Part 1
Multiwavelength Photometry and Spectroscopy of Interacting Binaries

From Interacting Binaries to Exoplanets: Essential Modeling Tools
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Advances in Telescope and Detector Technologies – Impacts on the Study and Understanding of Binary Star and Exoplanet Systems

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Abstract. Current and planned telescope systems (both on the ground and in space) as well as new technologies will be discussed with emphasis on their impact on the studies of binary star and exoplanet systems. Although no telescopes or space missions are primarily designed to study binary stars (what a pity!), several are available (or will be shortly) to study exoplanet systems. Nonetheless those telescopes and instruments can also be powerful tools for studying binary and variable stars. For example, early microlensing missions (mid-1990s) such as EROS, MACHO and OGLE were initially designed for probing dark matter in the halos of galaxies but, serendipitously, these programs turned out to be a bonanza for the studies of eclipsing binaries and variable stars in the Magellanic Clouds and in the Galactic Bulge. A more recent example of this kind of serendipity is the Kepler Mission. Although Kepler was designed to discover exoplanet transits (and so far has been very successful, returning many planetary candidates), Kepler is turning out to be a "stealth" stellar astrophysics mission returning fundamentally important and new information on eclipsing binaries, variable stars and, in particular, providing a treasure trove of data of all types of pulsating stars suitable for detailed Asteroseismology studies. With this in mind, current and planned telescopes and networks, new instruments and techniques (including interferometers) are discussed that can play important roles in our understanding of both binary star and exoplanet systems. Recent advances in detectors (e.g. laser frequency comb spectrographs), telescope networks (both small and large – e.g. Super-WASP, HAT-net, RoboNet, Las Combres Observatory Global Telescope (LCOGT) Network), wide field (panoramic) telescope systems (e.g. Large Synoptic Survey Telescope (LSST) and Pan-Starrs), huge telescopes (e.g. the Thirty Meter Telescope (TMT), the Overwhelming Large Telescope (OWL) and the Extremely Large Telescope (ELT)), and space missions, such as the James Webb Space Telescope (JWST), the possible NASA Explorer Transiting Exoplanet Survey Satellite (TESS – recently approved for further study) and Gaia (due for launch during 2013) will all be discussed. Also highlighted are advances in interferometers (both on the ground and from space) and imaging now possible at sub-millimeter wavelengths from the Extremely Long Array (ELVA) and Atacama Large Millimeter Array (ALMA). High precision Doppler spectroscopy, for example with HARPS, HIRES and more recently the Carnegie Planet Finder Spectrograph, are currently returning RVs typically better than ∼2-m/s for some brighter exoplanet systems. But soon it should be possible to measure Doppler shifts as small as ∼10-cm/s – sufficiently sensitive for detecting Earth-size planets. Also briefly discussed is the impact these instruments will have on the study of eclipsing binaries, along with future possibilities of utilizing methods from the emerging field of Astroinformatics, including: the Virtual Observatory (VO) and the possibilities of analyzing these huge datasets using Neural Network (NN) and Artificial Intelligence (AI) technologies.

Keywords. instrumentation: detectors, spectrographs; (stars:) binaries: eclipsing, planetary systems

1. Introduction

The advances in telescopes and detectors, and their impacts on the study of exoplanets and (eclipsing) binary star systems are briefly discussed. Because of page and time limits, we will give a broad overview, with more detailed discussions of several topics closely related to the theme of this symposium. We are lucky to live during wonderful time of discovery – at least for Astronomy and Astrophysics. Nearly 20 years ago at the "New Frontiers in Binary Star Research" conference held in Korea in 1990, I was asked to write a review paper on "New Directions in Eclipsing Binary Research" (Guinan 1993). And now, reviewing the interesting and exciting papers presented at this conference (and appearing in this volume) many of which are based on greater than expected advances in technology, discovery and theory since that time, we wonder what new and exciting (and unanticipated) discoveries await us during the next decade. And what awaits us in binary star and exoplanet research during the next decade (as anticipated from the pace and breath of discovery indicated by papers at this conference) could truly be breathtaking!

