Book Review

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The Light-Time Effect in Astrophysics: Causes and Cures of the O–C Diagram

Christiaan Sterken, ed., 2005, 370 + xiii pages; 23 × 15 cm., ASP Conference Series, Volume 335, ISBN 1-58381-200-8. Price $77.00 ($69.30 for ASP members), hardcover. Published by the Astronomical Society of the Pacific, San Francisco.

Christiaan Sterken is well known for his research in photoelectric photometry, for his long-term, high-precision studies of variable stars, and for his previous books, including *Light Curves of Variable Stars* (Cambridge UP, 1996) with Carlos Jaschek. He is also a friend of amateur astronomy, and the AAVSO. He hosted the AAVSO's First European Meeting in July 1990 at his institute in Brussels, and co-edited the proceedings, *Variable Star Research: An International Perspective* (Cambridge UP, 1992). Since then, he has organized a number of other conferences there, including the one in July 2004 on which this book is based. This one attracted 46 participants, including two well-known amateur variable star observers, Bill Allen (New Zealand) and Eric Broens (Belgium). Sterken's conferences are invariably both scientifically and socially interesting. They include fine Belgian beer-tasting and, at this conference, a reception at the Belgian Centre of Comic Strip Art. Unfortunately I was not able to attend this conference, so I am delighted to have these proceedings to read and review.

The light-time effect can be defined as a phenomenon in astronomy which is caused by a different or changing distance between a variable object and the observer, and by the finite speed of light. In variable star astronomy, it most commonly occurs if a pulsating or eclipsing variable is a member of a binary system in which the orbit is not in the plane of the sky; when the variable is on the far side of its orbit, its phase is "late"; when it is on the near side of its orbit, its phase is "early." When I first heard that this was to be the main topic of the conference, I wondered how such a subject could fill three days. But first of all, to quote Sterken's words in the Preface, "the *leitmotif* of this meeting was to discuss all facets of *the (O–C) procedure*..." (my italics). And secondly, though the light-time effect was a secondary topic, it turned out to be a much broader and more interesting one than I had initially guessed.

The (O–C) technique is absolutely central to many areas of variable star research. It refers to a comparison of the Observed ("O") time of maximum or minimum brightness of a variable star, and the Calculated ("C") time, based on an assumed constant period and epoch. It is widely used to refine the known period of a variable, and to detect and study period changes in the star. Small changes in period are cumulative, like the errors in the rate of a clock, and can be detected through long-term measurements. AAVSO observers make long-term measurements of pulsating and eclipsing variables, which lead to hundreds of useful (O–C) diagrams. This book, especially the introductory review by Sterken himself, provides a much-needed guide to the (O–C) technique. It has been two decades since Lee Anne Willson provided a short review of it in *The Study of Variable Stars using Small Telescopes* (Cambridge UP, 1985), and since Emilia Belserene published useful (O–C) articles and algorithms in the *Journal of the AAVSO* and *IAPPP Communications*. This volume shows that the (O–C) method has even broader significance in astronomy today.

Interpretation of (O–C) diagrams is still something of a "black art" and, as Sterken emphasizes in the Preface, can be unduly subjective. In fact, this book opens with a quotation from one of my 1980 papers: "The study and interpretation of period changes in variable stars has had a long and sometimes dubious history. In a few cases, it has produced interesting and worthwhile results. In most cases, however, it is a source of confusion and frustration...." Sterken's review is therefore followed by two important quantitative papers by Chris Koen and Ivan Andronov which remind us that most professional astronomers are amateurs when it comes to statistics. And statistics is what can often tell us when our interpretations are over-optimistic. Koen, for instance, has degrees in both astronomy and statistics, and it is people like him who try to keep the rest of us honest.

Then several papers describe applications of (O–C) analysis; I shall mention only a few. Michel Breger describes four applications to δ Scuti stars—short-period pulsating variables of types A7–F2 on or near the main sequence. The first is SZ Lyn, a high-amplitude variable with a pulsation period of 0.120535 day, and an orbital period of 1180 days which produces a "classic" light-time effect because the orbital motion causes the distance and therefore the phase of the pulsating variable to vary. The second is θ^2 Tau, a pair of δ Scuti stars in a 141-day binary system; both variables show light-time effects, but in opposite senses because, when one variable is on the far side of its orbit, the other is on the near side. The third is FG Vir, a δ Scuti star with 60 (!) pulsation periods, but with (O–C) variations which are no more than a few seconds; the periods are rock-solid. The fourth is BI CMi, a δ Scuti star in which the apparent (O–C) variations are not due to a light-time effect, but due to the interference or "beating" between two very close pulsation periods.

