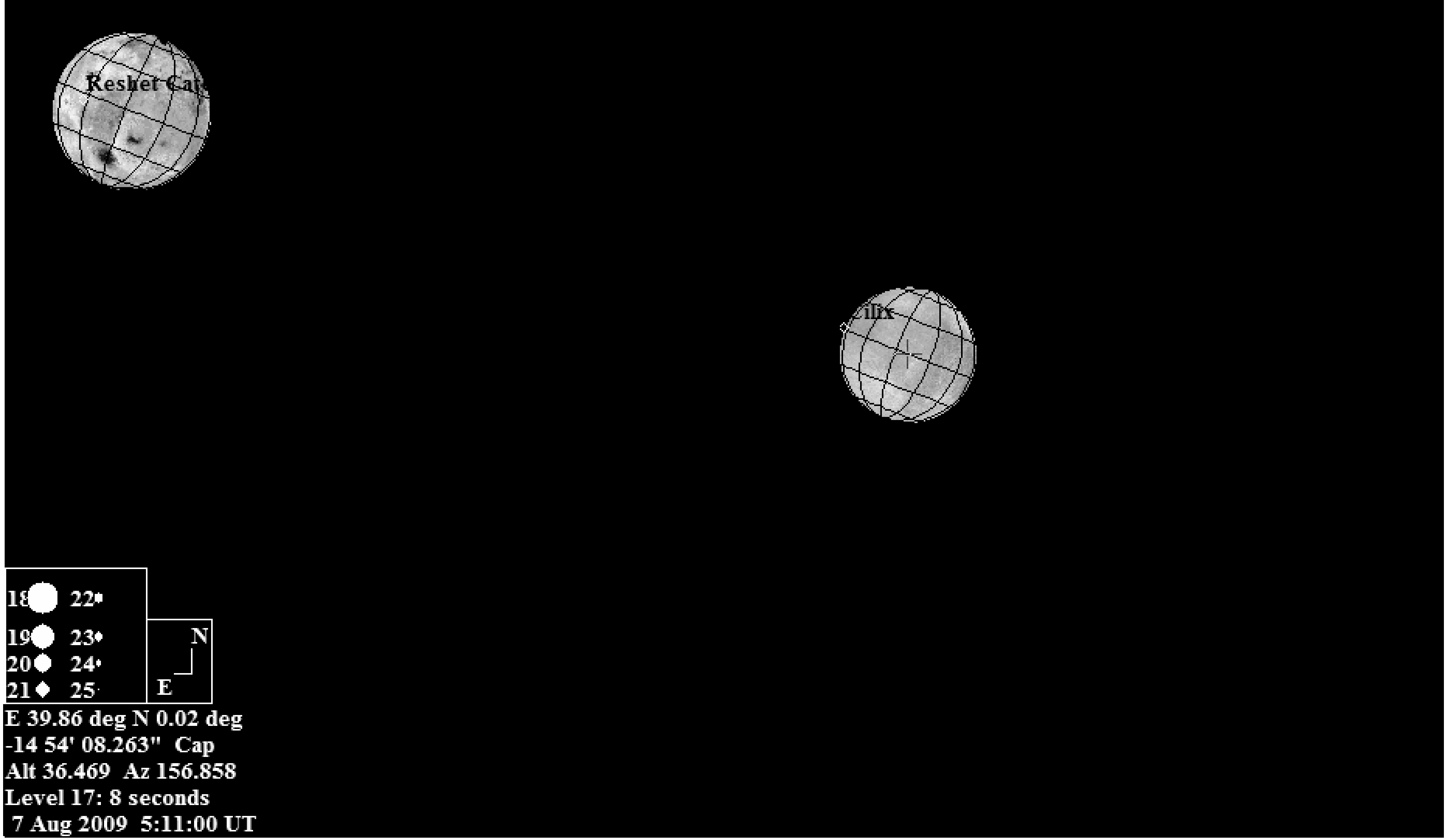
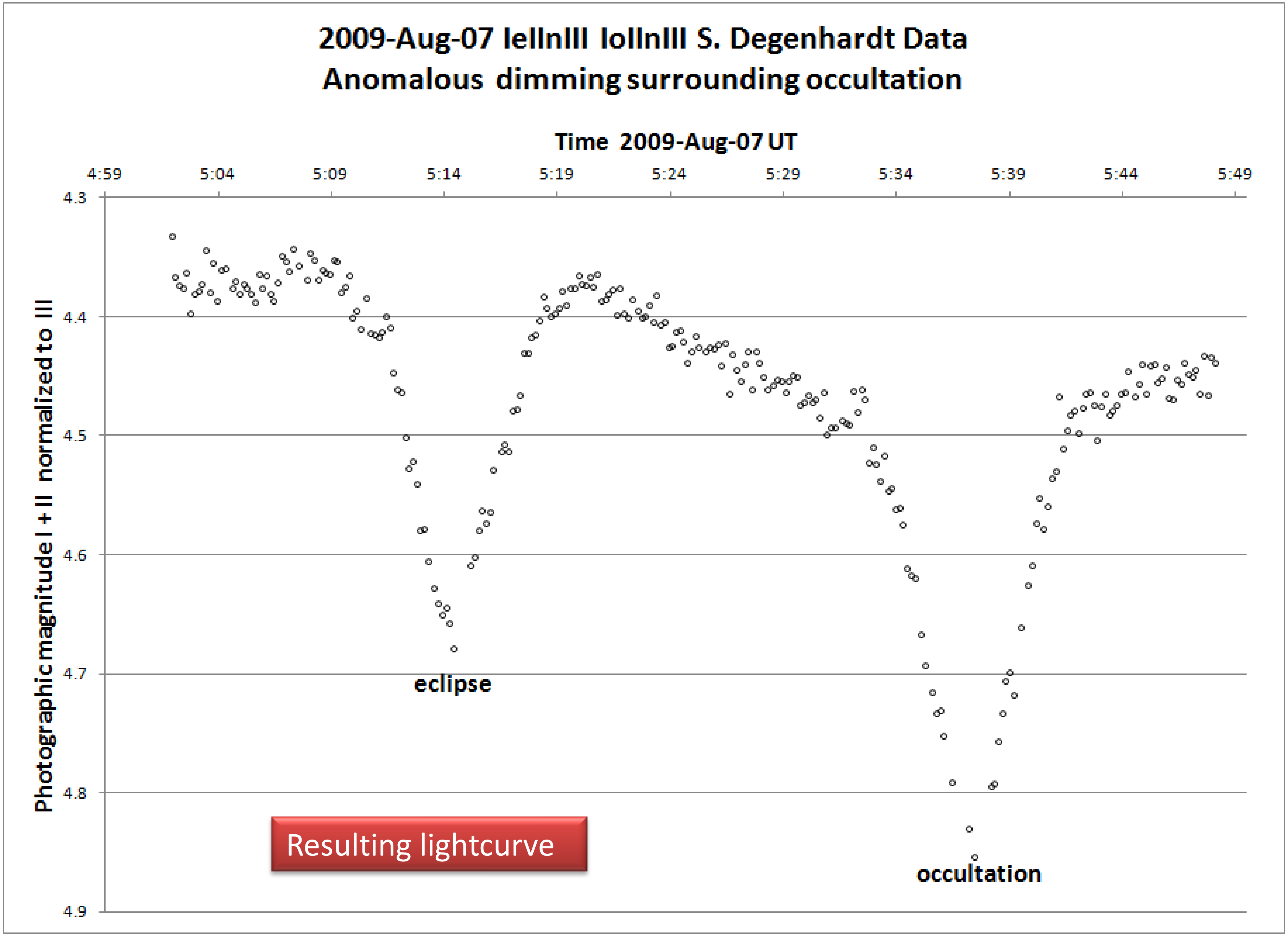
Jovian Extinction Events
JEE2012 Observing Campaign Preliminary Results

