Eclipsing Binaries in the 21st Century—Opportunities for Amateur Astronomers

Edward F. Guinan
Scott G. Engle
Edward J. Devinney
Department of Astronomy and Astrophysics, Villanova University, Villanova, PA 19085; edward.guinan@villanova.edu

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Abstract Eclipsing binaries play major roles in modern astrophysical research. These stars provide fundamental data on the masses, radii, ages, atmospheres, and interiors of stars as well as serving as test beds for stellar structure and evolution models. The study of eclipsing binaries also returns vital information about the formation and evolution of close binaries themselves. Studying the changes in their periods from the observations of eclipse timings provides insights into evolution of close binaries, mass exchange and loss, apsidal motion for eccentric systems, as well as the discovery of the low mass (unseen) third bodies. Moreover eclipsing binaries in clusters and other galaxies can provide accurate distances to the star clusters and galaxies in which they reside. More recently observations of eclipsing exoplanet-star systems (that is, transiting exoplanets) when coupled with spectroscopy are yielding fundamental information about the frequency and the physical properties of planets orbiting other stars. For the reasons discussed above, observations of eclipsing binary systems have been popular for AAVSO observers and many papers have been published (see Williams *et al.* 2012, this volume). A recent example is the highly successful AAVSO's Citizen Sky Project focused on the enigmatic long-period eclipsing binary ε Aur. Building on the success of the AAVSO during the last century, this paper explores the present and future prospects for research in eclipsing binaries. We focus on what can be done by AAVSO members and other amateur astronomers in the study of eclipsing binaries. Several examples of observing strategies and interesting (and scientifically valuable) projects are discussed as well as future prospects. As discussed, there are many opportunities for AAVSO members to contribute to the study of eclipsing binary stars and an increasing variety of objects to observe.

1. Introduction to eclipsing binaries

We can date the beginning of the study of eclipsing binaries (EBs) with the discovery of Algol (β Per) as an eclipsing binary by young "amateur" astronomer John Goodricke in 1783. The importance of eclipsing binaries stems from the fact that photometry and spectroscopy of eclipsing binaries and the analysis of their light and radial velocity curves returns essential information (which often cannot be found by any other means) about the physical characteristics of the stars—such as mass, radius, temperature, and luminosity (see Andersen 1991; Guinan and Engel 2006). Without eclipses most of these parameters could not be determined. These essential quantities are fundamental to the understanding of all stars, as well as to the star clusters and galaxies in which they reside, and to the basic physical laws that govern their behavior. Although the majority of stars in the solar neighborhood are members of binary or multiple star systems, only a tiny fraction (< 0.5%) of these have their orbital planes aligned closely enough to our line of sight that eclipses occur. To date about 15,000 eclipsing binaries have been discovered out of the possible ~100 million or more eclipsing binaries that are expected to be present in our Galaxy. Interestingly, most of these eclipsing binaries were discovered serendipitously in the Large and Small Magellanic Clouds and in the Galactic Bulge from photometric micro-lensing programs such as EROS, MACHO, and OGLE (see Guinan *et al.* 2004).

Nearly every type of star is represented as a member of an eclipsing binary system. These include main-sequence (as well as pre main-sequence) stars, subgiants, giants, and supergiants, with the entire range of spectral types and masses represented. Brown dwarfs, subdwarfs, white dwarfs, neutron stars, and black holes are also found as members of eclipsing binaries. And since 1999 with the discovery of HD 209458 as a short period eclipsing exoplanet system (Charbonneau *et al.* 2000), an increasing number of eclipsing planet-star systems (referred to as transiting exoplanet systems) have been discovered. Many of these systems have multiple planets. At the time of writing (May 2012) there are 2,321 exoplanet candidates, and 690 confirmed exoplanets—totaling about 3,012 possible exoplanets listed on the Kepler Mission web page. For a summary, see http://planetquest.jpl.nasa.gov. The vast majority of these exoplanets were discovered over the last three years from planetary transits in ultra-high precision photometry from the Kepler Mission (see Borucki *et al.* 2011) as well as many exoplanets found from the CoRoT Mission (see http://smsc.cnes.fr/COROT/).