2. Evolution of Telescopes and Detectors

In 1609, Galileo's first telescope (Optic Tube) was basically a tube containing two lenses. His first attempt was a 3-power instrument, followed by one that magnified objects $\sim 9\times$, but the quality of the lenses was poor, with many bubbles in the glass. Later refracting telescopes evolved and improved to larger achromatic refractors in the 18^{th} and 19^{th} centuries. This development culminated with the completion, in 1897, of the largest refracting telescope in the world – the Yerkes 40-inch telescope, which remained the largest in the world until 1907. However, since that time (and even before), reflectors (beginning around the time of Isaac Newton) also evolved in size and quality. Classical reflector designs culminated with the Mt. Wilson 100-inch telescope (1917) and the Hale 200-inch (5-m) telescope, operational since 1948. These were followed by light-weight, multi-segmented mirrors, and later adaptive optics innovations, culminating with the very large, powerful telescopes of today (e.g. the 10.3-m Gran Telescopio Canarias (GTC), the twin 10-m Keck telescopes, the twin 10-m Hobby-Eberle/SALT, the twin 8-m Gemini Telescopes, the four 8-m telescopes of the VLTI, and most recently the Large Binocular Telescope (LBT) with its 11.2-m effective aperture, and several other telescopes apertures of 4-m or greater). Also it is important to mention telescopes in space such the UV–Optical Hubble Space Telescope (HST) and the infrared Spitzer Space Telescope (SST). There are now over 100 telescopes with apertures of 1-m or larger; and there are over a dozen with apertures of >4-m. In addition to these ground-based telescopes that cover the visible and near-infrared, there are observatories in space and on the ground that cover nearly the entire electromagnetic spectrum, from gamma-rays/hard X-rays (COMPTON & RXTE), soft X-rays (e.g. XMM-Newton and Chandra), Far-UV–Ultraviolet (e.g. Hubble Space Telescope), Infrared (e.g. the Spitzer Space Telescope, as well as several ground-based telescopes), microwave–mm (e.g. ALMA, GMT), radio–cm (VLA, VLBI, ELVA etc.) and pushing out to the very long wavelength frontier with gravity wave instruments like LIGO (Laser Interferometer Gravitational Wave Observatory) and, in the future, LISA (Laser Interferometer Space Antenna). These and other instruments are having profound impacts on almost all aspects of Astronomy, including the studies of binary stars and exoplanet systems.

2.1. *Detector Development*

Although "developed" for other immediate survival purposes, the human eye (in a sense) is the first astronomical detector. The maximum quantum efficiency of the dark-adapted human eye (in the green-yellow spectral region) is typically ~5-6% (e.g. see Hallett 1987). However, our eyes are not well suited for accurate astronomical photometry due to a small, variable aperture: the pupil. Moreover, the eye has a very limited exposure time (time-constant < 0.05 sec) making long exposures (as carried out in photography and CCD photometry) impossible. The eye also has a non-linear response to light and, when processed by the brain, shows a well-known logarithmic response to stimuli (the Weber-Fechner Law). Nonetheless, visual photometry carried out before (and even after) photography (by F.W. Argelander and others), and currently being done by hundreds of amateur astronomers (e.g. the AASVO members) – has been very important for our understanding of variable and eclipsing binary stars. Typical photometric precisions of ~0.1 mag are returned by experienced amateurs. The historic visual photometry is of great value in many cases, providing otherwise unavailable long baselines (over 100 years in some cases) in monitoring long-period variable stars, searching for nova outbursts, and determining eclipse timings of eclipsing binary stars.

Photographic photometry (with quantum efficiencies usually $< 2\%$) has the advantage of panoramic fields of view for imaging and photometry. Moreover, long exposure times permit faint magnitude limits to be reached using large telescopes. Quantum efficiencies – starting with photo-diodes in the 1920-30s and photoelectric photo-multipliers in the 1940s and onward – improved up to ~10-30%. But the major revolution in astronomical detector technology took place during the 1980s with the introduction of charge-coupled devices (CCDs). CCD photometers have now evolved into high quantum efficiency (up to 95%), and low noise (and fast read-out) panoramic detectors that have changed the whole face of modern astronomy. Today, for example, a < 1.0-m telescope equipped with a CCD can achieve 1% photometric precision for stars as faint as $19^{\rm th}$ magnitude. This is superior to the earlier photographic photometry accomplished using the largest telescope of its time – the 5-m Hale Telescope at Palomar – during the 1950s and 60s. Now, with arrays of CCDs, wide fields can be covered. Also possible are "giant arrays," such as the 3.2-gigapixel CCD camera for the LSST. Such arrays are becoming much more common.

