JEE2012 Observing Campaign Preliminary Results

Scott Degenhardt
International Occultation Timing Association (IOTA)
1103 Willow Way
Santa Fe, NM 87507
scotty@scottysmightymini.com

B. Gährken
Munich, Germany

B. Giacchini
REA, CEAMIG, IOTA

E. Iverson, A. Scheck, B. Timerson,
IOTA

M. Miller
AAVSO

J. Talbot
RASNZ Occultation Section

D. Trowbridge
Tinyblue Observatory, AAVSO

Abstract

Jovian Extinction Events (JEE) occur when an object experiences a loss of intensity as it passes behind dust or gas in the Jovian system. This loss of light or extinction can be caused by material gravitationally bound around one of Jupiter's four major moons, material trapped in the magnetosphere or torus ring that surrounds Jupiter near Io's orbit, or possibly material streaming in the flux tubes that connect the four major moons to Jupiter's poles. Discovered in 2009 and observed through 2010, anomalous dimming was detected from material surrounding the target moon (in front) prior to and after occulting another probing moon (in back) as it passed behind. These measurements were made near the equators of the target moon. During 2012 the orbit of Jupiter was tilted open at about 3 degrees inclination. JEE2012 geometries probed the area above the pole of the target moon and yielded new anomalous trends. Preliminary results indicate these trends demonstrate asymmetry in the material surrounding the target moons, and possibly show structure associated with the flux tube connecting the target moon to Jupiter. Photometric deviation patterns found in the Io Torus Tip JEE possibly confirm predicted zebra patterns or bunching of the torus material via magnetic flux lines. Various reduction methods using JPL Horizons ephemeris are shown and provide initial interpretations of our derived photometric lightcurves.

Introduction

Jovian Extinction Events (JEE) occur when an object experiences a loss of intensity as it passes behind dust or gas in the Jovian system. This loss of light or extinction can be caused by material gravitationally bound around one of Jupiter's four major moons, material trapped in the magnetosphere or torus ring that surrounds Jupiter near Io's orbit, or possibly material streaming in the flux tubes that connect the four major moons to Jupiter's poles. One can use an object passing behind a target of interest to probe the material around the object in front by measuring the change in light of the object behind as its light passes through the this material.

The extinction phenomenon was first detected in 2009 during the end of the Jupiter Mutual Event (JME) season when Jupiter's orbital plane was still edge on enough that the major moons were eclipsing and occulting each other (Degenhardt et. al, 2010). It was noted then that an anomalous photometric dimming began many minutes prior to Io occulting Europa or when Europa occulted Io, and an anomalous brightening was observed over many minutes post occultation.

IAEP2009 and JEE2010 Summary

After the initial discovery, extinction event predictions were made to watch for extinction anomalies in future events where Io was the target object in front. The initial effort was called the Io Atmospheric Extinction Project (IAEP). Through early 2010 over fifty data sets were acquired that showed consistent dimming when Io was in front of a probing object that passed behind Io. On average we detected extinction out to 8 Io radii near its equator and an unfiltered magnitude drop of about 0.18. However there were exceptions depending on Io's position relative to Jupiter. Asymmetrical dimming to 30 Io radii was also noted and may be linked to the extra material that is pushed along and ahead of Io in its orbit.