2. Eclipsing binaries as astrophysical laboratories

The information provided by the study of eclipsing binaries quite often transcends the data obtained about stellar masses, radii, and luminosities (important as these quantities are to stellar physics and evolution). Certain types of eclipsing systems have properties that make them well-suited as astrophysical laboratories for the study of many diverse and important problems in modern physics and astronomy. A representative list of the major classes of binaries and the corresponding properties that make them astrophysically interesting is given in Table 1. Eclipsing binaries provide vital information on stellar atmospheres (limb darkening, gravity darkening, and atmospheric eclipse studies), stellar interiors and structure (through apsidal motion studies of eccentric eclipsing binaries), stellar activity and magnetic dynamos (X-ray, *UV*, and radio eclipse mapping of stellar coronae and chromospheres), and plasma physics (binaries with accretion disks). Moreover, there are a small number of systems that are well-suited for testing general relativity through apsidal motion studies. Others can be used for independent determinations of cosmic fractional helium abundances (Y), and some eclipsing binaries can be used to check the importance of convective overshooting in the nuclear cores of stars. For more details see "The Brave New World of Binary Studies" (Guinan and Engle 2006).

3. The study of eclipsing binaries by amateur astronomers—past and future

With the availability of reasonably priced, high quantum-efficiency (>70%) charge-coupled devices (CCDs), it is now possible for amateur astronomers to produce high quality photometry and light curves of relatively faint (~10–18th magnitude) eclipsing binaries with small to moderate aperture (< 0.5 m) telescopes. Moreover inexpensive (or free) software is available to reduce and analyze the CCD observations. With modest equipment and a good CCD photometer, the studies of many different kinds of interesting eclipsing binaries are within the reach of many amateur astronomers. These include astrophysically attractive eclipsing binaries (see Table 1) as well as those that are members of open clusters and globular clusters, and even those in some nearby galaxies have become possible (also see section 4 of this paper). Moreover, with CCDs, useful spectroscopy of many brighter eclipsing systems is now being acquired by an increasing number of amateur astronomers. This revolution in technology has led to some changes in the approach to the study of eclipsing binaries by amateur astronomers.

In 1965, an Eclipsing Binary Committee (EBC) was established within the AAVSO. There is an excellent summary paper about the accomplishments of the EBC by Williams *et al.* (2012, this volume) and the wealth of work done by the members of this group. From mostly visual observations, AAVSO observers determined and published ~17,000 eclipse timings, determined periods, and secured light curves of mostly neglected or newly discovered eclipsing systems. They also improved ephemerides and updated periods for many systems. However, in the amateur CCD photometry era (starting in the late 1990s), visual observations of eclipsing binaries have become less important. Because of this, in 2005 the EBC was reconstituted as the Eclipsing Binary Section of the AAVSO and now focuses on mostly CCD photometry. Eclipse timings determined from PEP or CCD measures are the order of ~10 to 100 times more accurate than can be realized from visual timings. Of course, as stated by Williams *et al.* (2012): "When visual eclipse timings were the only data available, they were invaluable." The unique value of visual timings of eclipsing binaries is well illustrated in Figure 1 (from Kreiner *et al.* 2005), which shows the (O–C)-plot of eclipse timings of β Lyr going back to the time of Goodricke. The parabolic nature of the (O–C) values indicates that β Lyr's orbital period is increasing by (a huge) ~19 sec/yr. due to rapid mass exchange and loss.

However, even if visual observations of eclipsing binaries have become less valuable scientifically, watching a star fade by ~1 magnitude or more in a few hours (as in the case of Algol and many other similar systems) remains a thrill!

4. Some examples of observing and research programs of possible interest to amateur astronomers

In the following sections, we have selected several themes from this imposing list of binary studies for expanded development. The choices illustrate some new and exciting things we can learn about eclipsing binaries and that can be done by amateur astronomers.

- *The Pro-Am Cooperation and Collaboration:* Continue to partner with professional astronomers to carry out coordinated photometry and spectroscopy of astrophysically interesting eclipsing binary systems and selected transiting exoplanet systems that are being done (or planned) with space missions such as Kepler, Hubble Space Telescope (HST), Chandra X-ray Observatory, and XMM-Newton X-ray missions and others. Standardized *BVR* observations of X-ray binaries, chromospherically active binaries, and exoplanet systems are vital in correctly interpreting these stars. As in the case of CVs (some of which are eclipsing binaries), AAVSO members have played important roles in the past and will continue to do so. The cooperation between amateur and professional astronomers in the study of CVs is discussed by Szkody and Gaensicke (2012) in this volume. Participation in observing campaigns and Citizen Sky Programs on selected targets such as the recently completed program on the long-period eclipsing binary ε Aur is fun, engaging, and builds a sense of community as well as provides important contributions to Astronomy.