2.2. *Wide-Field Telescopes*

While increases in telescope size and detector efficiency allowed us to peer much deeper into the Universe (and observe fainter variables and eclipsing binary stars), astronomers began using innovative combinations of telescope sizes and detectors to achieve wide-field surveys where many (1000s) stars can be measured in a single exposure. Some of the pioneers in this field were EROS, MACHO and OGLE. Although primarily microlensing missions to search for dark matter, they resulted in a cumulative wealth of information on all classes of variable stars, both inside and external to the Galaxy. In fact, even though these missions failed to solve the dark matter problem, they proved so useful to the field of observational astrophysics that the OGLE program continues to this day (OGLE-IV). The modern wide-field surveys of today (and tomorrow) seem to come in two flavors: those using small telescopes or camera lenses, and those using medium- and large-aperture telescopes. Notable small scope / lens surveys include ASAS, APASS and KELT. Notable medium-/large-aperture surveys include Pan-STARRS and LSST. Although Pan-STARRS and LSST are not designed for high-cadence observations of variable stars, the scientific community is already preparing itself for the rich, long-term datasets these surveys will be providing for variable stars (including extragalactic eclipsing binaries) down to 24^{th} magnitude.

2.3. *Telescope Networks*

Over the last twenty years, networks (some global) of telescopes have developed, many of which utilize commercially available, small telescopes (typically 20–50-cm), while others are wide angle camera lenses mounted on telescope drives (e.g. WASP, HAT-Net, RoboNet I & II). Several are in operation today and more are planned for the future. These networks carry out wide field (almost all sky) photometry for stars as faint as 11–12^{th} mag. Even though the science focus is mainly on planet hunting via transit eclipses, an important side-product is the synoptic photometry of all types of variable and eclipsing binary stars. These networks include HatNet, SuperWasp, TrES and others. The photometric precision is not very high (on the order of a several milli-mag), but is still quite sufficient to discover exoplanets with diameters equal to or greater than the size of Neptune, and in fact these networks have discovered several hot Jupiter-size exoplanets. For smaller red dwarf stars, it is even feasible to detect super-Earth size planets with such telescopes, as is the main goal of the MEarth program (https://www.cfa.harvard.edu/∼zberta/mearth/).

Also, a global network of small- to medium-aperture telescopes (10–15 × 0.4-m, 12 × 1-m and 2 × 2-m) is planned by the Los Cumbres Observatory Global Telescope (LCOGT) Network. The major focus of this network is global, uninterrupted time-series photometry of planetary transits, along with variable and eclipsing binary stars.

2.4. *Ultra-High Precision Photometry from Space*

Of course, some of the most exciting research being carried out recently has been coming from space-borne missions. HST and Spitzer have been involved in high-precision follow-up photometry of known planetary transits, returning excellent transit curves for several systems. The CoRoT satellite (http://smsc.cnes.fr/COROT/), launched in December 2006, was the first satellite dedicated to the detection of transiting exoplanets. As of June 2011, CoRoT has officially discovered 24 exoplanets, but over 100 more candidates are awaiting confirmation. The Kepler Mission was launched in March 2009, to provide near-constant monitoring of ∼150,000 stars within a ∼100-deg^2 field of view. Since that time, Kepler has become by far the primary contributor to the current database of planetary candidates. In fact, as of December 2011, 2326 planetary candidates have been identified. Of these, 207 are approximately Earth-size, 680 are super Earth-size, 1181 are Neptune-size, 203 are Jupiter-size and 55 are larger than Jupiter. Included are 48 planet candidates orbiting within their host star's habitable zone. Most recently, just before this paper went to press, the Kepler Mission confirmed that one of these candidates, Kepler 22b, is the smallest yet found to orbit within the habitable zone of a star similar to our Sun (Borucki *et al.* 2011). The planet is about 2.4× the radius of Earth. From the available data, it is not yet known if Kepler 22b has a predominantly rocky, gaseous or liquid composition. But more discoveries will surely follow.