Modeling the Jovian dust field, moon atmospheres, flux tubes and Io's Torus

IOTA Annual Meeting, Oct 19-21, 2012 Las Vegas, NV

Guide 8 animation sequence of the initial discovery event of Aug 7, 2009




2009-Aug-07 IeIInIII IoIInIII S. Degenhardt Data
Anomalous dimming surrounding occultation
Time 2009-Aug-07 UT
4:59
5:04
5:09
5:14
5:19
5:24
5:29
5:34
5:39
5:44
5:49
Photographic magnitude I + II normalized to III
4.3
4.4
4.5
4.6
4.7
4.8
4.9
eclipse
occultation
Resulting lightcurve

Io and Europa Atmosphere Detection through Jovian Mutual Events

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IOTA, Redding Observatory South

J. Talbot
RASNZ Occultation Section

IAEP Call for observers results published in 2010

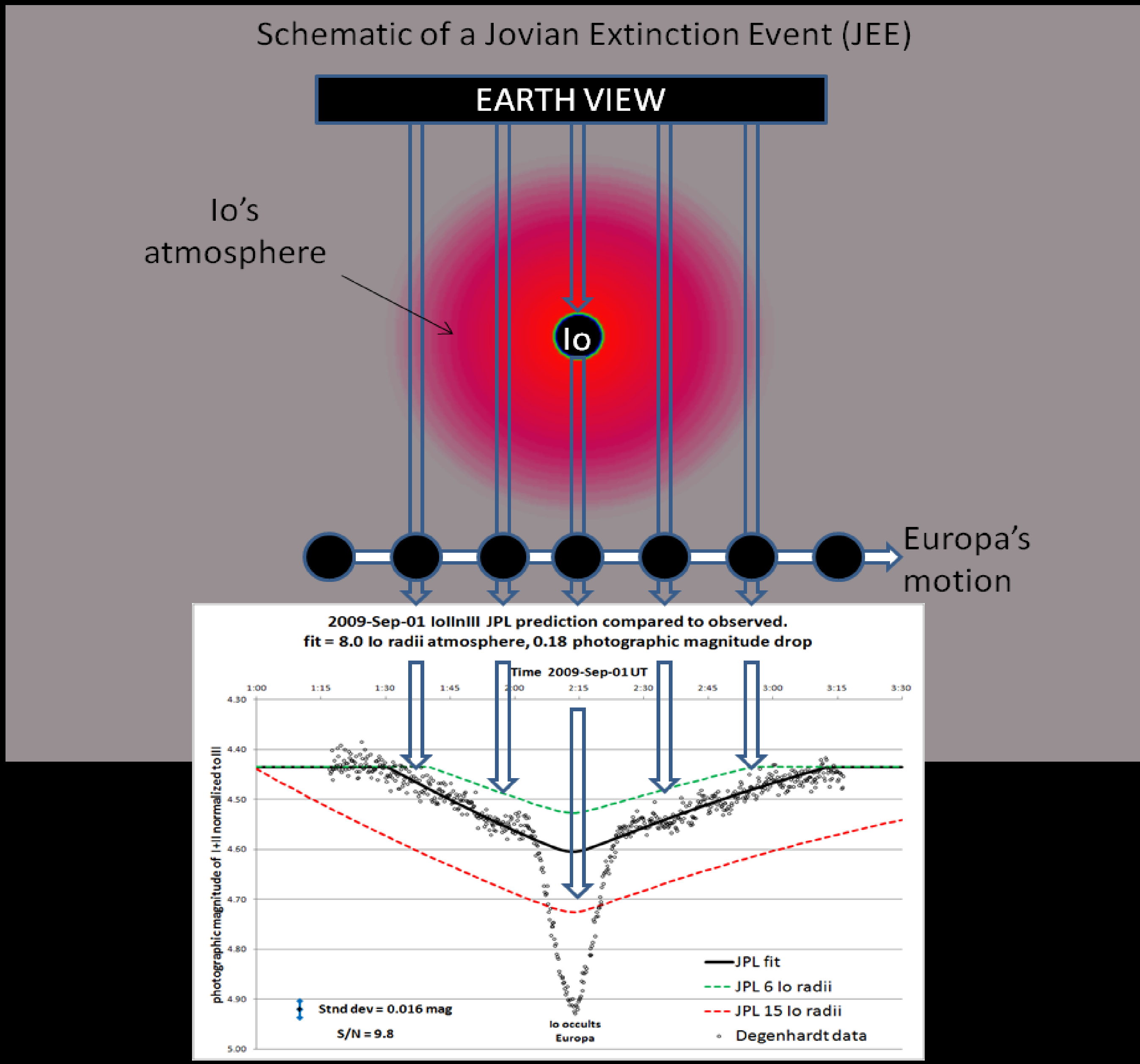
Degenhardt, S. et. al (2010), *Io and Europa Atmosphere Detection through Jovian Mutual Events,*
The Society for Astronomical Science: Proceedings for the 29th Annual Symposium on Telescope Science, p. 91-100

Abstract

Approximately every 6 years the orbital plane of the Jovian moons turns edge on from earth's line of sight giving us the opportunity to time the eclipses and occultations arising from this geometry known as Jupiter Mutual Events (JME). These timings help to refine the residuals in the orbital elements of Jovian moons.

