REAL TIME TRIGGERING ON DIMMING EVENTS

ALICE QUILLEN

Studies of the transient sky have predominantly focused on objects that brighten, such as novae or gravitationally micro-lensed objects. However during the epoch of planet formation, a circumstellar, circumplanetary or circumbinary disk or gaseous nebular material can occult a star. During an occultation, structure in an occulting disk can be measured on scales of a stellar radius or 0.01 AU, a scale that is difficult to resolve directly. An analogy might be the importance of opacity measurements in Saturn's rings only possible when Saturn's rings pass in front of a bright star[1]. Stellar occultations led to the discovery of planetary rings around Uranus and Neptune[2]. When an occulting object is in front of a star, its composition can be probed by how it absorbs star light. While planets are small, circumsecondary or circumplanetary disks could be relatively large, particularly if the secondary or planet is widely separated from the primary, making its Hill or Roche radius large. While gaseous or debris disks may only be present in young star systems, the fraction of solid angle that they fill may not be small, perhaps making it possible to see them in rare occultations[3]. Tight binaries and hot planets in short period systems are unlikely to host disks, but widely separated systems could host debris that might be seen during a rare but long transit.

Only a few stars that are periodically occulted by circumsecondary disks are known and of these two are visible to the naked eye, EE-Cephei and Epsilon Aurigae[4]. It is significant that these two are naked-eye visible stars, suggesting that similar systems can be discovered via on-going and forthcoming surveys. Both EE-Cep and Epsilon Aur have long periods, making it possible to study their disks in occultation only rarely.

Recent surveys have revealed more events of transient obscuration. Of a few million bright stars surveyed over 6 years, the KELT collaboration discovered a deep and long dimming of RW Aurigae A[5]. Among the eclipsing binaries in the LMC, OGLE-LMC-ECL-11893 displays a long deep and red eclipse on a 468 day period[6]. The RW Aurigae A event was isolated (the only dimming event in a 30 year timeline), and the OGLE-LMC-ECL-11893 system is faint at 18 mag in V band, and so difficult to study in detail. The RW Aurigae A obscuration event was discovered well after it took place, making follow-up in absorption impossible.

Following up an ongoing dimming or obscuration event with multicolor and accurate photometry with a micro-lensing search or planetary transit network would give accurate photometry, and color measurements, in the depth of the eclipse. If the eclipse is due to a gas cloud stream, we would gain detail on its structure from extinction as a function of time during the event. If the occulter is a disk or a nebulae surrounding a planet or surrounding a secondary star then we obtain information on small scales in the nebula that we would not be able to get in any other way, and potentially during a time of planet formation or when the proto-stellar nebula is dispersing. Color variations during a transit constrain the material doing the occultation. Dust can be grey, as in EE-Cep's disk, and so comprised of large, rather than interstellar, dust grains[4].

A long, deep dimming event on a bright star would also allow spectroscopic study. We could search for and study as a function of time, absorption in the 3.1μm water ice feature and the 4.6μm CO ice feature. In the near-infrared a series of CO features could allow constraints on gas temperature. The detection of ice would be particularly interesting as it would imply collision products in a debris disk. In the visible bands, high resolution spectroscopy of atomic species (e.g., Ca, Mg, Na) may allow study of the velocity of the intervening gaseous material as well as improving upon spatial resolution by determining what quadrant of the star the intervening material obscures.

Eventually we would like to be able to find and follow up a slow, few day, 0.1 mag deep transits of a planet like Saturn, with rings passing in front of a star. However, such a transit is currently difficult to differentiate from an eclipsing binary. However, a deep (greater than a magnitude) and long (few day) dimming event is unlikely to be confused with an eclipsing binary. Such an event would be very interesting to follow up in real time, both with accurate photometry, and with spectroscopy.

How many stars must be monitored to find a dimming events? Current estimates of the number of periodic systems that are due to obscuration by disks is 1/1000 in an early type eclipsing binary sample[7]. Of field stars, 1/4000 displays a dimming event of an unidentified object, but excepting in young stellar objects these are of short duration and many are likely to be eclipsing binaries[8]. A survey that has already identified eclipsing binaries in the field could pull out new objects in a dimming search. The least obscured young stellar objects, that display deep dimming events, sometimes called "dippers"[8] would be an interesting set to study in real time during an dimming event. Perhaps 10% of class III young stellar objects display this type of event[10]. Of the few million bright stars in the KELT survey over 6 years, a couple have displayed long and deep dimming events[11]. Existing archives of light curves[12] can be used to improve upon some of these estimates, and search for new objects. But no archival search would replace the opportunities provided by real-time triggering of a deep dimming event.