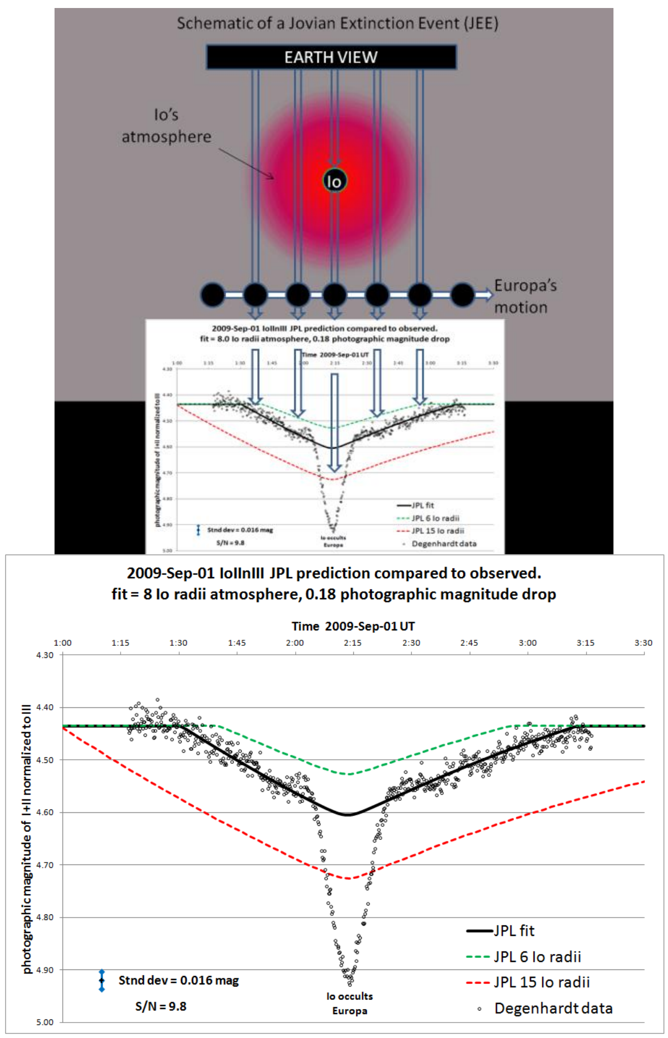

Figure 1 Note the gradual dimming starting an hour before and brightening that lasted an hour after the occultation. The dashed lines are a prediction envelope representing a simulated Io atmospheric extinction using JPL Horizons ephemeris, and the solid line is the fit using those ephemeris suggesting an 8 Io radii of extinctive material.

The material surrounding Io migrates away and is captured for a period of time in Io's Torus ring. S. Degenhardt theorized when Io passes through the tips of the torus where the extinctive material is collimated to our line of sight that Io should experience a self extinction of its reflected light (Figure 2). November 1st, 2010 J. Talbot collected five hours of photometric data and validated that when Io's orbit was 0.4 degrees inclined Io experienced almost 0.13 unfiltered magnitude dimming during its transit through the western torus tip (Figure 3).

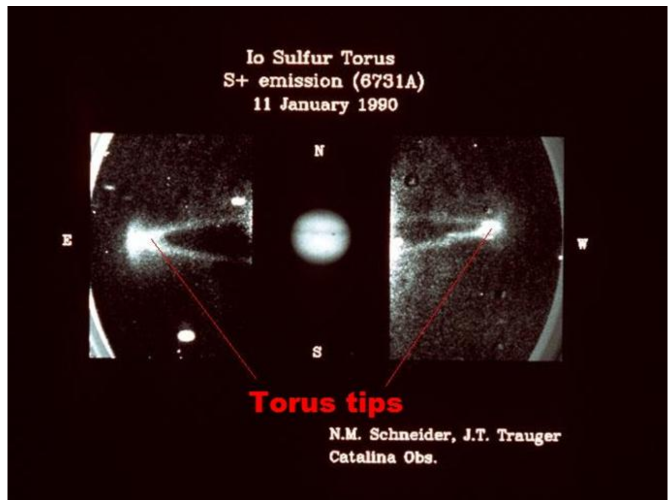

Figure 2 Schneider, et al. 1990 image of the Torus of Io.

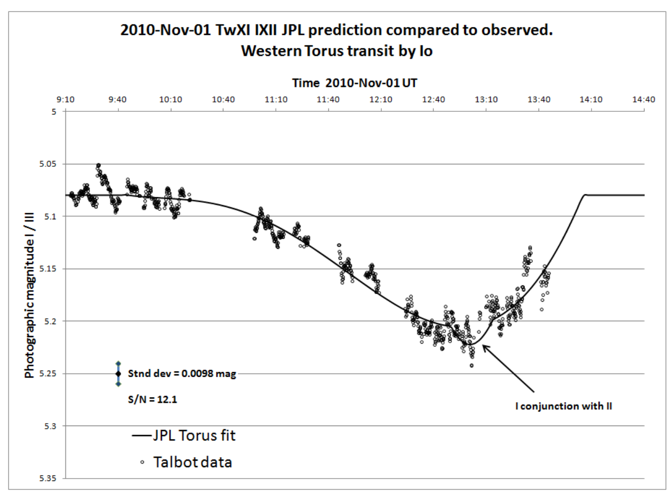

Figure 3 J. Talbot's lightcurve demonstrating self dimming of Io by its own debris as it transits the western tip of the Torus.

