Activity: Cosmic Yardsticks

Variable stars can be used as cosmic yardsticks to measure the distance to celestial objects. The idea is to observe the apparent brightness B of the variable star, somehow find out how bright it actually is (i.e. its luminosity L), and calculate the distance to it by comparing the two. We know that $B=k\,L/d^2$, i.e. the apparent brightness increases with the actual brightness or luminosity, and decreases with the square of the star's distance from us; k is some constant.

The three most useful variable stars are Cepheids, RR Lyrae stars and supernovae. The first two are periodically changing their brightness, supernovae flare up just once. In all cases we want to plot the apparent brightness of the star as a function of time. This so-called lightcurve will be characteristic in the sense that it can be used to identify which type of the three this variable is. It is also use to study the properties of the star.

Case A: Cepheids

Lightcurve: period of several days between maxima; no secondary maxima
Luminosity: between 500 and 20,000 Suns, determine with period-luminosity curve

Case B: RR Lyrae

Lightcurve: period of one or two days between maxima; small secondary maxima exist
Luminosity: 100 Suns

Case C: Supernovae

Lightcurve: aperiodic, just one peak; if plateau exists, it is Type II, otherwise Type I
Luminosity: Type I: 80 million Suns, Type II: 100 million Suns

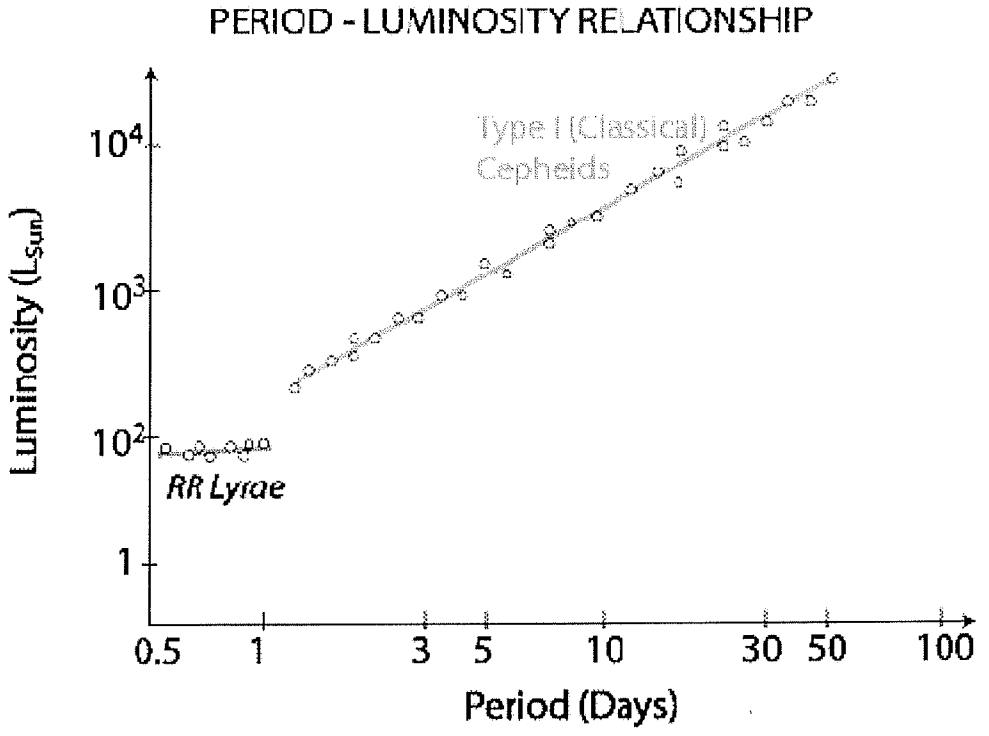
Procedure:

1. Identify which category (A,B, or C) the lightcurve falls into
2. Determine the luminosity of the star.
3. Read off the apparent brightness of the star at the maximum of the lightcurve.
4. Find the distance from the distance vs. luminosity table (Table 1) or use the following formula: $d_{star} = 1.58\sqrt{L}\times 10^{(B+21.73)/5}\,ly$, where B is the apparent brightness of the star in magnitudes, and L the luminosity of the star in Suns.

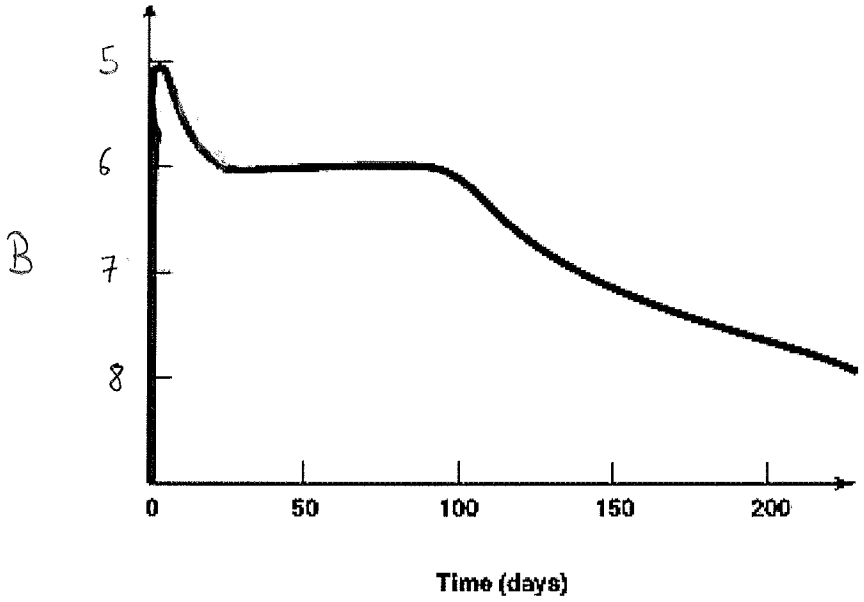
Table 1: Distance to the star as a function of its luminosity L and its brightness B

