K]	*Δ* [mg]	Mv [mg]
SAO 51645	6.15	6.25								
GSC 2410:1204	11.68	11.65								
GSC 2410:26	13.22	12.97								
GSC 2410:1029	14.88	14.27								
GSC 2410:1619	13.46	12.09								

Notes:

- SAO is a star catalog of field stars by the Smithsonian Astrophysical Observatory. SAO 51645 is a nondescript ***main sequence*** star in Lacerta.
- GSC is the Guide Star Catalog, which contains stars up to 13-14 magnitudes, used to aim the Hubble Telescope. All the above GSC stars are ***main sequence stars inside M37***, an open cluster in Auriga.
- Because the last step would involve solving the equation $\Delta = 5 \times lg(D) - 5$ for *D*, we did that for you, with the result $D = 10^{1+\frac{\Delta}{5}}$.

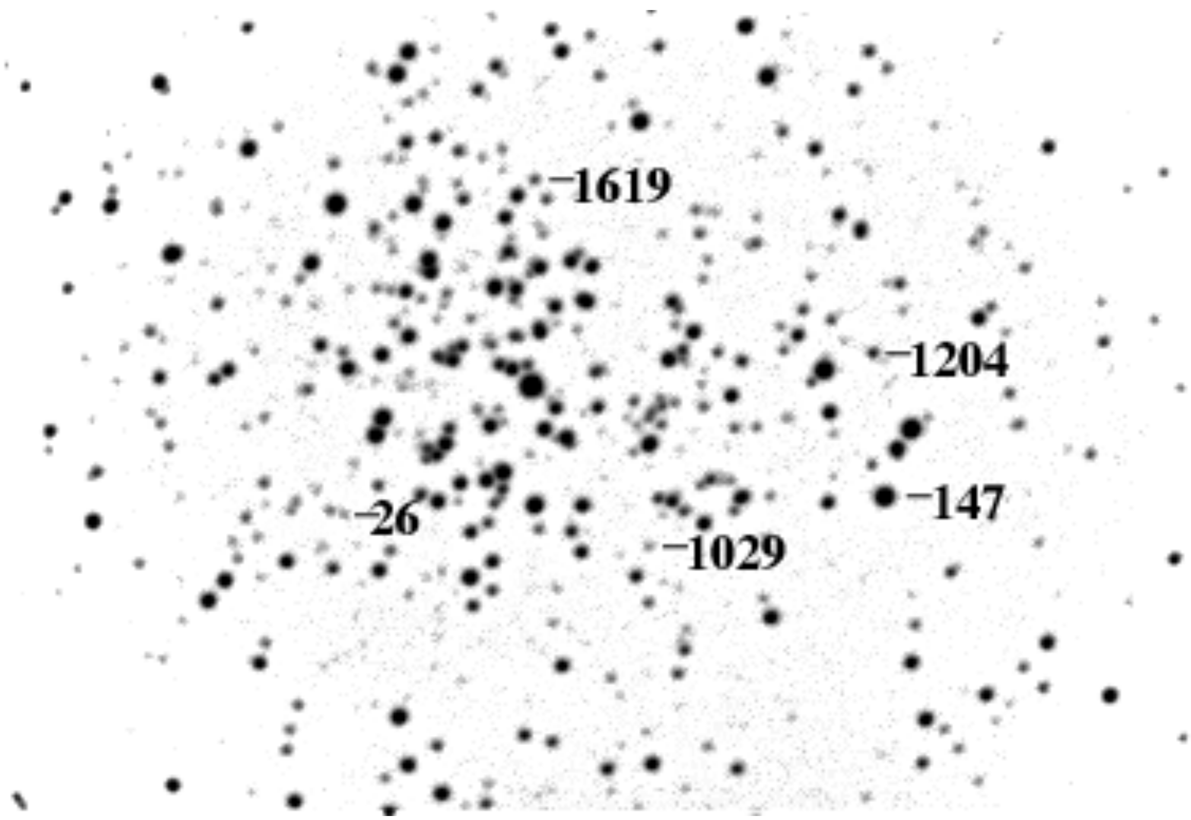
Step 2: Use the HRD to determine distances

- Fill out four of the blank columns of the third table.
  A good sequence to do it in would be: Color index→Color→Spectrum→Temperature.
- Plot these stars on your Hertzsprung-Russel diagram, knowing the stars' color, and knowing that they all are on the main sequence.
- Read off the stars' absolute magnitudes from the HRD.
- Calculate the stars' distance moduli, then their distance, then their ("*spectroscopic*") parallax.

Read:

You have determined the distance to stars that are too distant for geometric parallax to work. You have determined the distance to SAO 51645. You have also determined the distance to the GSC stars in the table.

A negative image of the open cluster M37



Answer:

(1) Describe in your own words the logic of establishing the HRD, and then using it for measuring distances.

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(2) Which star(s) on your HRD are red giants or white dwarfs? Any more non-main-sequence stars?

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(3) Which one(s) of the above GSC stars belong to the open cluster M37? How far is M37?

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(4) Many stars in M37 are brighter than the GSCs we chose in Table 3. For example, the ‘bright’ star GSC 2410:147 has B = 10.77 mg, and V = 9.47 mg, and its proper motion indicates that it is a member of M37. Could we have used that star to determine the distance to M37? What sort of a star is it?