Once Io's material leaves the Torus of Io some of it is swept up and captured temporarily by Europa (Brown et. al, 1996). It was estimated by Brown et. al that Europa's tenuous atmosphere extends to 25 Europa radii. During IAEP2009 we noted as well an even longer dimming and deeper extinction when Europa was the target object in front compared to Io in front. Of the several Europa JEE data we detected extinctive material out to almost 20 Europa radii and extinction of about 0.18 to 0.25 unfiltered magnitude drop (Figure 4).

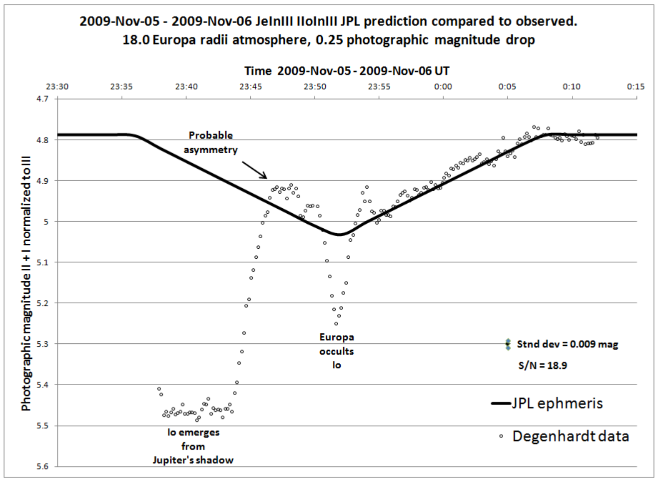

Figure 4 One of several JEE lightcurves from IAEP2009 detecting extinctive material surrounding Europa.

JEE2012 Summary

The orbital plane of Jupiter's moons were open to over 3 degrees during 2012 and it was initially assumed that there were no extinction events to observe due to the likelihood that no moon would pass close enough to suffer extinction behind another moon's theoretical debris radius. A more open orbit of the debris in the Torus of Io would contribute to less column depth at the tips of the Torus. However, when geometrical calculations were performed it was found that assumption was incorrect and there were several close conjunctions between Io and Europa with Europa being the target object in front and Io being the probing light source in back. Predictions were posted and a call for observers and AAVSO Alert Notice 464 went out for JEE events occurring between June through August of 2012. Initial observations turned up new anomalous trends indicating continual observations of the Jovian systems were prudent.

Predictions were then posted through the end of 2014 for all conjunctions and near eclipses of the four major moons, all Io Torus Tip transits, as well as any moon in conjunction behind the poles of Jupiter.

2009 JEE events were detected around JME occultations where the body of the target moon in front passed directly in front of the probing moon in back. In 2012 there were no JME occultations involved. Instead conjunctions occurred where the target moon passed in front of the probing moon from our line of sight and the probing moon was separated by 10 to 30 arc seconds. Thus the moon in back was probing regions above or below the poles of the target moon. New repeatable anomalous photometric trends occurred in these outer regions. Predictions of dimming were initially based on a first order assumption of a spherical distribution of material around a target using trends observed in 2009 at the equators. In some alignments we expected to see gradual dimming in the outer regions based on this spherical distribution model, but instead in some cases no dimming extinction would occur. In other observations instead of faint dimming we found repeatable sharp magnitude dips exceeding anything expected symmetrically surrounding the target moon.