	Distance(ly)					
Luminosity	B=1	B=1.3	B=1.5	B=3.65	B=5	B=10
50	392773.4	450964.2	494472.4	1330890	2478233	24782327
100	555465.5	637759.7	699289.6	1882162	3504750	35047503
200	785546.8	901928.4	988944.9	2661780	4956465	49564655
300	962094.5	1104632	1211205	3260001	6070406	60704057
400	1110931	1275519	1398579	3764325	7009501	70095007
500	1242059	1426074	1563659	4208643	7836860	78368600
600	1360607	1562186	1712903	4610337	8584850	85848500
700	1469624	1687354	1850146	4979734	9272698	92726978
800	1571094	1803857	1977890	5323559	9912931	99129309
900	1666396	1913279	2097869	5646487	10514251	1.05E+08
1000	1756536	2016773	2211348	5951920	11082994	1.11E+08
2000	2484117	2852148	3127318	8417286	15673720	1.57E+08
3000	3042410	3493154	3830167	10309028	19196308	1.92E+08
4000	3513072	4033547	4422696	11903840	22165987	2.22E+08
5000	3927734	4509642	4944724	13308898	24782327	2.48E+08
10000	5554655	6377597	6992896	18821624	35047503	3.5E+08
1.00E+07	1.76E+08	2.02E+08	2.21E+08	5.95E+08	1.11E+09	1.11E+10
1.00E+08	5.55E+08	6.38E+08	6.99E+08	1.88E+09	3.5E+09	3.5E+10
1.00E+09	1.76E+09	2.02E+09	2.21E+09	5.95E+09	1.11E+10	1.11E+11
1.00E+10	5.55E+09	6.38E+09	6.99E+09	1.88E+10	3.5E+10	3.5E+11

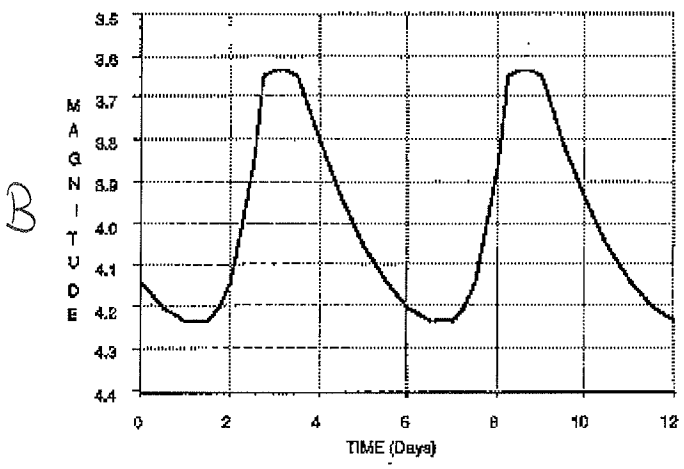
Cepheid luminosity as function of the period



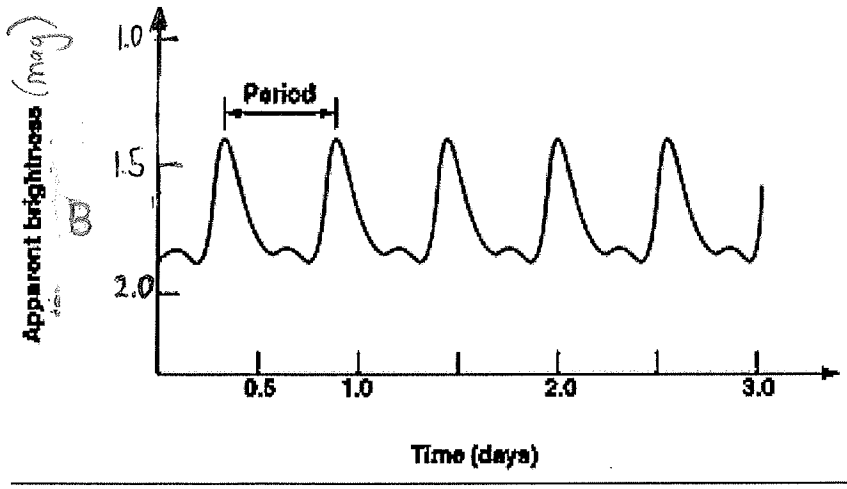
Apparent Brightness (mag)



Lightcurve 1



Lightcurve 2



Lightcurve 3

Cosmic Yardsticks

Lightcurve 1:

1) · single peak
   · plateau
   } ⇒ Type II Supernova

2) $L = 10 \cdot 10^9 L_\odot$

3) Apparent brightness B: 5^m

4) $d_{star}\ (L = 10^8,\ B = 5) = 3.5 \cdot 10^9$ ly $= 3.5$ billion ly

Lightcurve 2:

1) Periodic, no sec. maxima, period 5 days ⇒ Cepheid

2) $L = 10^3 L_\odot$

3) Apparent brightness at peak: 3.65^m

4) $d_{star}\ (L = 1000,\ B = 3.65) = 5,951,920 \approx 6$ mill. ly

Lightcurve 3:

1) Periodic, secondary maxima, period $\frac{1}{2}$ day ⇒ RR Lyrae

2) $L = 100 L_\odot$

3) Apparent brightness at peak: 1.3^m

4) $d_{star}\ (L = 100,\ B = 1.3) = 637,759.7$ ly $\approx 640,000$ ly