Also, ultra-high precision photometry promises valuable binary star scientific returns, such as:

• Tidally Excited Pulsating Binary Stars ("Heartbeat Stars"): Tidally induced pulsations occur in a binary system when, during a period of time around periastron passage, the proximity of the stars and the gravitational forces at play excite pulsations in either (or both) of the stars. The precise characterization of these events can serve almost as a form of asteroseismology, returning a wealth of new information about the stars involved.

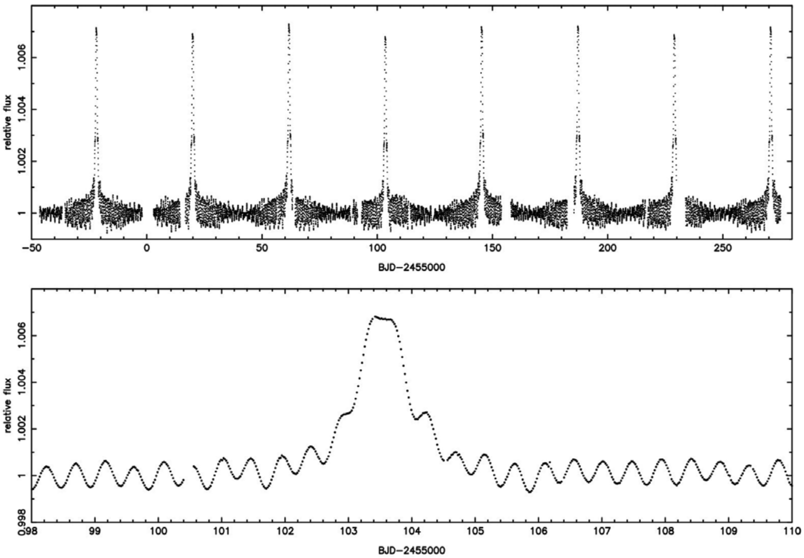

Figure 1. Kepler lightcurve of KOI-54 (from Welsh *et al.*(2011)) showing tidally induced pulsations and brightening events.

Recently, tidally induced activity has been observed in Kepler photometry of the system KOI-54 (Welsh *et al.* (2011) and papers cited within – see Fig. 1). Burkart *et al.* (2011) develop a general framework for interpreting and analyzing high precision light curves from eccentric stellar binaries, such as KOI-54, that display this effect. They refer to the studies of these tidally induced pulsations as "Tidal Asteroseismology." Also in this volume, Kelly Hambleton discusses a case study of an interesting tidally-excited star in the paper "KIC 4544587: An Eccentric, Short Period Binary with δ Scuti Pulsations and Tidally Excited Modes." The topic of tidally excited stars is also discussed by Carla Maceroni in her review paper on the impact of CoRoT and Kepler on eclipsing binary science (in this volume).

• Doppler and Relativistic Beaming (also called light amplification) – motion of stars produces small (<0.2% light variations) from the Doppler Effect, Aberration and Special Relativistic beaming (time dilation effects). Beaming in binary stars is a new and interesting effect recently observed with ultra-high precision photometry. The light variations arising from beaming effects in binary systems are very small (a few millimag) and can only really be studied with CoRot and Kepler. Doppler beaming in stellar binary systems and star-planet systems has been theoretically discussed by Loeb & Gaudi (2003) and Zucker *et al.* (2007). Additional discussions about beaming in binary stars are provided in this volume in the paper by Carla Maceroni and in Andrej Prsa's paper on "Advances in Modeling Eclipsing Binary Stars in the Era of Large All-Sky Surveys with EBAI and PHOEBE."

• Light variations from Orbital Doppler Beaming behave in a similar way to spectroscopic radial velocities, and their analysis can give the mass ratio, eccentricity, omega and $asini$ values for a system. For example see the recent study of the beaming binary KPD 1946+4340 given by Bloemen *et al.* (2011) – see Fig. 2.