Figure 5 shows one of several events displaying such sharp dips surrounding the target moon Europa. Io passed behind the target at about 14 Europa radii line of sight above Europa's northern pole, and the minima of these dips occurred at approximately 7.5 Europa radii east and west of the target. Such sharp features seem indicative of a boundary layer of some sort. It is understood that flux tubes emerge from a pole of Jupiter, goes through all four major moons, and reconnects back to the opposite pole of Jupiter (Figure 6). A high rate of electrical current flows through these flux tubes (Lang, 2010). One working theory is that these charged particles may carry ionized dust and gas from Europa's atmosphere with it and the sharp photometric dips in lightcurves such as Figure 5 represent the walls of this flux tube that are detectable through extinction by this material flowing inside that flux tube. Much more data needs to be collected to validate this theory. With enough data one might eventually be able to trace out the flux tube all the way back to Jupiter.

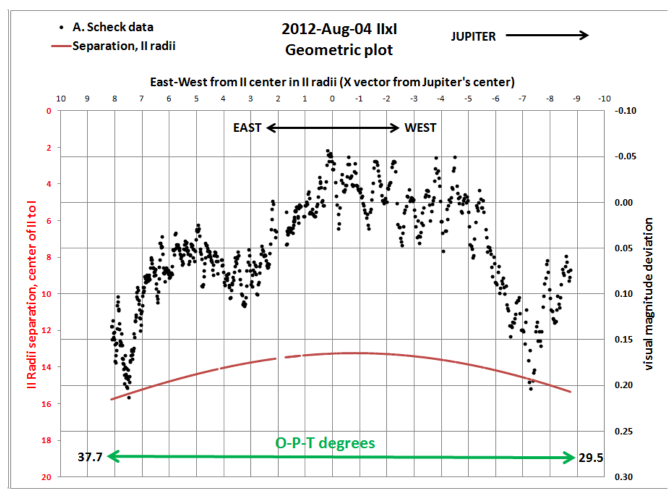

Figure 5 This geo-photometric plot of lightcurve data relative to the position of the moon Io behind Europa and shows a symmetrical sharp dip at about plus and minus 7.5 Europa radii.

Another unexpected find in lightcurve trends of JEE2012 was fast periodic variations in Io's intensity as it began its transit at the western torus tip. Notice in Figure 7 that after about 9:30 UT the intensity of the probing moon Io enters a periodic variation. It becomes especially noticeable after 10:30 UT. Research into the source of this periodic variation found a possible explanation called zebra patterns suspected in the Torus of Io (Kuznetsov, et. al 2012). The theory presented in Kuznetsov's work is that when the Cassini space probe was flying past Jupiter it detected fluctuating radio emissions that were likely caused by electron accelerations in the magnetic flux lines bunched up in the torus. It remains possible that these magnetic flux lines also bunch up the material in the torus in a zebra pattern such that Io passes behind a clump of debris followed by a void, followed by another clump, thus causing the photometric lightcurve to contain the detected periodic ups and downs noted in Figure 7.

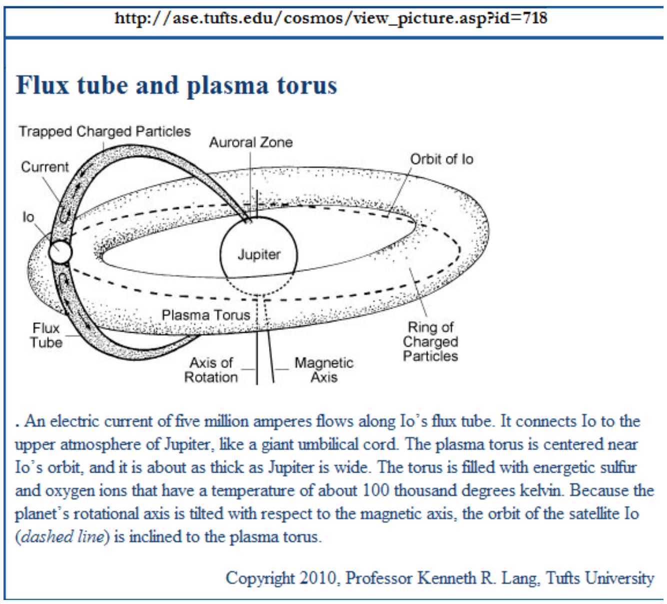

Figure 6 The schematic of the Torus of Io and Io's flux tube. All four major Jovian moons have a similar flux tube.