While taking several tens of minutes of wing data surrounding an occultation by Io in 2009 during that JME cycle, an anomaly was detected in the lightcurve prior to and following the actual occultation. Analysis of this anomaly led to the hypothesis that it was the result of atmospheric extinction of the light from the occulted moon by the atmosphere of Io. The same anomaly was then found when Europa was the occulting body. Occultations by Ganymede showed no dimming anomaly.

Eleven observers from 4 countries contributed 53 data sets for 28 individual events in an observing program for the study of this phenomenon. This paper will detail the results including camera response, observing method, reduction method, and atmospheric extinction detection. The atmospheric extinction hypothesis is supported by several independent methods which will also be detailed. Derived atmospheric models will be presented including a noted asymmetry.

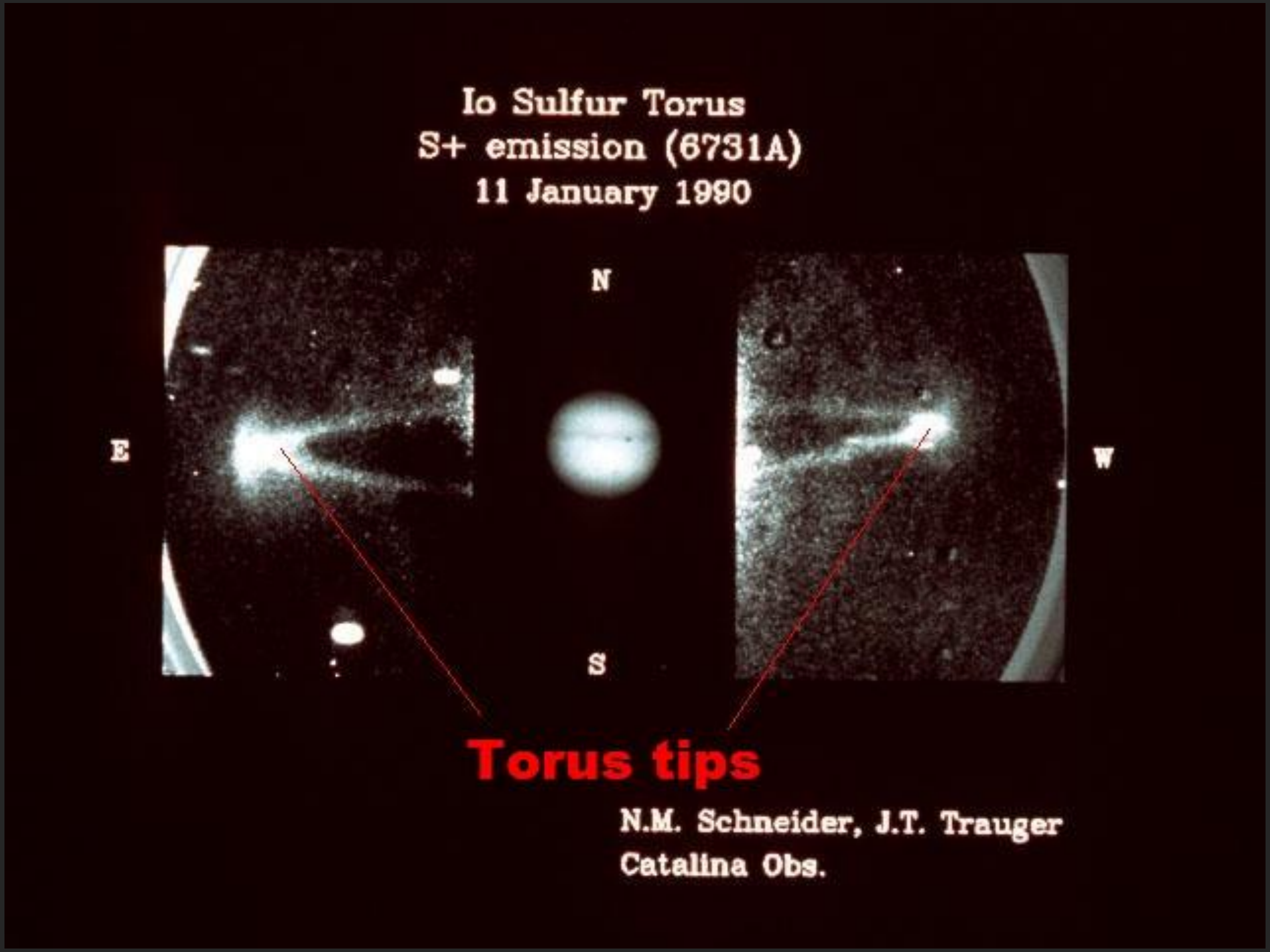


Schematic of a Jovian Extinction Event (JEE)
EARTH VIEW
Io's atmosphere
Io
Europa's motion
2009-Sep-01 IoIInIII JPL prediction compared to observed.
fit = 8.0 Io radii atmosphere, 0.18 photographic magnitude drop
Time 2009-Sep-01 UT
1:00
1:15
1:30
1:45
2:00
2:15
2:30
2:45
3:00
3:15
3:30
4.30
4.40
4.50
4.60
4.70
4.80
4.90
5.00
photographic magnitude of I+II normalized to III
Stnd dev = 0.016 mag
S/N = 9.8
Io occults Europa
JPL fit
JPL 6 Io radii
JPL 15 Io radii
Degenhardt data