- *Photometry of bright Eclipsing Binaries undergoing rapid evolution:* For those who have photoelectric (PEP) or photodiode photometers, securing modern light curves of many eclipsing systems (brighter than ~5th mag.) is scientifically valuable. With sensitive CCD photometers photometry of bright (often neglected) eclipsing binaries is not practical or even feasible. Many of the brightest prototypical classical eclipsing binaries—such as Algol, β Lyr, U Cep, R Ara, VV Cep, μ Sgr, and many others are worth observing with photoelectric/diode photometers with standard *BVR* filters since in several cases their light curves and orbital periods change with time.

• *Eclipsing Binaries with Changing Eclipse Depths (orbital plane precession):* Photometry of eclipsing binaries that are undergoing rapid changes in their eclipse shapes and depths over time could be another interesting program. Most notable among these are several eclipsing binaries that have apparently stopped eclipsing, such as SS Lac (Torres 2001), QX Cas (Bonaro *et al.* 2009), and SV Gem (Guilbault *et al.* 2001). For QX Cas, Figure 2 shows the changes in the eclipse depths of QX Cas over the last fifty years and Figure 3 shows the derived model of the system depicted at secondary eclipse for these epochs. A recent list of such eclipsing binaries (or former eclipsing binaries) is given by Mayer (2005) and more recently by Zasche and Paschke (2012). Eclipsing binaries that have apparently stopped eclipsing include QX Cas, SV Cen, SV Gem, AY Mus, and SS Lac, while those whose eclipse depths are changing include IU Aur, V685 Cen, AH Cep,V699 Cyg, HS Hya, RW Per, V907 Sco, and possibly even Algol. The cause of these light curve variations, including the cessation of eclipses, is best explained from the precession of their orbital planes (that is, change of the inclination of their orbits) arising from the gravitational effects of a third star. The recent study of HS Hya by Zasche and Paschke (2012) indicates that its eclipses are becoming very shallow and that this would be an excellent star to observe as soon as possible. Also it would be worthwhile to secure photometry of the above systems to search for changes in their light curves (that is, eclipse depths). For example, the depth of the primary eclipse of Algol has not been checked for several years and this could also be a good project.

• *Coordinated* BVR *photometry of Eclipsing Binaries discovered by the Kepler Mission:* An interesting and important program would be to carry out coordinated CCD observations of interesting (and unusual) eclipsing binaries discovered recently by the Kepler Mission (see Prša *et al.* 2011; Slawson *et al.* 2011). Kepler returns exquisite ultra-high precision photometry and beautiful light curves but the photometry is essentially unfiltered, covering a very broad wavelength range. Standardized *BVR* photometry (even though much less precise than returned by Kepler) of selected ~10–14th magnitude Kepler eclipsing binaries would be very useful to help to better define the physical properties of the stars—especially the stars' temperatures. Systems with deep eclipses, or eccentric orbits, or with pulsating components, as well as those with changing light curves from the Kepler Mission sample of nearly 2,200 stars are the most compelling to observe. Carrying out photometry during the eclipses with multiband photometry is particularly valuable. It should be noted that the ultra-high precision photometry from Kepler on these stars (and ~150,000 others) is available for study from NASA's Mikulski Archive for Space Telescopes (MAST) website at http://archive.stsci.edu. The instructions for downloading, plotting, and analyzing these exquisite data are also available at the MAST site or can be found at the Kepler Mission website. This is worth taking a look at on cloudy nights. Programs for analyzing light curves of eclipsing binaries are discussed later in the paper.

• *Supporting* BVR *photometry (and Spectroscopy) for the BRITE-Constellation Mission:* An interesting program suitable for amateurs would be to carry out standardized photoelectric (PEP) or photodiode *BVR* photometry of bright eclipsing binaries that will be monitored by the BRITE-Constellation Mission starting this year. The BRITE-Constellation Mission is a planned network of up to six Nano-satellites designed to carry out filtered time-series photometry of the brightest stars in the sky (down to ~4th mag.). Each will fly a small-aperture telescope (3 cm) with a CCD camera to perform high-precision filtered (one filter designated for each instrument) photometry of the brightest stars in the sky (< 4th mag.) continuously for up to several years. These Nano-satellites are 20-cm cubes and each "orbiting camera" has a field of view of ~24 degrees. The first two of these satellites are expected to be launched during 2012. The BRITE Mission research team would be interested in collaborations with amateurs to carry out coordinated photometry (or better yet spectroscopy) of BRITE targets when these stars are being observed by the mission. This could be an interesting project—see BRITE (http://www.brite-constellation.at/).

