
Chapter 13: Variable Stars and O–C Diagrams

Summary

If a phenomenon is perfectly regular, then it is possible to predict its future behavior. If the period of a variable star is known and it is periodic, then the times of maxima and minima can be predicted. If the predictions and the future observations are plotted on an O–C (O minus C) diagram, any changes in the period can be detected. The O–C diagram is a sophisticated diagnostic tool to analyze periodicity.

Terminology

accretion disk	mode switching	secondary
composite-spectrum binary	O–C diagram	semi-detached binary
conjunction	primary	tertiary
ephemeris, ephemerides	Roche lobe	very long baseline interferometry

SUGGESTIONS FOR THE POSTER PAGES, INVESTIGATIONS, AND ACTIVITIES

Investigation 13.1: Constructing an O–C Diagram

Your students need some type of a timing activity to collect data to construct an O–C diagram. The timing needs to be something long enough to count and short enough to handle. The student pages suggests timing a street light when it changes for a certain period of time, or timing the breaks between commercials during a television program. If you are in a physics lab and want this to be a classroom activity you can use an object mounted on a slowly turning bicycle wheel or a torsion pendulum. Whether it is a homework activity or a classroom activity, the students need to have observed ten cycles or occurrences of their system. You may have students determine their own systems, have the entire class use the same system, or have groups do different systems.

Core Activity 13.2: Understanding *O–C* with Miras

Answer key:

SU Vir—The period is longer than average until about cycle 70. Then, there is a *single* short cycle, which causes an effective shift of *epoch*. The period is still slightly longer than average up to about cycle 112, then the period shortens until about cycle 120. It goes back to average until about cycle 137, then the period shortens.

X Aur—The period is about average until about cycle 45. Then it shortens considerably, until about cycle 60. Then there is a long stretch of longer-than-average period, until about cycle 110, followed by a long stretch of shorter-than-average period until about cycle 190.

Y Per—The period is shorter than average until cycle 30 or so, longer than average until about cycle 100, then shorter again. Note that a single short cycle around cycle 121 causes a large shift in epoch.

Z Aur—The period is very stable, and shorter than average, until about cycle 122. Then the period lengthens. *Z Aur* is the most clear-cut example of a sudden period change.

RU And - The period is longer than average until about cycle 35, then shorter than average until about cycle 72. The period shows large fluctuations until about cycle 90, then a longer-than-average period up to the present.

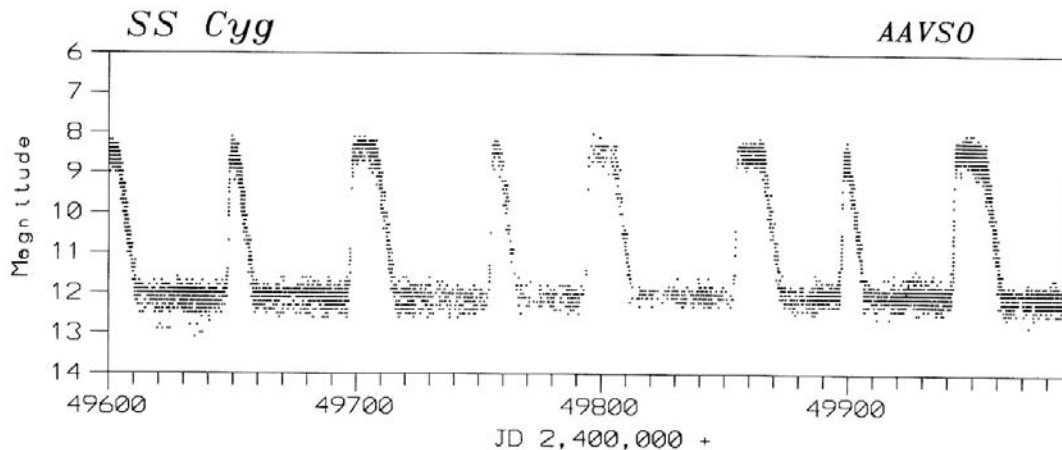
SS Cas—The period is first longer (about cycles 70-90), then shorter (cycles 90-120), then longer (cycles 120-170), then shorter (cycles 170-220.)