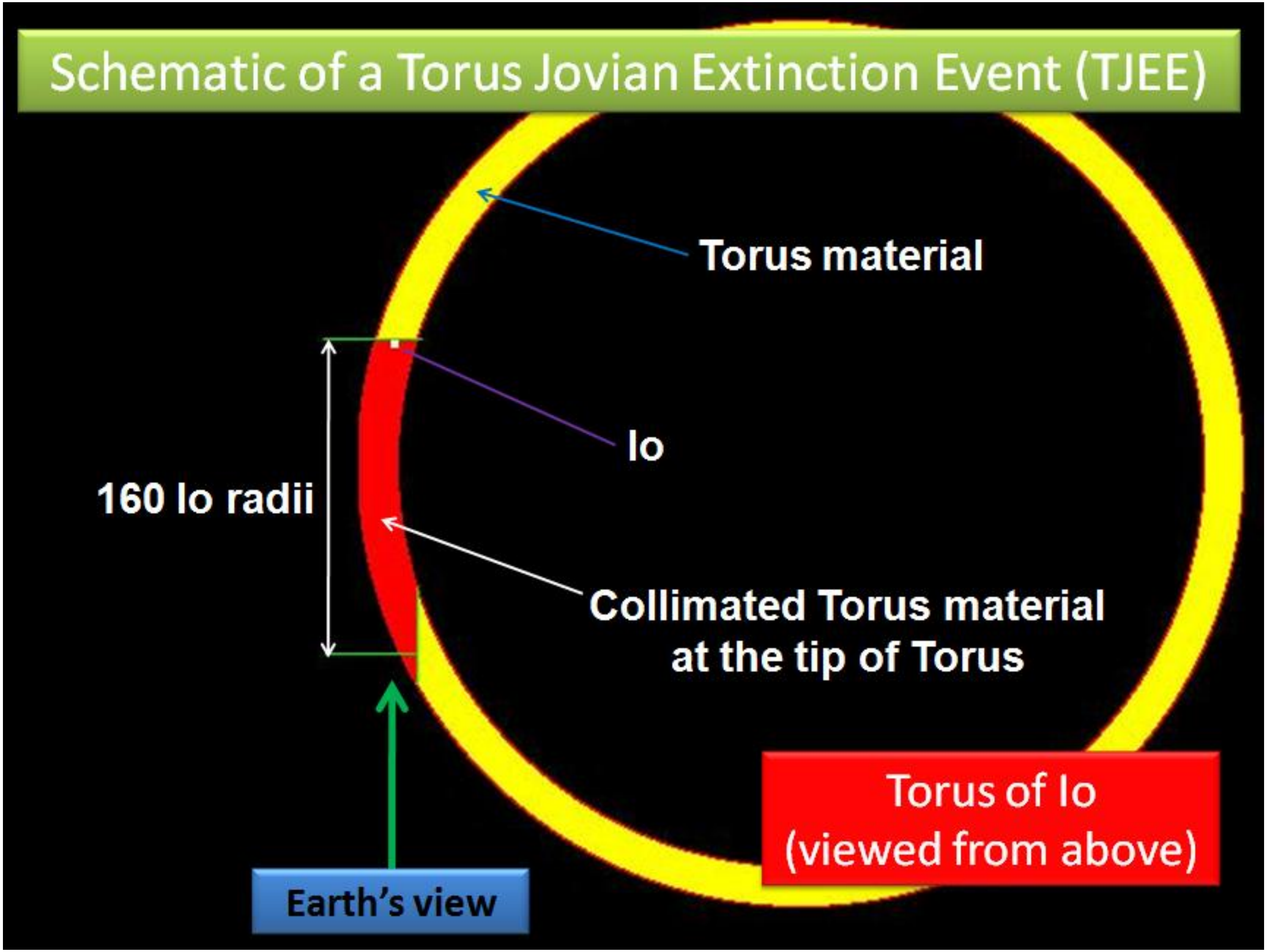
Accomplished in IAEP2009

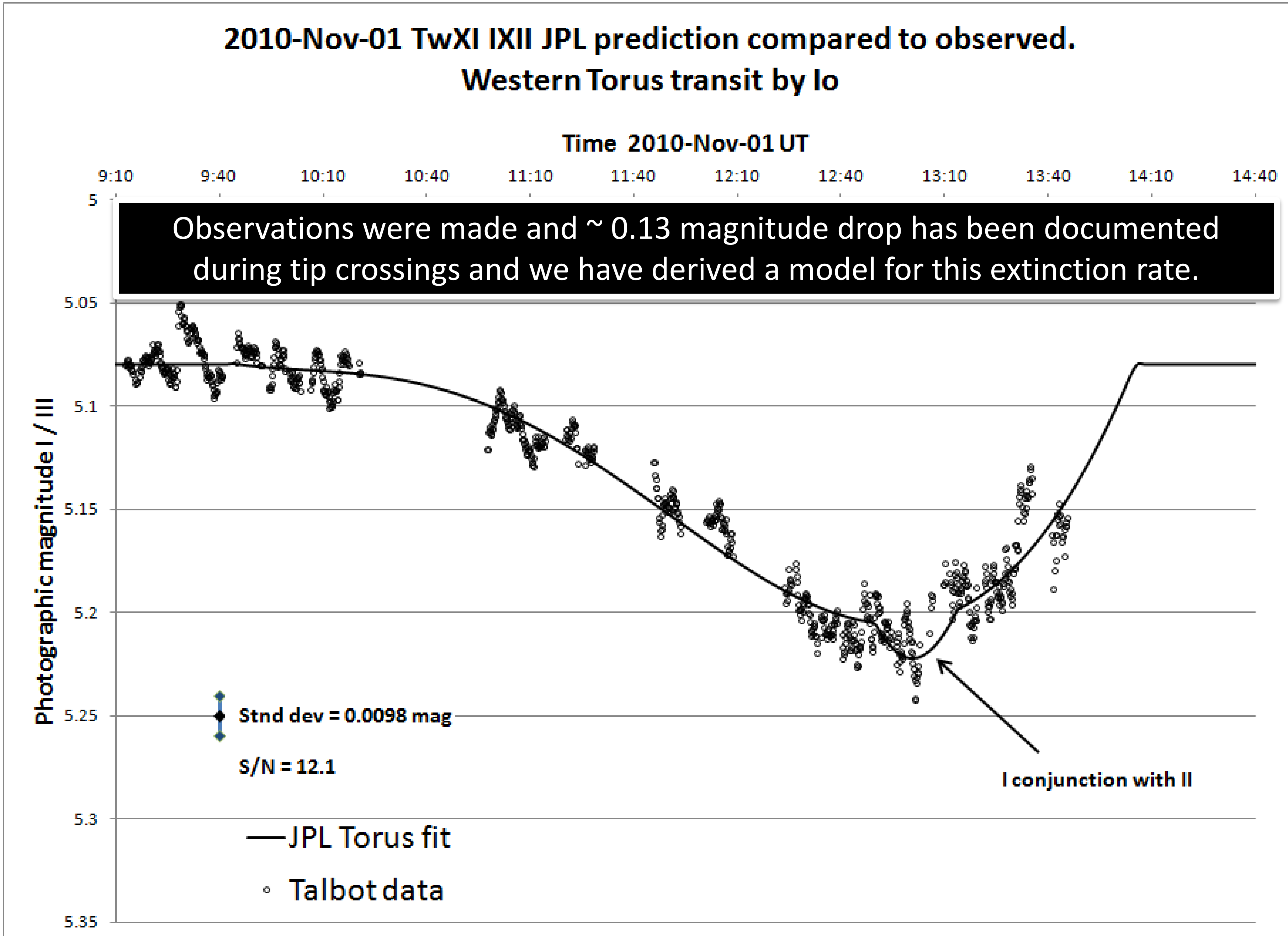
- We find for Io that ~ 8 Io radii extinction detection with an 0.18 magnitude drop common.
- We have very few Europa JEE data (because our initial focus was on Io events), but we see ~ 20 Europa radii extinction with an 0.18 to 0.25 magnitude drop so far.
- We do also note asymmetrical events with Io and Europa and uneven lightcurves suggesting clumps of material.