5. Data mining: "observing" without a telescope—exploiting archival eclipsing binaries

As discussed previously (in the case of the Kepler Mission), there are large photometric data sets on variable stars, including eclipsing binaries, that are available over the internet. These archival data can be used directly or to supplement photometry for the study of eclipsing binaries. For example, photometry from early micro-lensing programs such as EROS, MACHO, and OGLE are available over the internet. These programs operated during the 1990s and serendipitously discovered thousands of relatively faint (fainter than 14th magnitude) eclipsing binaries in the Large and Small Magellanic Clouds, and also in the direction of the center of our Galaxy in the Galactic Bulge region. Data from these programs are available over the internet but much of this photometry has been exploited and published. However, some astronomical nuggets could turn up with deeper data mining.

The All Sky Automated Survey (ASAS) is a Polish project started in 1997 as a follow-up to the successful OGLE program. But unlike the previous survey programs, the ASAS program is devoted to the study of variable stars. It is a wide field ($4 \times 4°$ per pointing) photometric monitoring program to observe ~18 million stars south of declination +28° and brighter than ~14th magnitude. This highly successful variable star discovery and monitoring program uncovered over 50,000 variable stars including many eclipsing binaries (~80% of which are new variables). The photometry from ASAS is available over the internet (see: http://www.astrouw.edu.pl/asas/). Recently ASAS-North started operations so that photometry from that program may also soon be available.

In the near future, hundreds of thousands (possibly millions) of additional eclipsing system are expected to be discovered by Pan-STARRS, the Large Synoptic Survey Telescopes (LSST), and from space with the ESA Gaia Mission. Gaia has a billion-pixel CCD array that will measure positions and fluxes (magnitudes) for over one billion stars and galaxies (see http://gaia.esa.int/ for more information). Gaia is planned to be launched during 2013. Also, there are several transit planet search missions being carried out with networks of small telescopes. In addition to discovering exoplanet transit systems, they are also returning photometry for eclipsing binary stars. A partial list of some of these planet-search programs include: HATNet, MEarth, SuperWASP, and several others. And last but not least is AAVSOnet—a network of robotic photometric telescopes being developed by Arne Henden for use by AAVSO members and others to carry out photometry of variable stars (see http://www.aavso.org/aavsonet). AAVSOnet can be used free-of-charge by AAVSO members to carry out photometry of specific (~9–15th mag.) eclipsing binary systems (among other targets).

To help cope with the expected deluge of data (petabytes) in the near future from these programs, we are developing a Neural Network (NN) Artificial Intelligence (AI) based program to help to automatically analyze the light curves of tens of thousands of eclipsing binaries (see Prša *et al.* 2008; Guinan *et al.* 2009). More information can be found at the PHOEBE or EBAI websites.

6. Examples of useful programs and software for work on eclipsing binaries

Several examples of programs and software available for the study of eclipsing binaries are given below. These programs and websites are useful for modeling the light curves of eclipsing binaries and also to visualize most types of eclipsing binaries. Several additional programs (and software) are available over the internet.

PHOEBE (PHysics Of Eclipsing Binaries) is an excellent free downloadable astronomical software that permits the modeling of eclipsing binaries (EBs) based on real photometric and spectroscopic (radial velocity) data. It is based on the Wilson-Devinney code (Linux or Unix based). The software is highly recommended. The PHOEBE homepage is located at: http://phoebe.fiz.uni-lj.si. The contact person for PHOEBE is Dr. Andrej Prša.

BINARY MAKER 3 is commercial software (cost ~100 USD) that accurately calculates light and radial velocity curves for almost any type of binary, simultaneously displaying the theoretical and observed curves as well as a 3-D model of the orbiting stars. Professional-quality PostScript output can be created of all the major displays. The program comes complete with an extensive User Manual on a CD as well as a very complete Help System which not only explains how to use the program but also gives details on how to analyze eclipsing binary light curves. Individual displays can be customized and saved to meet the user's needs. Star spot modeling, eccentric orbits, and asynchronously rotating stars can also be accurately modeled (www.binarymaker.com).