X Cam—The period is shorter than average until about cycle 50. Then it is slightly longer than average until about cycle 130. Finally, the period is about average from about cycles 150 to 220.

T Phe—There is no apparent change in the period, except for fluctuations from one cycle to the next; those fluctuations appear to be random.

Core Activity 13.3: Prediction of SS Cyg

SS Cyg is an eruptive variable and it is not possible to accurately predict future eruptions. Show your students the second diagram below to compare with their results.



Activity 13.4: Prediction and Observation of Delta Cep

If there are classroom observations for delta Cep or any other variable star, have the class predict future maxima at an appropriate time for actual observations. Writing a calculator or computer program to calculate the times is the most efficient. Have the class observe the star at some of the appropriate times. They will have to watch for more than the time of predicted maxima in order to determine when the observed times of maxima actually occur. An analysis of the *O-C* diagram should show that delta Cep is not changing its period and the data will cluster around 0 on their graph. If they have the wrong epoch, the points will cluster around a horizontal line that is not located at 0.

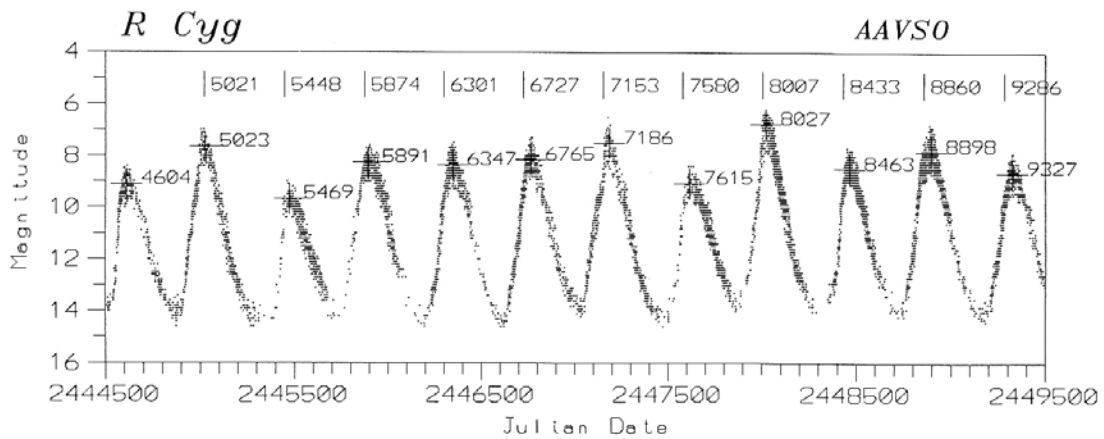
Poster Page: Universal Models

No part of astronomy is more fascinating to young people than that of the shape and structure of spacetime and space travel. Sadly, this subject is rarely included in science curricula. “Modern physics,” including quantum mechanics and Einstein’s theories of general and special relativity, have been around since the beginning of the 20th century!

Though cosmological models involve rigorous mathematics, the basic ideas of relativity and quantum mechanics can be grasped by students at all levels of ability. One short and easy-to-read book, *Flatland*, by Edwin S. Abbott (ISBN 048627263x), is an excellent introduction to the idea of dimensionality, as well as containing a wealth of social and historical science issues for research projects and extensions into literature and history classes. An excellent book for understanding motion at the quantum level is *Alice in Quantumland*, by Robert Gilmore (ISBN 0387914951), a take-off of Lewis Carroll’s *Alice in Wonderland*.

Core Activity 13.5: Prediction and Analysis of the Period of R Cyg

After the students have determined the times and maximum brightness for R Cyg by fitting a polynomial with the V STAR program, show them the following chart with the predicted values. The students can construct an *O-C* diagram using their results from the observational data and the predictions to determine if the behavior of R Cyg is changing. Students may notice that the interval between consecutive maxima and their brightnesses is related in the following way: the fainter the maximum, the longer the interval from the previous maximum, and vice versa.