JEE2010



After finding repeated atmospheric extinction JEEs, PI Degenhardt theorized that the Torus material of Io should cause Io to self extinct at the tips of the Torus where the material is line of sight collimated.

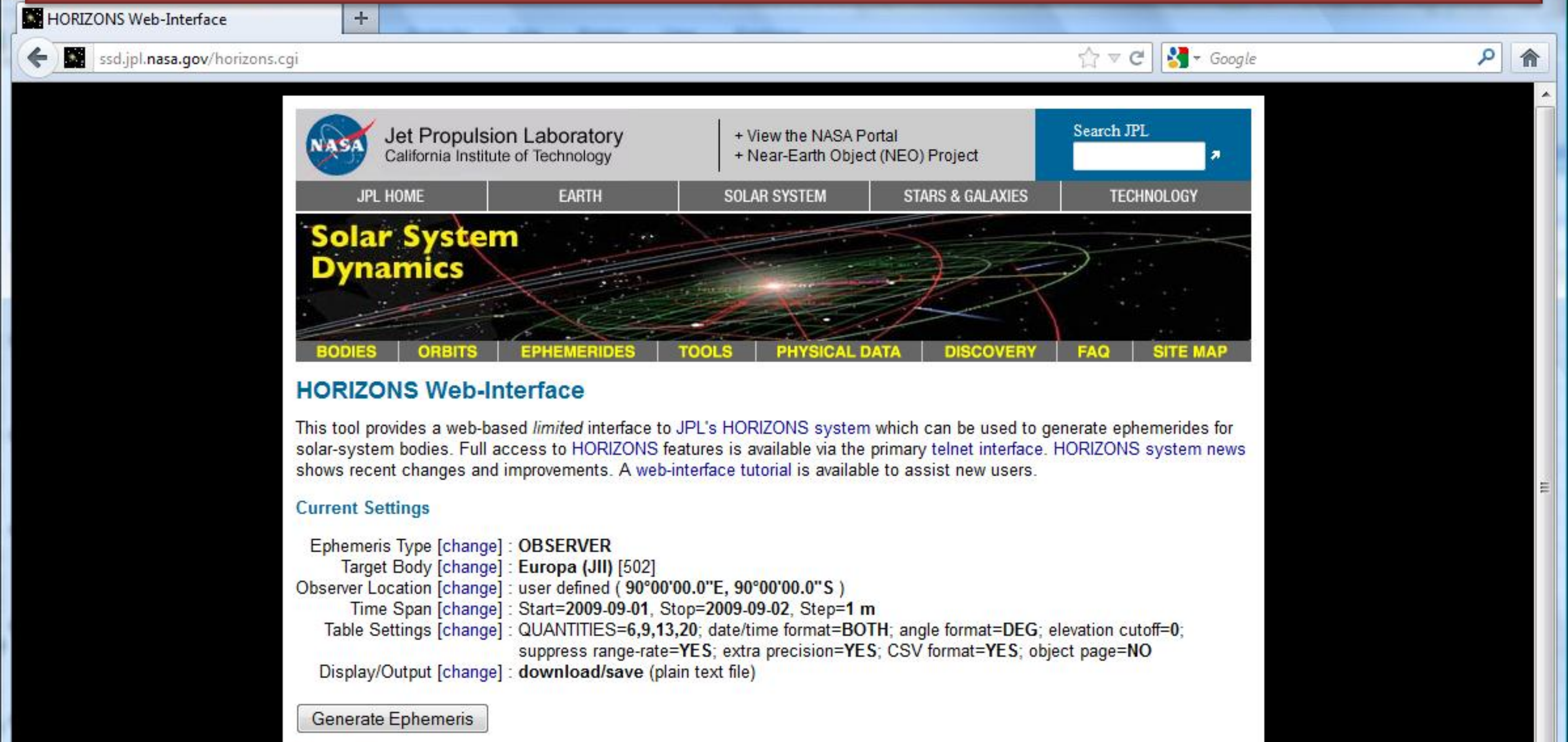

Schematic of a Torus Jovian Extinction Event (TJEE)
Torus material
Io
160 Io radii
Collimated Torus material
at the tip of Torus
Torus of Io
(viewed from above)
Earth's view