STARLIGHT PRO produces animations of eclipsing binary stars and generates synthetic light curves. The effects of limb darkening, temperature, inclination, stellar size, mass ratio, and star shape are included. There is a free download for Windows (see http://www.midnightkite.com/index.aspx?URL=Binary for more information) .

NIGHTFALL eclipsing binary star program is online software that can be used to produce animated views of eclipsing binary stars, calculate synthetic light curves and radial velocity curves, and eventually determine the best-fit model for a given set of observational data of an eclipsing binary star system (Linux or Unix based: www.hs.uni-hamburg.de/DE/Ins/Per/Wichmann/Nightfall.html).

ECLIPSING BINARY SIMULATOR (EBS) is a Window-based astronomy application to visualize the orbit and synthetic light curve of binary star systems. EBS was mainly developed for educational purposes and visualization of different types of eclipsing binary systems. This is an easy application to use to pass time on cloudy nights (see: http://astro.unl.edu/naap/ebs/anima).

7. Conclusions and future projections

Since the discovery of the first eclipsing binary system nearly 230 years ago by John Goodricke, these fascinating stars (and stars with transiting planets) have played important roles in the development of Astronomy. The availability of sensitive CCDs, photometric reduction and analysis programs, and reasonably priced telescopes has created a revolution, making it possible for motivated amateur astronomers to make significant contributions to this field. Moreover, CCDs, when coupled with commercially available spectrographs, also now make it possible to conduct useful spectroscopy of the brighter stars even with small telescopes.

Also past, present, and future wide-field photometry programs are providing (or will soon provide) the ever-expanding datasets on eclipsing binary stars in the Milky Way Galaxy and beyond. It is expected that over one million eclipsing binaries will be discovered within the next decade by these programs. It is hoped that important contributions will continue to be made by amateur astronomers in the exciting field of eclipsing binaries. It should be noted that many amateur astronomers today have more powerful equipment and telescopes (some completely robotic) than most professional astronomers had access to as recently as a few decades ago. So go for it and enjoy the ride! (and the eclipses!).

8. Acknowledgements

The authors acknowledge the hard work and efforts made over the last century (and up to the present) of the avid AAVSO, and other, amateur observers of eclipsing binary systems. Many have spent cold nights securing light curves or eclipse timings to improve orbital periods and study changes in periods. The authors wish to acknowledge support of grants from NASA and NSF for this study. We also thank the editors of this special AAVSO centennial volume for the work put in producing a fine compilation of papers. Also we wish to thank them for their patience and understanding for the late submission of this paper.

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Table 1. Binary systems as astrophysical laboratories.

Type of system	*Properties*
Detached eclipsing systems: both components located within their Roche lobes; form the backbone for the Mass-Luminosity Law.	Masses, radii, luminosities, and densities of stars; checks on stellar evolution; fundamental properties and precise distances.
Eclisping binaries with pulsating components (such as δ Sct, β Cep, γ Dor variables, and Cepheids). Examples: δ Cap, RZ Cas, R CMa....	Permits the measurement of radii, masses, densities, age, and evolution of the pulsating components. Calibration of age-mass for astereoseismology studies.
Eclipsing binaries with eccentric orbits: apsidal motion studies—internal structure of stars / tests of General Relativity in a few cases. Also “Heart Beat” Stars—induced pulsations near orbital periastron observed from Kepler data. A possible bright “Heart-beat” binary is μ Sgr.	Apsidal motion—stellar structure and interiors; gravitationally induced pulsations; several systems provide tests of general relativity. “Heart beat” binaries can provide probes of the internal structure of stars.
Chromospherically active binaries: RS CVn, BY Dra, and related systems.	Magnetic activity; star spots, chromospheric and coronal emissions; “solar-stellar connection.”
Semi-detached systems: Algol-type binaries; W Ser and β Lyr—mass exchanging / losing systems.	Stellar and binary star evolution; mass exchange and loss; accretion processes; enrichment of ISM from mass loss.
Contact Binaries: a) Cool: W UMa-type systems (W UMa, VW Cep….); b) W-type / A-type systems (AW UMa).	Stellar activity and magnetism; binary star evolution; angular momentum loss; binary star coalescence from studies of long-term changes in orbital periods.
Hot contact systems: AO Cas-type systems; Wolf-Rayet (WR) binaries (e.g. V444 Cyg).	Binary star evolution and dynamics; interacting winds; mass loss (chemical enrichment of ISM).