Activity 13.6: O–C Diagram for Eclipsing Binary Stars

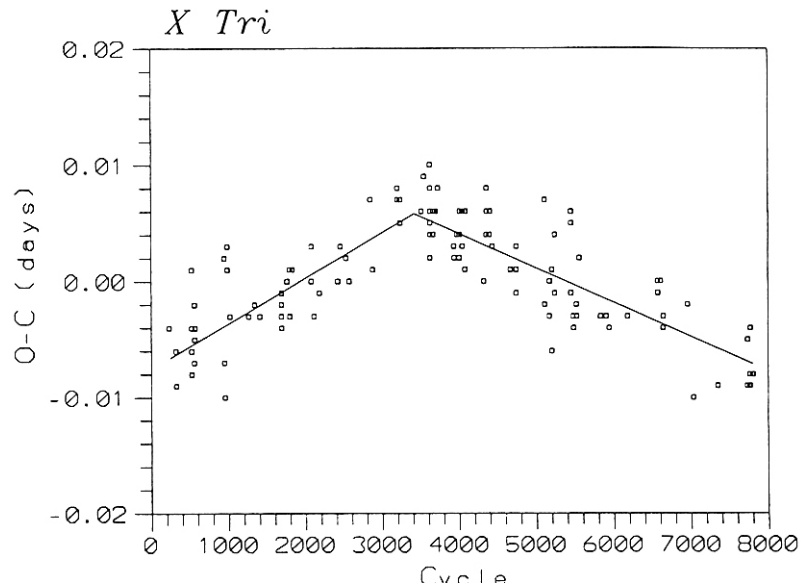
Answer Key

Correct results for minima of X Tri:

Cycle	JD(observed)	JD(computed)	O–C
230	2442726.175	2442726.179	-0.004
318	2442811.668	2442811.674	-0.006
322	2442815.551	2442815.560	-0.009
523	2443010.832	2443010.838	-0.006
524	2443011.802	2443011.810	-0.008
524	2443011.806	2443011.810	-0.004
524	2443011.811	2443011.810	0.001
557	2443043.863	2443043.870	-0.007
560	2443046.783	2443046.785	-0.002
564	2443050.666	2443050.671	-0.005
567	2443053.582	2443053.586	-0.004
945	2443420.818	2443420.825	-0.007
948	2443423.741	2443423.739	0.002
952	2443427.615	2443427.625	-0.010
984	2443458.717	2443458.714	0.003
985	2443459.687	2443459.686	0.001
985	2443459.689	2443459.686	0.003
1020	2443493.687	2443493.690	-0.003
1021	2443494.658	2443494.661	-0.003
1262	2443728.797	2443728.800	-0.003
1338	2443802.635	2443802.637	-0.002
1408	2443870.641	2443870.644	-0.003
1686	2444140.727	2444140.730	-0.003
1687	2444141.700	2444141.701	-0.001
1688	2444142.671	2444142.673	-0.002
1689	2444143.641	2444143.645	-0.004
1760	2444212.623	2444212.623	0.000
1762	2444214.566	2444214.566	0.000
1795	2444246.628	2444246.627	0.001
1797	2444248.567	2444248.570	-0.003
1829	2444279.660	2444279.659	0.001
2075	2444518.656	2444518.656	0.000
2077	2444520.602	2444520.599	0.003
2112	2444554.600	2444554.603	-0.003
2182	2444622.609	2444622.610	-0.001
2419	2444852.863	2444852.863	0.000
2452	2444884.926	2444884.923	0.003
2527	2444957.790	2444957.788	0.002
2566	2444995.678	2444995.678	0.000
2845	2445266.743	2445266.736	0.007
2878	2445298.797	2445298.796	0.001
3197	2445608.722	2445608.715	0.007
3198	2445609.694	2445609.686	0.008
3233	2445643.695	2445643.690	0.005
3233	2445643.697	2445643.690	0.007
3508	2445910.867	2445910.861	0.006
3544	2445945.845	2445945.836	0.009
3619	2446018.711	2446018.701	0.010
3621	2446020.646	2446020.644	0.002
3621	2446020.649	2446020.644	0.005
3621	2446020.652	2446020.644	0.008
3622	2446021.618	2446021.616	0.002
3622	2446021.618	2446021.616	0.002
3622	2446021.618	2446021.616	0.002
3622	2446021.620	2446021.616	0.004