We have focused here on dimming caused by obscuration by gaseous, dusty or icy material, however there are alternative causes such as implosions, "collapsars" or "un-novae"[13]. What would real time identification allow? A better search for residual emission soon after collapse or identification of a source of gamma rays or neutrinos perhaps. Occultations by nearby objects, such as planetesimals in the Kuiper belt can occult a star giving interference fringes but these last only a few seconds[14].

How difficult is it to identify interesting dimming events? It has been non-trivial to ensure that spurious dimming is not due to seeing variations, source confusion, weather and other instrumental or observational problems. Differential photometry is probably needed to make sure that weather does not cause false photometric drop-outs and that photometric errors are correct even if an objected is detected in bad conditions. Variable stars with large brightness variations must be previously identified so that ordinary and continuous variations are not flagged. It is possible to eliminate most eclipsing binaries by requiring a slow, long and deep dimming or a red dimming, however it would require effort to adjust search parameters to only identify interesting events for follow-up.

References

[1] Hedman, M. M., Nicholson, P. D., Salo, H., Wallis, B. D., Buratti, B. J., Baines, K. H., Brown, R. H., & Clark, R. N. 2007, AJ, 133, 2624, *Self-Gravity Wake Structures in Saturn's A Ring Revealed by Cassini VIMS*

[2] Sicardy B., Roques F., and Brahic A. 1991, Icarus, 89, 22024, *Neptunes rings, 19831989 ground-based stellar occultation observations*

[3] Mamajek, E. E., Quillen, A. C., Pecaut, M. J., Moolekamp, F., Scott, E. L., Kenworthy, M. A., Collier Cameron, A., & Parley, N. R. 2012, AJ, 143, 72, *Planetary Construction Zones in Occultation: Discovery of an Extrasolar Ring System Transiting a Young Sun-like Star and Future Prospects for Detecting Eclipses by Circumsecondary and Circumplanetary Disks*

[4] Galan, C., Mikolajewski, M., Tomov, T., et al. 2012, A&A, 544, 53, *International observational campaigns of the last two eclipses in EE Cephei: 2003 and 2008/9*

[5] Rodriguez, J. E., Pepper, J., Stassun, K. G., Siverd, R. J., Cargile, P., Beatty, T. G., & Gaudi, B. S. 2013, AJ, 146, 112, *Occultation of the T Tauri Star RW Aurigae A by its Tidally Disrupted Disk*

[6] Dong, S., Katz, B., Prieto, J. L., Udalski, A., Kozlowski, S. Street, R. A. 2014, `http://arxiv.org/abs/1401.1195`, *OGLE-LMC-ECL-11893: The Discovery of a Long-Period Eclipsing Binary with a Circumstellar Disk*

[7] Meng, Z., Quillen, A. C., Bell, C. P. M., Mamajek, E. E., & Scott, E. L. 2014, submitted to MNRAS, `http://arxiv.org/abs/1401.1248`, *A search for eclipsing binaries that host discs*

[8] Quillen, A. C., Ciocca, M., Carlin, J. L., Bell, C. P. M., & Meng, Z. 2014, `http://arxiv.org/abs/1402.1198`, *Variability in the 2MASS Calibration Fields: A Search for Transient Obscuration Events*

[9] Herbst, W., Herbst, D. K., Grossman, E. J., & Weinstein, D. 1994, AJ, 108, 1906, *Catalogue of UBVRI photometry of T Tauri stars and analysis of the causes of their variability.*

[10] Cody, A. M. et al. 2014, ApJ in press, `http://arxiv.org/abs/1401.6582`, *CSI 2264: Simultaneous optical and infrared light curves of young disk-bearing stars in NGC 2264 with CoRoT and Spitzer– evidence for multiple origins of variability*

[11] Josh Pepper, private communication

[12] *Transit Survey Data in the Exoplanet Archive*, `http://exoplanetarchive.ipac.caltech.edu/docs/intro.html`

[13] Kochanek, C. S., Beacom, J. F., Kistler, M. D.; Prieto, J. L., Stanek, K. Z., Thompson, T. A., & Yuksel, H. 2008, ApJ, 684, 1336 *A Survey About Nothing: Monitoring a Million Supergiants for Failed Supernovae*

[14] Roques, F., Georgevits, G., & Doressoundiram, A. 2008, *The Kuiper Belt Explored by Serendipitous Stellar Occultations* in "The Solar System Beyond Neptune", Edited by M. A. Barucci, H. Boehnhardt, D. P. Cruikshank, A. Morbidelli, and Renee Dotson, University of Arizona Press, Tucson Arizona, page 545-556.