2010-Nov-01 TwXI IXII JPL prediction compared to observed.
Western Torus transit by Io
Time 2010-Nov-01 UT
9:10
9:40
10:10
10:40
11:10
11:40
12:10
12:40
13:10
13:40
14:10
14:40
Observations were made and ~ 0.13 magnitude drop has been documented during tip crossings and we have derived a model for this extinction rate.
Photographic magnitude I / III
5
5.05
5.1
5.15
5.2
5.25
5.3
5.35
Stnd dev = 0.0098 mag
S/N = 12.1
I conjunction with II
JPL Torus fit
Talbot data

Hiatus for 2011 – 2013…

- Or so I thought! The last Jovian Mutual Event for JME2009 was 2010-Jan-04. The next JME season wont start until September 2014.
- I had planned on taking a few years off to gear up strong for 2014.
- While attended the SAS Conference in May 2012 I started organizing more observers and collaborators. I soon discovered that there were very well placed conjunctions in July and August of this year (2012).
- JEE2012 was born!
- The call for observers for the JEE2012 Observing Campaign went out, this time to the AAVSO, MPML, and IOTA.

JEE2012 Major shift using JPL ephemeris



- Recent introduction by Wayne Green of the Horizons JPL ephemeris for the accurate data of Jovian moons has revolutionized our data reduction and future prediction methods.

- Reducing all past JEE lightcurves by overlaying the intensity data on top of JPL ephemeris has derived potentially useful scientific data.

NASA ADS: The structure of Io's corona - Mozilla Firefox

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NASA ADS: The structure of Io's corona

adsabs.harvard.edu/abs/1991ApJ...368..298S

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The structure of Io's corona

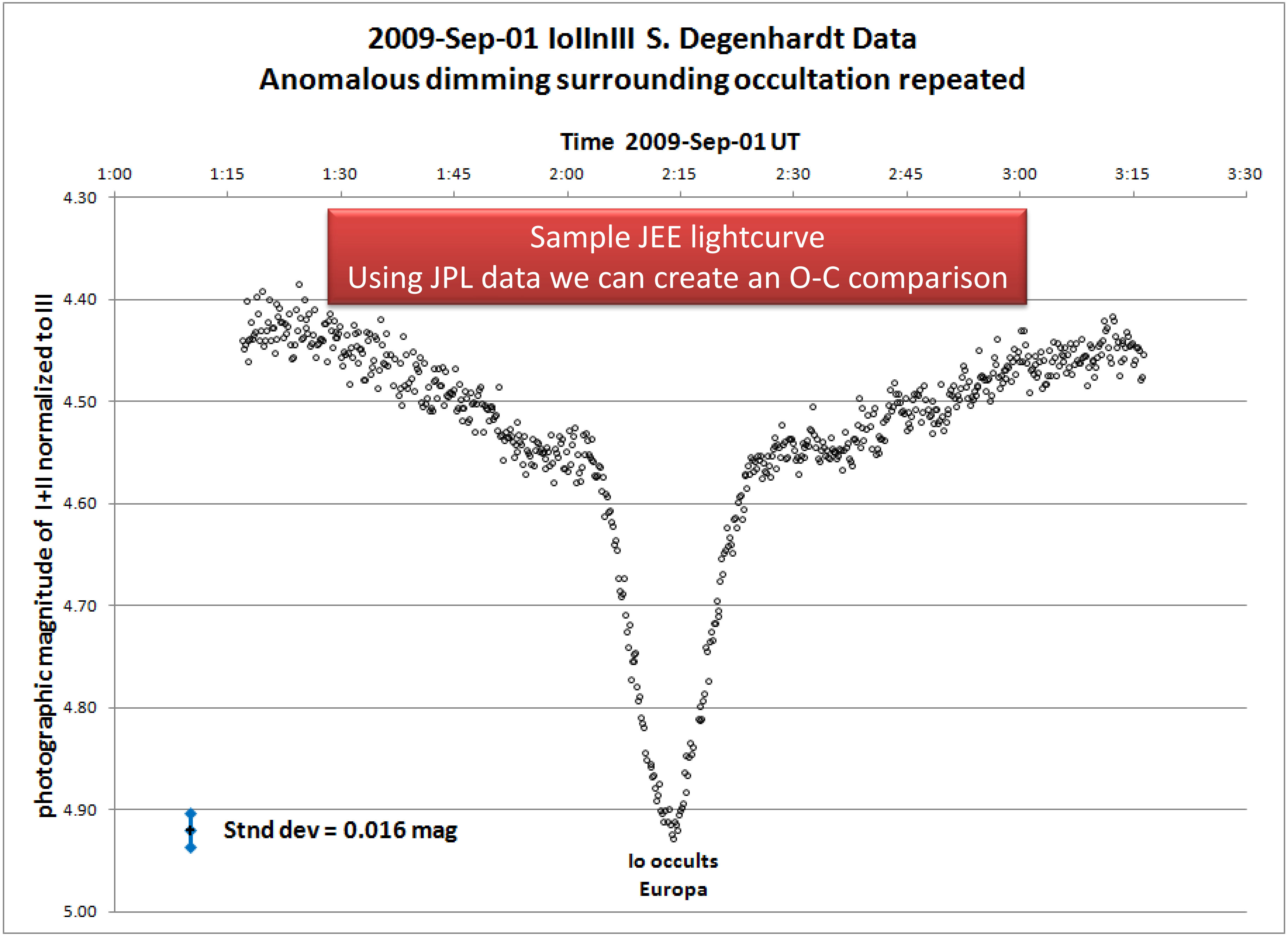
Schneider, N. M.; Hunten, D. M.; Wells, W. K.; Schultz, A. B.; Fink, U.