Table 1 continued on following pages

Table 1. Binary systems as astrophysical laboratories, cont.

Type of system	*Properties*
Near Contact Systems (NCBs): V1010 Oph-type and FO Vir-type systems.	Stellar evolution; mass transfer and loss; magnetic activity in systems with cool components; marginal contact systems. Light curves change with time.
ζ Aur and VV Cep Systems: Long period interacting supergiants systems and ε Aur; supergiant + large disk (see recent AAVSO Citizen Sky Project).	Properties of evolved supergiant stars: masses, radii and atmospheric structure (from atmospheric eclipses) of evolved stars; mass loss rates; accretion processes.
Cataclysmic variables (CV) and nova-like (NL) binaries: (see Szkody and Gaensicke 2012, this volume).	Masses of white dwarf stars; accretion/accretion disks; accretion and plasma physics; angular momentum loss from magnetic braking and relativistic effects.
X-ray binaries with neutron star and black hole components: Low mass X-ray binaries (LMXBs) with neutron stars and high mass X-ray binaries (HMXBs) with mostly black hole components and related systems.	Properties of neutron stars; accretion; physics of hot plasmas and magnetic fields; black holes (e.g. Cyg X-1, CAL 87, V404 Cyg, Cir X-1).
Planet-star systems (transiting exoplanets); HD 209458 / hot Jupiter transiting exoplanets; over 690 verified systems from radial velocity and transits studies.	Properties of exoplanets (mass, radii, and densities); frequency of exoplanets; discovery of Earth-size planets from transits from Kepler and CoRoT Missions (3,100+ verified and exoplanet candidates).
Symbiotic Binaries: (M III + wd); long period binaries (examples of eclipsing symbiotic variable include CH Cyg, AR Pav, and V1413 Aql).	Wind accretion and mass loss rates from red giants; plasma physics. Some with high mass white dwarfs could be SN Ia progenitors.

Table 1 continued on next page

Table 1. Binary systems as astrophysical laboratories, cont.

Type of system	*Properties*
Eclipsing binaries displaying rapid changes in their light curves: 1. Evolutionary changes/mass loss/mass exchange (e.g. W Ser, β Lyr, R Ara…). 2. Changes in eclipse depths from variations in their orbital inclinations as viewed from Earth (examples: SS Lac, SV Gem, and QX Cas, have stopped eclipsing. 3. Varying star spot coverage and star spot cycles; RS CVn and related stars.	1. Test beds for stellar and binary star evolution. Studies of mass exchange and mass loss. 2. Dynamical test beds for effects of tertiary companions on the orbits of the close eclipsing binary. The third body causes the orbit to precess. 3. Study star spot properties and motions including differential rotation and also possible star spot cycles. Use eclipses to map star's surface.
Post common envelope binaries: main-sequence star + white dwarf systems: V471 Tau; Binary Nuclei of Planetary Nebulae; Pre-CV systems and double degenerate short period systems.	Common envelope evolution; mass loss / chemical enrichment of ISM / subdwarfs / white dwarf. Double-degenerate (D-D) systems are important to study but are faint and need high speed photometry. The more massive D-D systems are candidates for Type-Ia Supernovae.

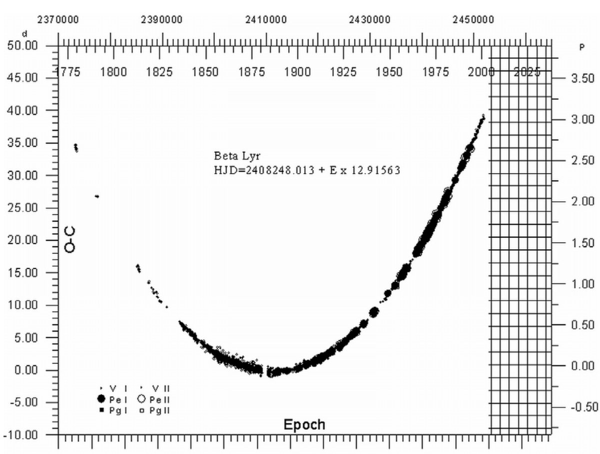

Figure 1. The O–C plot for β Lyr eclipse timings, including AAVSO data, from Kreiner *et al.* (2005). The orbital period is found to be increasing by ~19 sec/year due to rapid mass exchange and loss. The amount of mass being transferred between the two stars (or lost) is ~ 2×10^{-5} solar masses per year, or the equivalent of the Sun's mass every ~50,000 years.