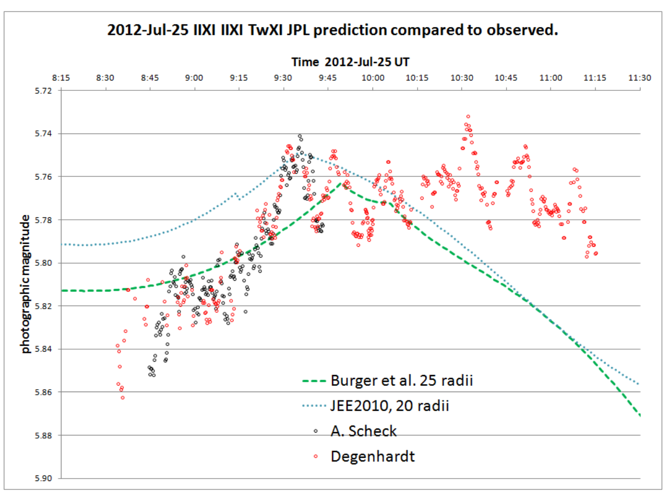

Figure 7 A complex JEE lightcurve involving first Io passing behind Europa, followed by Io entering its western Torus tip. Note the periodic up and down intensity possibly associated with a zebra pattern caused by magnetic flux lines bunching up torus material.

JPL Horizons ephemeris

Free access to the JPL Horizons ephemeris brought about both an analysis as well as a predictions revolution for the JEE Project in 2012. The JPL Horizons data is the same ephemeris used to guide NASA's spacecraft and is likely the most accurate ephemeris available for calculating the exact location of objects in the Jovian system at any given moment in time. A number of reduction and prediction macros were developed by Degenhardt which allowed the JEE data to be compared to professional data, thus providing potential validation to previously theorized geometries of structures depicted in the lightcurves.

The example in Figure 1 shows one reduction method using the JPL ephemeris to predict how a lightcurve would actually be affected if a given atmospheric radius is simulated to produced a given extinction rate. Schneider, et. al 1991 published initial results that a sodium atmosphere surrounding Io might extend to 6 Io radii. The dashed lines in Figure 1 represent an envelope that data would fall in if an extinctive atmosphere between 6 to 15 Io radii existed. We see that the photometric data of this event falls inside this theoretical envelope and additionally the JPL data shows an 8 Io radii fit. Other JEE lightcurves have been modeled with the JPL Horizons ephemeris and derived consistent results.

The Io Torus Tip can also be modeled with JPL Horizons ephemeris. Figure 10 shows how we can plot any photometric data relative to how many minutes before and after Io was positioned to its exact western elongation. This allows us to combine data from different observing nights. In Figure 10 two different observing runs from 2012 are plotted and then fitted with the green dashed line. The black dashed line represents the fit from western Torus Tip events modeled in 2010 when the Torus was tipped 0.4 degrees. The two different dashed fits highlight the deeper extinction from 2010 compared to 2012 when the Torus was tipped 3.1 degrees. Note that maximum extinction occurred a little over 20 minutes after western elongation, which is to be expected as Io travels deeper into the collimated material before emerging from the back side of the column of torus dust and gas.

In addition to new graphical plotting methods, one can invert the lightcurve data by taking the JPL Horizons ephemeris and overlay the photometric data that has been scaled to a 0 to 255 ADU intensity to form an image representing this data set. Figure 8 is the result of taking the lightcurve of Figure 3 and inverting it by scaling photometric intensity variation to a pixel intensity value, and using ephemeris to place the intensity at an X-Y pixel position.

An effort is underway to reprocess all JEE lightcurve data using the JPL Horizons ephemeris.