• Rotation Beaming: This is analogous to the Rossiter-McLaughlin effect and occurs as a transiting planet covers the advancing/receding hemispheres of the star. The potential

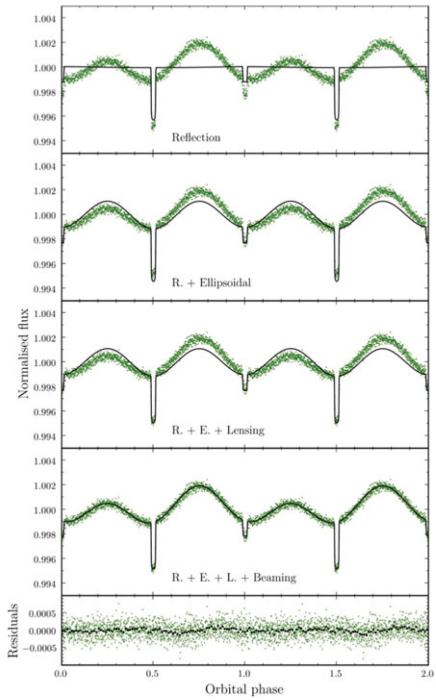

Figure 2. Phase-folded light curve of KPD 1946+4340, with the best-fitting models overplotted. One can clearly see the benefits of including the effects of beaming (bottom lightcurve, just above the residuals) in the model. Figure taken from Bloemen *et al.* (2011).

of studying rotational Doppler Beaming in eclipsing binaries has been recently discussed by Groot (2011).

• Eclipse Mapping: The analysis of high precision photometry during the eclipses of a spotted star in well-suited eclipsing binaries can permit the unambiguous determination of starspot sizes, distributions and motions. See, as an example, Huber *et al.* (2010) for planetary eclipse mapping of CoRoT-2a.

2.5. *Transit Timing Variations (TTVs) – What Can Be Learned*

The study of exoplanet Transit Timing Variations (TTVs) is now a very active field of research since CoRoT and Kepler. For eclipsing binary stars, the study of variations in eclipse timings is over a hundred years old. The detection of third bodies in eclipsing binary systems, from small periodic variations in the system's distance from us that arise from the gravitational pull of the tertiary companion, is made possible by the Light Travel Time Effect (LTTE). For transiting exoplanet systems, TTV studies can reveal the following:

• the presence of addition unseen (low mass) planets (TTVs of several seconds to minutes).

• the presence of hosted moons (Exomoons) – this is a very small effect, best detected in the presence of larger moons (>0.2 $M_\oplus$) in short periods (see Kipping 2009).

• changes in the exoplanet's orbital period arising from tidal (and/or magnetic) coupling. The bright transiting exoplanet system HD 189733 could be a good candidate for studying this effect since it's of hot Jupiter-size and short period (P=2.2 days), and appears to be losing its orbital angular momentum to its K-type host star (see Santapaga *et al.* 2011).

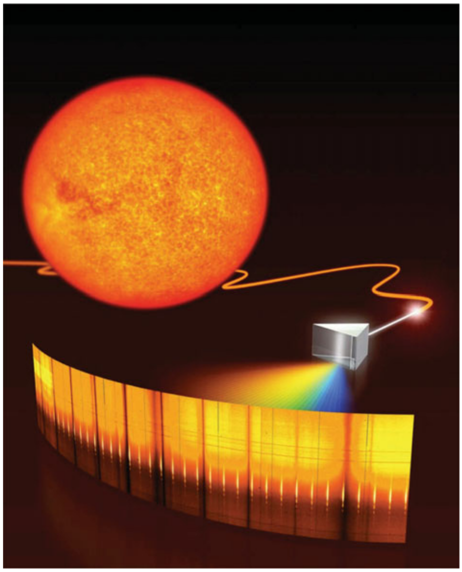

Figure 3. An artist's representation of a laser frequency comb. This very promising technology will be used in many of the ultra-high precision, next generation spectrographs. Since 2005, over 100 papers have been published dealing with laser frequency combs.

3. State of the Art Spectrographs – Impacts on Exoplanets and Eclipsing Binary Stars

Modern spectrographs have throughputs of >50% (the amount of incoming photons that reach the detector), where older ones had only ∼10%, but spectrographs have benefitted greatly from more advances than throughput alone. When spectrographs are fiber-coupled to the telescopes, and thermally stabilized, amazing things can be accomplished. Most modern spectrographs used to measure the small radial velocities (RVs) of stars arising from hosted planets are very carefully constructed, thermally stabilized, bench mounted and fiber-fed. Some examples include HIRES, HARPS, HERMES and the Carnegie Planet Finder Spectrograph (PFS) which can currently achieve RV measures of 1–2-m/s precision (perhaps even 50-cm/s – Paul Butler, private comm.). The ultimate goal is to develop spectrographs with sufficiently high precision to allow the detection of terrestrial-mass planets.