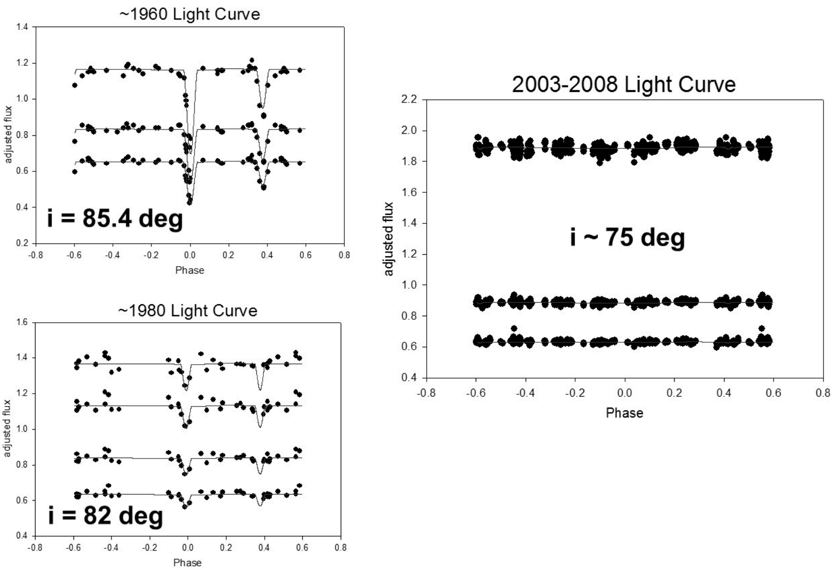

Figure 2. QX Cas light curves and PHOEBE model fits, showing changes in the orbital inclination. The epoch ~1960 UBV photometry is from Sandage and Tammann (1969) and the epoch ~1980 UBVR photometry is from Moffett and Barnes (1983); the 2003–2008 photometry was secured with the Four College Automatic Photoelectric Telescope by the authors. The photoelectric UBV and UBVR light curves of QX Cas (V ~ 10.5 mag; P = 6.007 days; e = 0.21) are shown for three observing epochs. Analyses of the light curves were carried out using the PHOEBE program and the best model fits are plotted among the data. No eclipses are evident from photometry secured after 2003 (even during the mid-1990s photometry of QX Cas from Arne Henden shows no evidence of eclipses). The resulting orbital inclinations are shown in the plots. The light curve analysis shows that QX Cas consists of B1.5 V and B3 IV stars with masses of $M_1 \sim 5.5\ M_\odot$ and $M_2 = 6.5\ M_\odot$, respectively and fractional radii (R/a) = 0.11 and 0.16. QX Cas is a member of the young open cluster NGC 7790 at an estimated distance of 3.3 kpc. Solutions adopted from Bonaro *et al.* 2009.

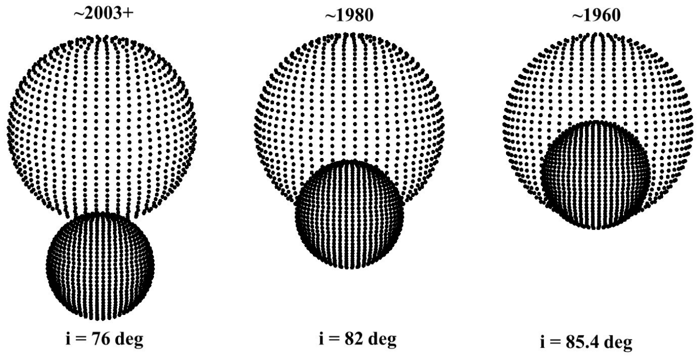

Figure 3. The models of the eclipsing binary QX Cas are shown at secondary eclipse. The relative sizes of the stars and orbital inclinations are derived from the analysis of the available photoelectric light curves using PHOEBE. As shown, the orbital inclination decreases from i ~85.4° during ~1960 to i ~76° from 2003 onward (from the analysis of the Villanova photometry).