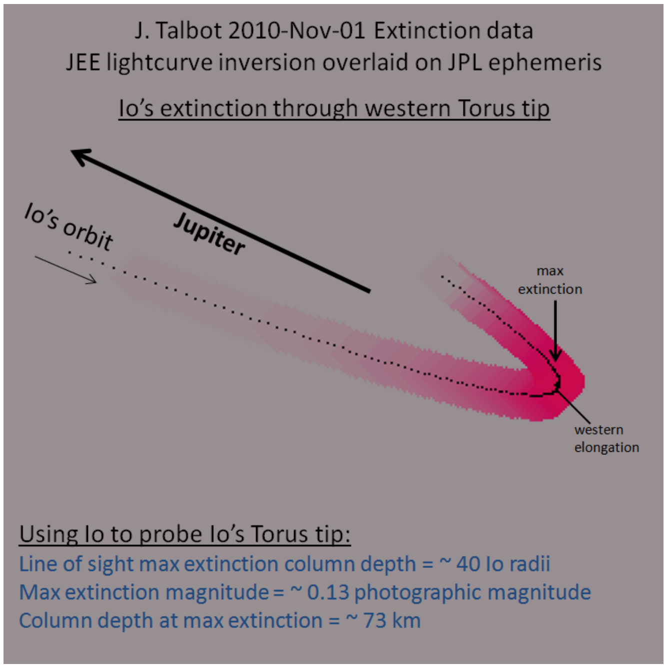

Figure 8 Taking the photometric lightcurve data and scaling it to a BMP intensity of 0 to 255 ADU, and then plotting it against geometric positions of Io relative to Jupiter one can invert an Io Torus Tip transit JEE and derive valuable data.

Discussion

Most data acquisitions to date were done with streaming video. In the USA the NTSC video rate is 30 frames per second, and overseas PAL is 25 frames per second. The target front moon, the probing back moon, and preferably one other moon used for reference photometry are kept in the field of view at all times. We photometrically reduce the video with a software tool commonly used in IOTA called LiMovie. A measurement aperture is placed over each moon and a background aperture is configured as well so that a photometric intensity of each object is corrected for the underlying background noise. By carefully configuring the shape and position of the measurement apertures one can minimize noise from the signal. By placing the background aperture on either side of the object being measured at an angle tangent to Jupiter one can completely cancel out Jupiter's glare effects on the background (Figure 9).

LiMovie tracks each object for every frame in the video and gives you a CSV file of a number of parameters including photometric intensities corrected for background. This column of ADU intensities represents on data point for each video frame, so there are 30 ADU measurements per second for NTSC video and 25 data points per second for PAL. Ten seconds of video data is then binned to a single data point in an effort to eliminate effects of earth atmospheric scintillation, camera noise, and other random noise. Since AVI intensities are scaled from 0 to 255 and we are binning 300 frames for NTSC our effective intensity resolution is 256 times 300, or 76,500 (2x10^{16} bits). This significantly reduces the noise inherent in video and enables us to commonly resolve photometrically to 0.015 magnitude.

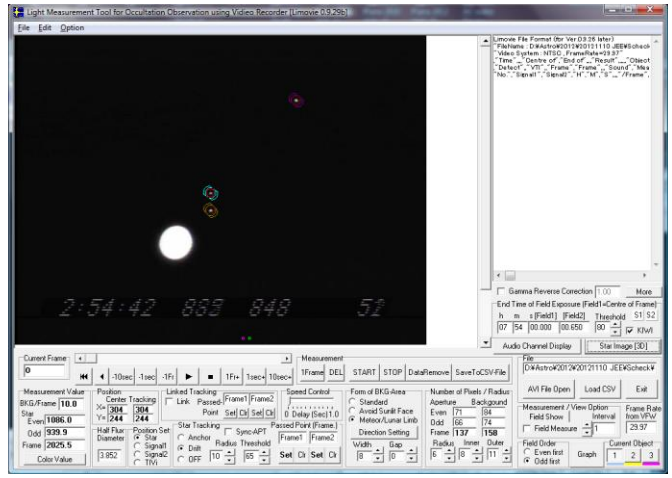

Figure 9 A screen shot of LiMovie and the configuration of the measurement and background apertures.