3.1. *Toward Ultra-high precision (<10-cm/s) radial velocity determinations*

Laser Frequency Combs (see Fig. 3) can produce a spectrum of evenly spaced narrow lines spanning the optical into the IR. Combining a fiber-fed frequency comb with a stable spectrograph can result in RV measures of ∼6-cm/s precision, allowing the possibility of discovering Earth-mass exoplanets – e.g. the Earth causes the Sun's RV to shift by ± 10-cm/s (for comparison Jupiter produces a reflex motion of ± 13-m/s). Steinmetz *et al.* (2008) and Murphy *et al.* (2007) give excellent reviews, and the first stellar RV measures using a laser comb are presented in Osterman *et al.* (2011).

ESPRESSO (Echelle SPectrograph for Rocky Exoplanet Stable Spectroscopic Observations) is a new generation, very stable, fiber-fed Echelle spectrograph (R=140,000) designed to operate at visible wavelengths. ESPRESSO is being developed by ESO for use with the 8-m Very Large Telescope. It is designed to secure RV measures of ∼6–10-cm/s (you can walk faster than that speed). Installation and commissioning of ESPRESSO at the VLT is expected during 2016. The instrument is designed to operate with a single telescope or using the combined light gathering power of all four 8-m telescopes configured to form a 16-m equivalent telescope. This arrangement will permit ESPRESSO to reach faint stars or achieve very high signal-to-noise measures for brighter targets.

4. Some Impacts of Large Telescopes

It is obvious that large, next generation telescopes will be excellent tools for studying eclipsing binaries and exoplanets. For example, very faint (distant) stars can be effectively observed. Or brighter stars can be observed with very high signal-to-noise (100,000×) as well as with very high dispersion. Most notable among the many large telescopes now available for this work are the Large Binocular Telescope, with the largest light-gathering power of a single instrument (11.3-m effective aperture when the light of the two mirrors are combined), exceeded however by the four 8-m telescopes of the VLTI, with the combined light gathering power of a 16-m telescope. The enhanced light gathering power of these great telescopes will allow us to study in detail the atmospheres of transiting exoplanets, and enable us to determine the physical properties of faint eclipsing binary stars in other members of the Local Group, and further, to secure direct distances to them, as reported in this volume and described briefly below.

4.1. *Exoplanet Systems:*

Today's great telescopes (and even larger ones in the future) will be invaluable in spectral studies of the atmospheres of exoplanets using both spectrum subtraction (spectrum of [planet + star] minus the spectrum of star alone) techniques as well as in planet atmosphere transmission techniques discussed at this Symposium in Adam Burrow's comprehensive paper "Towards a Theory for the Atmospheres, Structure, and Evolution of Giant Exoplanets." In addition, there is a recent book on this topic, "Exoplanet Atmospheres: Physical Processes" by Seager (2010). We can expect such investigations as follows:

• Reflection and Transmission Spectra: providing the chemical compositions of Exoplanet atmospheres, cloud cover etc. (See Burrows in this volume, and Seager (2010) for reviews).

• Exoplanet Dynamics: Rossiter-McLaughlin (R-M) Effect (Simon Albrecht/Amaury Triaud in this volume). As discussed in these papers and references therein, the application of the R-M effect to transiting exoplanets is truly amazing. These studies indicate that many exoplanet star systems (unlike our solar system) have highly inclined orbits (even retrograde orbits in some cases) relative to the rotational planes of their host stars. This result was totally unexpected.

• More precise RV orbits for exoplanet systems leading, ultimately, to Earth-mass exoplanets.

• Direct imaging of planetary accretion disks and protoplanets.

• Imaging and spectra of exoplanets (with sufficiently large ground- and space-based telescopes).

4.2. *Eclipsing Binaries*

Large telescopes are needed to study faint eclipsing binary stars in other galaxies such as M33 and M31. This is discussed by a paper in this volume by Alceste Bonanos. With large telescopes, faint eclipsing binaries in distant galaxies can be studied photometrically and spectroscopically. Moreover, excellent distances to M31 and M33 are being returned using eclipsing binaries (Vilardell *et al.* (2010) and references therein).

• Radial velocity curves of selected extragalactic eclipsing binaries in Local Group galaxies to determine accurate masses, and unbiased distances.