3626	2446025.508	2446025.502	0.006
3659	2446057.567	2446057.563	0.004
3660	2446058.540	2446058.534	0.006
3690	2446087.686	2446087.680	0.006
3725	2446121.692	2446121.684	0.008
3934	2446324.737	2446324.734	0.003
3936	2446326.679	2446326.677	0.002
3974	2446363.599	2446363.595	0.004
4003	2446391.772	2446391.770	0.002
4004	2446392.745	2446392.741	0.004
4008	2446396.633	2446396.627	0.006
4042	2446429.665	2446429.659	0.006
4044	2446431.605	2446431.602	0.003
4078	2446464.635	2446464.634	0.001
4079	2446465.612	2446465.606	0.006
4322	2446701.688	2446701.688	0.000
4354	2446732.781	2446732.777	0.004
4356	2446734.726	2446734.720	0.006
4358	2446736.671	2446736.663	0.008
4389	2446766.785	2446766.781	0.004
4391	2446768.728	2446768.724	0.004
4397	2446774.559	2446774.553	0.006
4432	2446808.560	2446808.557	0.003
4668	2447037.839	2447037.838	0.001
4740	2447107.788	2447107.789	-0.001
4741	2447108.761	2447108.760	0.001
4742	2447109.735	2447109.732	0.003
4742	2447109.735	2447109.732	0.003
5107	2447464.348	2447464.341	0.007
5108	2447465.310	2447465.312	-0.002
5168	2447523.601	2447523.604	-0.003
5169	2447524.576	2447524.576	0.000
5200	2447554.687	2447554.693	-0.006
5202	2447556.637	2447556.636	0.001
5237	2447590.644	2447590.640	0.004
5238	2447591.611	2447591.612	-0.001
5446	2447793.689	2447793.690	-0.001
5447	2447794.661	2447794.662	-0.001
5447	2447794.667	2447794.662	0.005
5448	2447795.639	2447795.633	0.006
5449	2447796.604	2447796.605	-0.001
5477	2447823.805	2447823.808	-0.003
5478	2447824.776	2447824.779	-0.003
5481	2447827.690	2447827.694	-0.004
5516	2447861.695	2447861.697	-0.002
5520	2447865.581	2447865.584	-0.003
5555	2447899.589	2447899.587	0.002
5829	2448165.784	2448165.787	-0.003
5903	2448237.677	2448237.680	-0.003
5903	2448237.677	2448237.680	-0.003
5942	2448275.566	2448275.570	-0.004
6180	2448506.792	2448506.795	-0.003
6570	2448885.692	2448885.692	0.000
6573	2448888.606	2448888.607	-0.001
6608	2448922.610	2448922.610	0.000
6637	2448950.781	2448950.785	-0.004
6639	2448952.724	2448952.728	-0.004
6641	2448954.668	2448954.671	-0.003
6642	2448955.638	2448955.642	-0.004
6957	2449261.673	2449261.675	-0.002
7031	2449333.558	2449333.568	-0.010
7348	2449641.535	2449641.544	-0.009
7728	2450010.717	2450010.726	-0.009
7734	2450016.550	2450016.555	-0.005
7763	2450044.721	2450044.730	-0.009
7764	2450045.693	2450045.701	-0.008
7769	2450050.555	2450050.559	-0.004
7800	2450080.669	2450080.677	-0.008

The O-C values for X Tri gradually increase until about cycle 3400; thereafter they gradually decrease. The general trend is shown by the two straight line segments in the following graph.



Each straight line represents a different period, so we see two different periods of X Tri. Up to cycle 3400, the slope of the line is positive, so the actual period is slightly longer than the given period. After cycle 3400, the slope of the line is negative, so the actual period is slightly shorter than the given period.

In summary: X Tri shows a period change, from a period slightly longer than the given period, to a period slightly shorter.

Poster Talk: The Birch Street Irregulars

This humorous poster talk addresses the serious topic of the need for variable star observers to be careful and precise when recording and reporting observational data. “The Birch Street Irregulars” is also an excellent example of the lengths to which the staff of supporting scientific organizations such as the AAVSO will go to ensure that the data disseminated to the scientific community are as error-free as possible.