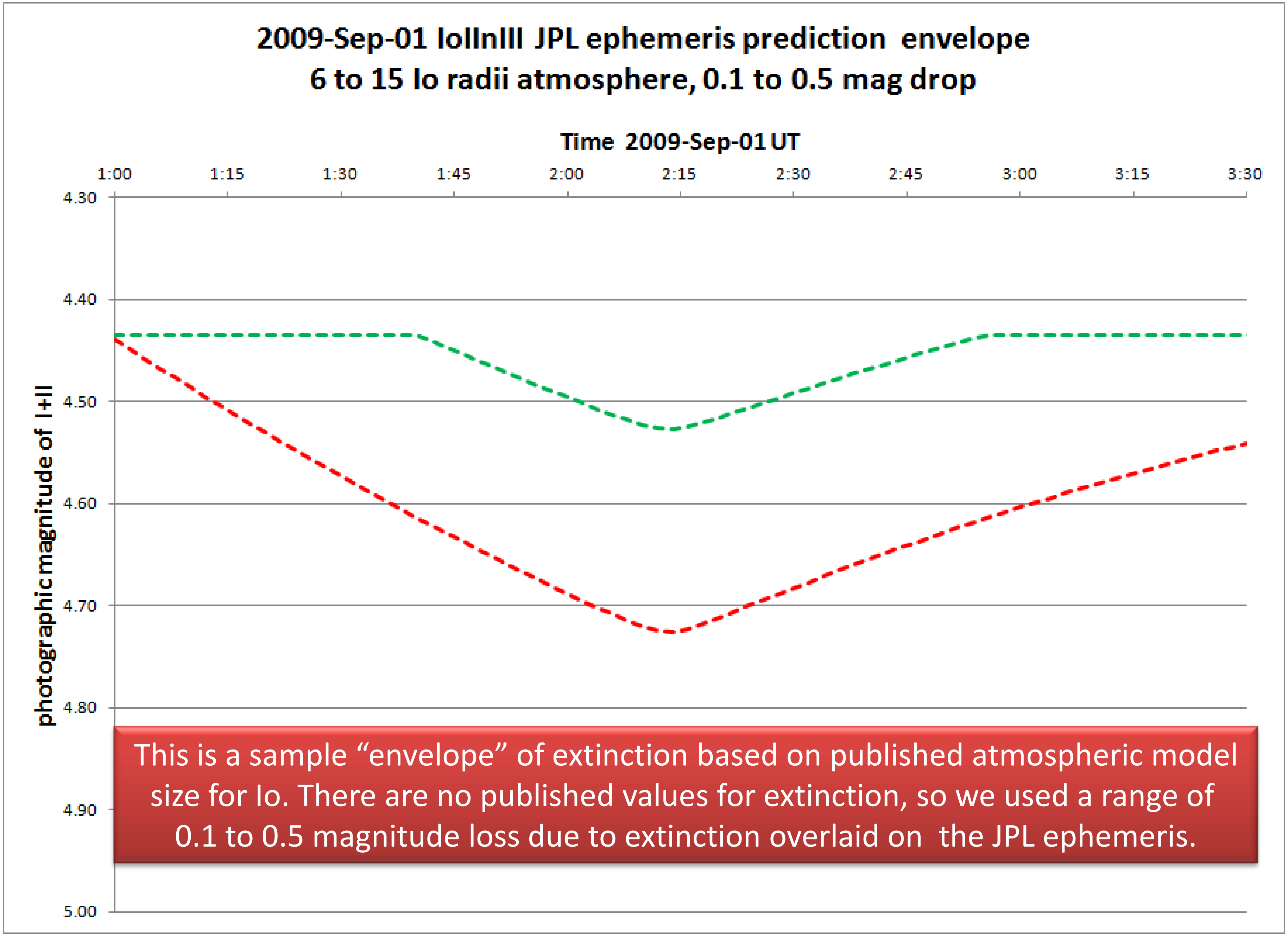
Astrophysical Journal, Part 1 (ISSN 0004-637X), vol. 368, Feb. 10, 1991, p. 298-315.

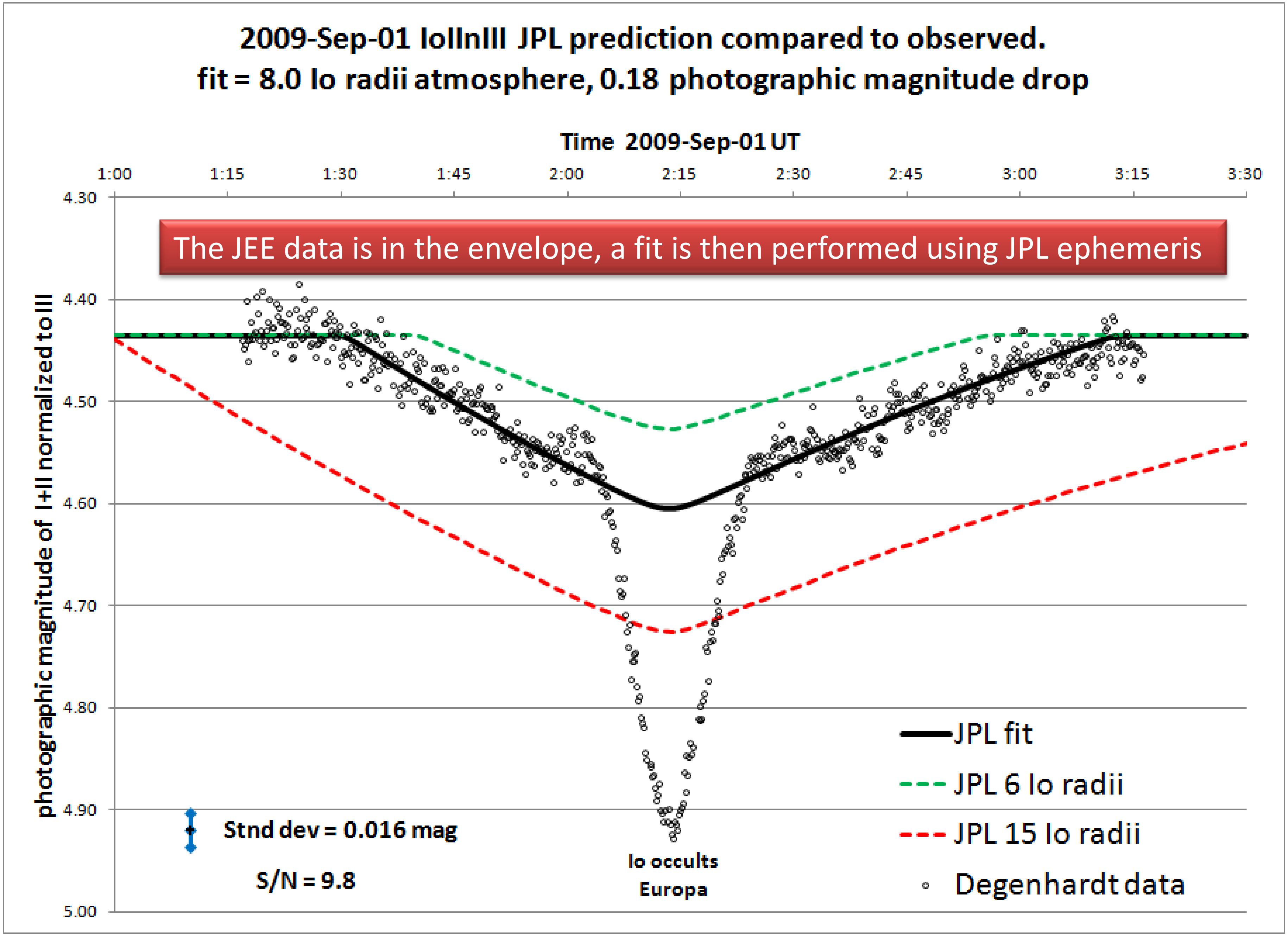
A spatial profile of the distribution of sodium in Io's corona has been constructed using measurements obtained during satellite mutual eclipses. The data reveal a fairly symmetric corona whose density falls steeply from the surface out to 6 r(Io) and more slowly outside. An upper limit of 700 km is placed on the exobase altitude, but the observations do not constrain the surface density. Several theoretical models adequately match some traits of the corona, but none satisfies all the observations. No strong upstream/downstream asymmetry of the corona is observed, so it is unlikely that the corona is primarily generated by the impact of corotating ions into the trailing hemisphere.