For the first time we are receiving photometric data in multicolor. Members of AAVSO have submitted large amounts of data in red, green, and blue wavelengths. As of the writing of this paper this data is still being processed in a way to be combined with our unfiltered data. One lesson learned from the multicolor data sets is the cadence rate of image sequencing has to be sufficiently fast. Video offers superior coverage of long term photometric events because it provides an image stream of 30 images per second for NTSC and 25 images a second for PAL, and one can continually image for as long as your method of recording the video stream has capacity. Typical color data comes from still CCD imaging cameras. This may mean your image rate can be sporadic. Given that some of the trends like the potential flux tube walls can occur in a matter of a few minutes one might completely miss a minima with standard CCD imaging rate. However it was found that most CCD cameras offer a pseudo video mode where the camera can continuously acquire and download images. Some of the JEE2012 AAVSO participants were able to convert their observing to this streaming image mode increasing their chances of capturing fast transient photometric events while also observing over long periods of time. There are still lessons to be gained in imaging methodology as we go into 2013 and beyond.

Color data is valuable in potentially helping us determine what wavelengths are suffering the most extinction and could help identify the materials involved in the extinction process. Spectrometry of a JEE event will be most valuable in identifying absorptive material but has not yet been achieved and techniques are still under development.

IAEP2009 and JEE2010 derived first order atmospheric models of dust and gas surrounding Io to nominally 8 Io radii and Europa to about 20 Europa radii. Predictions for

JEE2012 were made using these numbers and assuming a first order assumption of spherical distribution around each moon. Initial lightcurves did not confirm this spherical distribution. This may indicate the material surrounding Io and Europa is more squashed at the poles. It may also be that the currents from the flux tubes disturb the material at the poles of each major moon of Jupiter. The symmetry of the atmospheres can be resolved with more data throughout 2013 and 2014 as Jupiter's orbital plane closes allowing us to trace out the extinction gradually closer to a target body as Jupiter's orbit closes to edge on. Given the implications of nonsymmetrical distribution of Jovian dust and gas predictions for JEE2013 and JEE2014 were simply based on any conjunction or near eclipse where a probing object passes behind a target moon within 30 radii of the front target moon.

The source of the sharp drops in the JEE2012 photometry still needs to be resolved. While the flux tubes provide one possible explanation, the mechanism by which a flux tube could cause detectable extinction is elusive.

Early on in JEE2012 it was thought that since the Torus of Io was open by more than 3 degrees the collimated material at the tips may not have a column depth thick enough to cause measurable extinction to Io. However several tip transits were recorded and indeed showed a detectable extinction. Figure 10 demonstrates that when the torus was 3.1 degrees inclined a fainter extinction was detected compared to when the torus was 0.4 degrees inclined, the difference being a smaller column depth line of sight compared to when the orbit is open.

Io Torus Tip transits occur once a day. Periodic photometric variations in the torus material need additional mapping for confirmation of the zebra pattern hypothesis.

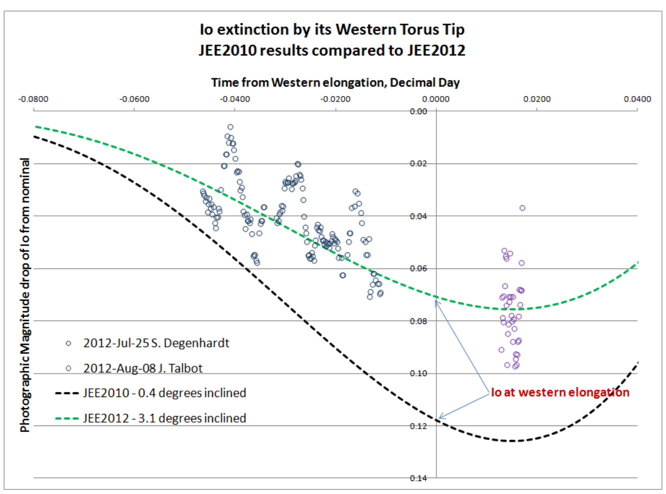

Figure 10 Using JPL Horizons ephemeris one can plot JEE photometric intensity data relative to western elongation of Io to achieve this plot. We also see as expected the extinction amount was less when Io's orbit was at 3.1 degrees compared to 0.4 degrees inclination due to less column depth of collimated material to our line of sight.

In 2012 a Yahoo Discussion Group "JEE_Talk" was started in an effort to further organize JEE Observing Campaigns. The end goal of JEE Observing Campaigns is to receive enough extinction lightcurve data of the Jovian System over varied geometrical view angles to be able to create a 3-D map of the dust and gas in the Jovian System. Currently observers have submitted data from six different countries providing continual coverage of Jupiter at times. With enough coverage our goal can be accomplished. Additionally the NASA Juno Space Probe has also expressed interested in collaborating with the JEE Community, as Juno is scheduled for insertion in the Jovian System in August of 2016.