Katrien Kolenberg then discusses the *Blazhko project*, which is only peripherally related to the (O–C) technique, but is of definite interest to RR Lyrae star observers such as those who contribute to the AAVSO RR Lyrae program. The *Blazhko effect* is a long-term variation of the pulsation amplitude and/or phase which occurs in at least a quarter of RR Lyrae stars. Its cause is unknown, though there are two promising hypotheses:(i) that the Blazhko effect is due to the rotation of a star with a global magnetic field which is inclined to the rotation axis (a so-called oblique rotator), or (ii) that it is due to the interaction between the primary radial pulsation mode and one or more secondary non-radial modes. Kolenberg and her colleagues have organized a large international photometric and spectroscopic campaign on a small sample of RR Lyrae stars in order to solve this mystery.

Theodor Pribulla and others then discuss the light-time effect in eclipsing binaries. About a third of all binary stars are actually triple stars. In this case, the eclipsing pair will exhibit the light-time effect in their (O–C) diagram, which can then be used to determine the presence of the third star, and to study some of its properties.

The second section of the book contains papers related to planetary systems—ours and others. Two are historical, and reflect Sterken's own deep interest in the history of astronomy. One deals with the most historically-significant application of the light-time effect—Ole Roemer's "measurement" of the speed of light. He noted that the transits and eclipses of Jupiter's satellite Io were observed to be early when Jupiter was closer to the Earth than average, and late when it was further away. Contrary to popular belief, Roemer apparently did not explicitly give a value for the speed of light, but concluded only that the speed was finite. The second section of the book also contains a paper by Richard Stephenson and Leslie Morrison which shows how historical observations of eclipses of the sun and moon, from 700 BC to 1600 AD, can be used to study long-term changes in the earth's rotation period, due to tides and other mechanisms, using an equivalent of the (O–C) technique.

The third section of the book contains papers which describe the light-time effect in two of the most exciting areas of modern astronomy. *Quasars* are star-like active galactic nuclei (AGNs), powered by supermassive black holes, which vary in brightness on time scales of days to years. Amateur astronomers contribute significantly to AGN research by monitoring these. If a massive galaxy lies between the quasar and the observer, the light from the quasar is gravitationally "lensed" into two or more images. Both are images of the same source, but their light has travelled different paths, with different distances. The variability of the images will be the same, but will be offset in time because of the different light travel times along the different paths. By measuring this difference, astronomers can deduce the distance to the quasar, and thereby estimate the value of the *Hubble Constant*—the parameter which measures the rate of expansion of the universe.

The second application is to *pulsars*, rapidly-rotating neutron stars which emit pulses of radio energy, lighthouse-style, with exquisitely-regular periods of 0.001 to 10 seconds. Pulsars in binary systems are especially important, because they enable astronomers to measure the mass of the neutron star, and also to test the General Theory of Relativity which governs how the neutron star moves. The rarest and most important are binary systems consisting of *two* pulsars. As the pulsars orbit, the light-time effect results in the pulses being observed slightly early or late, depending on the positions of the pulsars in their orbits. This provides very precise information about the pulsars, their orbits, and the laws which govern their motion.

The final section of the book consists of summaries of a mixed bag of over twenty specific applications of the (O–C) technique to individual stars and stellar classes. We hear about FO Aqr, "The King of the Intermediate Polars"; about eclipsing binaries such as XX Cep which AAVSO eclipsing binary observers may be familiar with; η Car, one of the most remarkable variables of all time; and about

V1500 Cyg, which was Nova Cygni 1975 (discovered independently by Minoru Honda and many others including my then-eleven-year-old daughter) and is one of the rare "asynchronous polars."

As is increasingly the norm, Sterken makes room for dozens of candid photos of the participants at the conference. This is a wonderful way to personalize science by portraying the people behind the papers.

If I had attended the conference, I would have talked about a topic which I and my students have worked on for many years, often using AAVSO data: the phenomenon of random cycle-to-cycle period fluctuations which are found in Mira stars and RV Tauri stars, and which complicate the interpretation of the period changes. They completely dominate the (O–C) diagrams of Mira stars. That's one of the few things that is missing from this book!

But it illustrates one problem with conference proceedings: the program committee can be pro-active in who they invite, and in what they ask the invitees to talk about, but the content of the conference, and the proceedings, is ultimately determined by who attends and, in the case of the contributed papers, what the attendees choose to contribute. Sterken, with his broad interests, has wisely chosen to fill some of the gaps himself. In this and many other respects, Sterken has done a conscientious and effective job of editing this volume.

And for those of you who have not been following the conference proceedings scene: the Astronomical Society of the Pacific's Conference Series, now up to Volume 335, is the dominant player. They produce a good product, at a reasonable price, and support a good cause.

This is by no means a "popular" book; it is intended for research astronomers. But it could certainly be understood and appreciated by amateur astronomers and students with some background in variable star astronomy—readers of the AAVSO's wonderful "Variable Star of the Season," for instance. It illustrates some of the many ways in which amateurs' observations contribute to our understanding of variable stars.

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