• Observations of faint, astrophysically selected eclipsing systems: e.g. SN Ia progenitors, rare binaries in fast stages of evolution or with black hole and neutron star components, pre- and post-common envelop binaries, and many other interesting or extreme binary systems would be great targets.

Just as the large observatories have negotiated the learning curve on adaptive-optics (AO) technology, interferometry now stands to follow. Interferometry is becoming a powerful tool to "image" stars and proto-planetary disks. There are some interesting papers on imaging techniques in this volume. For example, with the VLTI and/or with Adaptive Optics (AO), protoplanetary disks are being imaged, showing what appear to be planet-forming regions contained within the disks. Recently, Kloppenborg *et al.* (2010) used the CHARA Interferometer to "image" the large dark disk transiting the F-supergiant component during the recent ∼2-yr long eclipse of the ∼27.2-yr eclipsing binary ϵ Aur. Many more additional binary stars (including β Lyrae), proto-planetary disks and even proto-planets are likely interferometry targets, with improved AO methods using larger telescopes.

5. Great Expectations: Looking into the Future, From Very Large to Tiny

The James Webb Space Telescope (JWST) will be a large infrared telescope with a 6.5-m primary mirror. In spite of its financial and technical problems, JWST is working to a 2018 launch date, after which it will be the premier observatory of the next decade, serving thousands of astronomers worldwide. JWST will study every phase in the history of our Universe, ranging from the first luminous glows after the Big Bang, to the formation of solar systems capable of supporting life on planets like Earth. It will also be useful for faint binary stars in other galaxies. Several innovative technologies have been developed for the JWST, including: a folding, segmented primary mirror, adjusted to shape after launch; ultra-lightweight beryllium optics; detectors able to record extremely weak signals; micro-shutters that enable programmable object selection for the spectrograph; and a cryro-cooler for cooling the mid-IR detectors to ∼7K. The long-lead items, such as the beryllium mirror segments and science instruments, are presently made or under construction.

During 2012, the BRITE Constellation satellites, which are 20-cm^3 nano-satellite systems (Schwarzenberg-Czerny *et al.*2010), are expected to be launched. The individual BRITE satellites are essentially orbiting filtered CCD cameras, each having a wide ∼20° field of view. They are designed to carry out continuous millimag photometry of bright stars (brighter than 4$^{\mathrm{th}}$ mag) in selected regions for several months at a time. Each of these nano-satellites is equipped with a different filters (the first two will have blue and red wide-band filters). And within the next few years, the ambitious ESA Gaia mission is expected to launch. Gaia will be amazing! Gaia will be carrying out parallax measures, photometry of millions of stars (as well as low dispersion spectroscopy of a subset of these stars). In the process, hundreds of thousands of new eclipsing binaries will be found each with measured parallaxes, colors and spectra. While on the ground, huge telescopes such as the OverWhelmingly Large (OWL) Telescope, the Thirty Meter Telescope (TMT), and maybe others, will be built within the next decade or two. As for exoplanet research, DARWIN and/or the Terrestrial Planet Finder (TPF) may eventually merge and get approved to image and secure spectra of nearby exoplanets (using nulling interferometers or other methods) to search for life-supporting atmospheres or even spectroscopic bio-signatures. Also, to save money, an innovative way of doing this could be to deploy a star occulting shroud several km in front of JWST to use as a coronagraph to block out the star hosting planet. But the logistics of such an arrangement would be very challenging.

Finally we desperately need to address the expected overwhelming amount of data (petabytes) to be pouring in from astronomical missions in the near future. The emerging new field of Astroinformatics (see Borne *et al.* 2009) is being developed to cope with and take advantage of these splendid datasets. Astroinformatics focuses on data organization, taxonomies, data mining, machine learning / artificial intelligence (AI), visualization and cyber infrastructure (e.g. Virtual Observatory). These methods are necessary to scientifically exploit the ever expanding "deluge" of astronomical data. In this volume, the example of the Virtual Observatory (VO) is discussed by Gerrie Peters. In closing, the telescopes, equipment, innovative technologies and supercomputers (available today and in the near-future) offer thrilling opportunities for research in our fields of study. Moreover, with the internet and VO, these important datasets are accessible for use to many more people not directly involved with building the missions; for use not only by professional astronomers, but as exciting resources for "citizen" astronomy projects and in the education and training of high school students with internet access.

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