For the latest in JEE information including predictions and results visit http://scottysmightymini.com/JEE/.

References

- AAVSO Alert Notice 464: Observers requested for Jovian Extinction Events (JEE2012), http://www.aavso.org/aavso-alert-notice-464
- Arlot, J.-E., Thuillot, W.,Ruatti, C. and 116 coauthors observers of events: 2009, The PHEMU03 catalogue of observations of the mutual phenomena of the Galilean satellites of Jupiter, Astronomy and Astrophysics, Volume 493, Issue 3, pp.1171-1182
- Michael E. Brown* & Richard E. Hill Discovery of an extended sodium atmosphere around Europa *Nature* ***380, 229 - 231 (21 March 1996); doi:10.1038/380229a0*** http://www.nature.com/nature/journal/v380/n6571/abs/380229a0.html
- Burger, M.H. et al. "Mutual Event Observations of Io's Sodium Corona" (2001) http://www.iop.org/EJ/article/0004-37X/563/2/1063/52792.text.html
- Europa's neutral cloud: morphology and comparisons to Io Matthew H. Burger & Robert E. Johnson Icarus 171 (2004) 557–560, http://www.igpp.ucla.edu/public/mkivelso/refs/PUBLICATIONS/burger%20neutral%20cldEuropa04.pdf
- Degenhardt, S. et. al (2010), *Io and Europa Atmosphere Detection through Jovian Mutual Events*, **The Society for Astronomical Science: Proceedings for the 29th Annual Symposium on Telescope Science**, p. 91-100
- Degenhardt, S.M., "JEE2012 Call for Observers" (2012) http://scottysmightymini.com/JEE/
- Degenhardt, S.M., "JEE2013 Call for Observers" (2012) http://scottysmightymini.com/JEE/
- Degenhardt, S.M. (2012), Yahoo Discussion Group JEE_Talk, JEE_Talk-subscribe@yahoogroups.com
- Degenhardt, S. M., Jovian Extinction Event Predictions and Reduction Methods, Author and

developer: scotty@scottysmightymini.com. Observations and data from *S. Aguirre, S. Degenhardt, M. Hoskinson, A. Scheck, B. Timerson , D. Clark , T. Redding, J. Talbot , JPL Horizons On-Line*

- Degenhardt, S.M., “Io atmospheric extinction predictions for 2009 Jovian Mutual Events” (2009) http://scottysmightymini.com/mutuals/Io_atm_extinct_predict2009_2010.htm
- Degenhardt, S.M., “Jovian Extinction Event (JEE) predictions for 2010” (2010) http://scottysmightymini.com/JEE/
- Kuznetsov, A.A. et. al, “Formation of zebra pattern in low-frequency Jovian radio emission” (2012), arXiv:1209.2923v1 [astro-ph.EP], Planetary & Space Science
- Lang, K.R., flux tube diagram, (2010) http://ase.tufts.edu/cosmos/view_picture.asp?id=718
- LiMovie 20030503 http://www005.upp.so-net.ne.jp/k_miyash/occ02/io_ganymede.html
- Miyashita, K., LiMovie, (2008) software to photometrically reduce AVIs. http://www005.upp.so-net.ne.jp/k_miyash/occ02/limovie_en.html
- NASA, Juno Space Probe Mission, http://www.nasa.gov/mission_pages/juno/main/index.html
- NSDC (Natural Satellites Data Center) database web address: http://www.imcce.fr/hosted_sites/saimirror/obsindhe.htm
- Schneider, N. M. et al., “The structure of Io's corona” (1991), ApJ, 368, 298
- Solar System Dynamics Group, Horizons On-Line Ephemeris System, Author : Jon.Giorgini@jpl.nasa.gov, http://ssd.jpl.nasa.gov/horizons.cgi
- Warner, B., “Lightcurve Photometry and Analysis”, (2006), Springer Science+Media, Inc.