Keywords: CORONAS, IO, JUPITER (PLANET), SODIUM, CHARGE COUPLED DEVICES, ECLIPSES, EMISSION SPECTRA, SPATIAL DISTRIBUTION; JUPITER, SATELLITES, IO, STRUCTURE, CORONAS, DIAGRAMS, SODIUM, DENSITY, MODELS, THEORETICAL STUDIES, SYMMETRY, ATMOSPHERE, MIXING, ALTITUDE, STRUCTURE, IONIZATION, TRANSPORT, ECLIPSES, PARAMETERS, SPECTRA, GEOMETRY, EMISSIONS, THICKNESS, THERMAL EFFECTS, SPUTTERING, ESCAPE

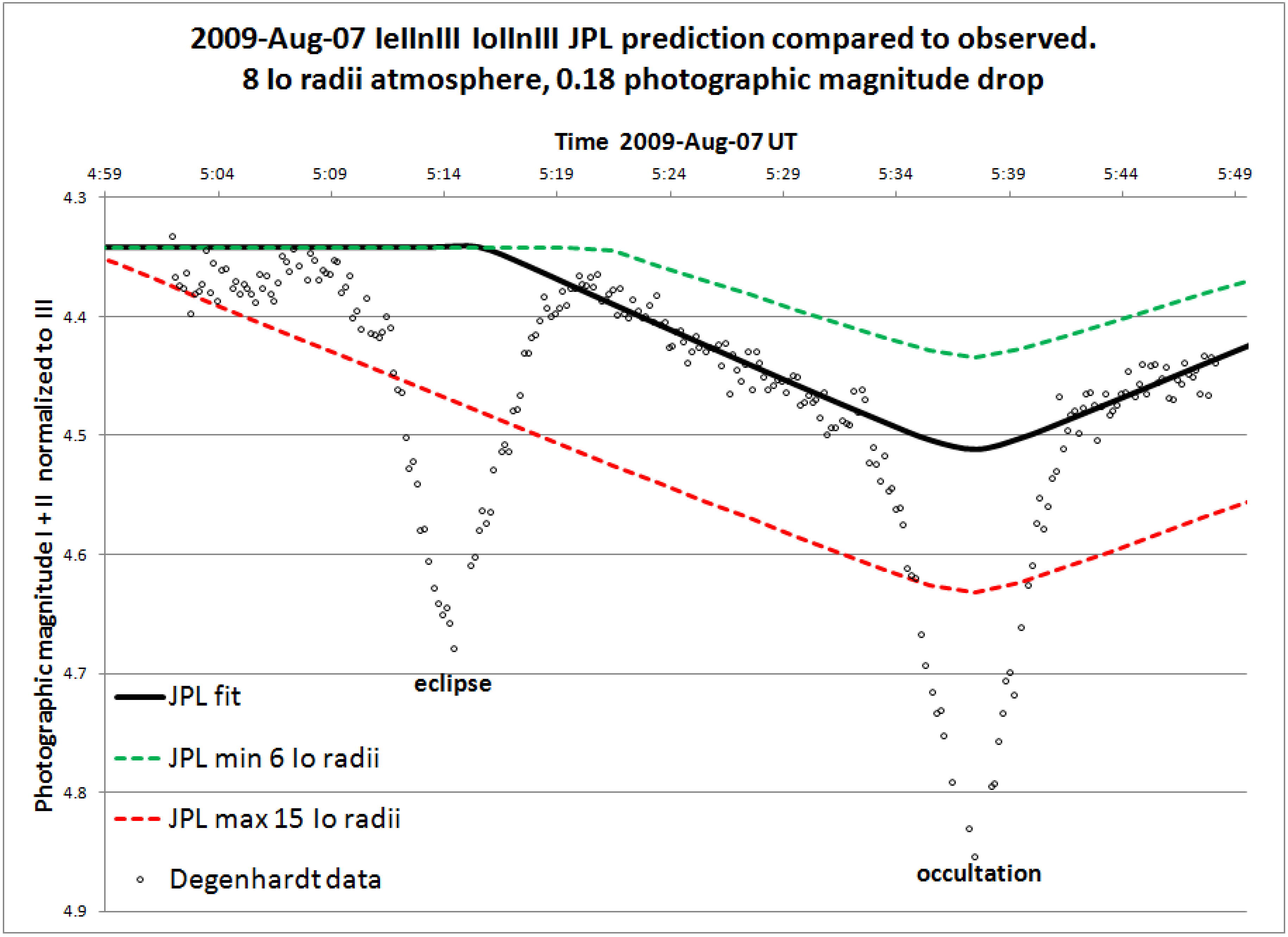
DOI: 10.1086/169694

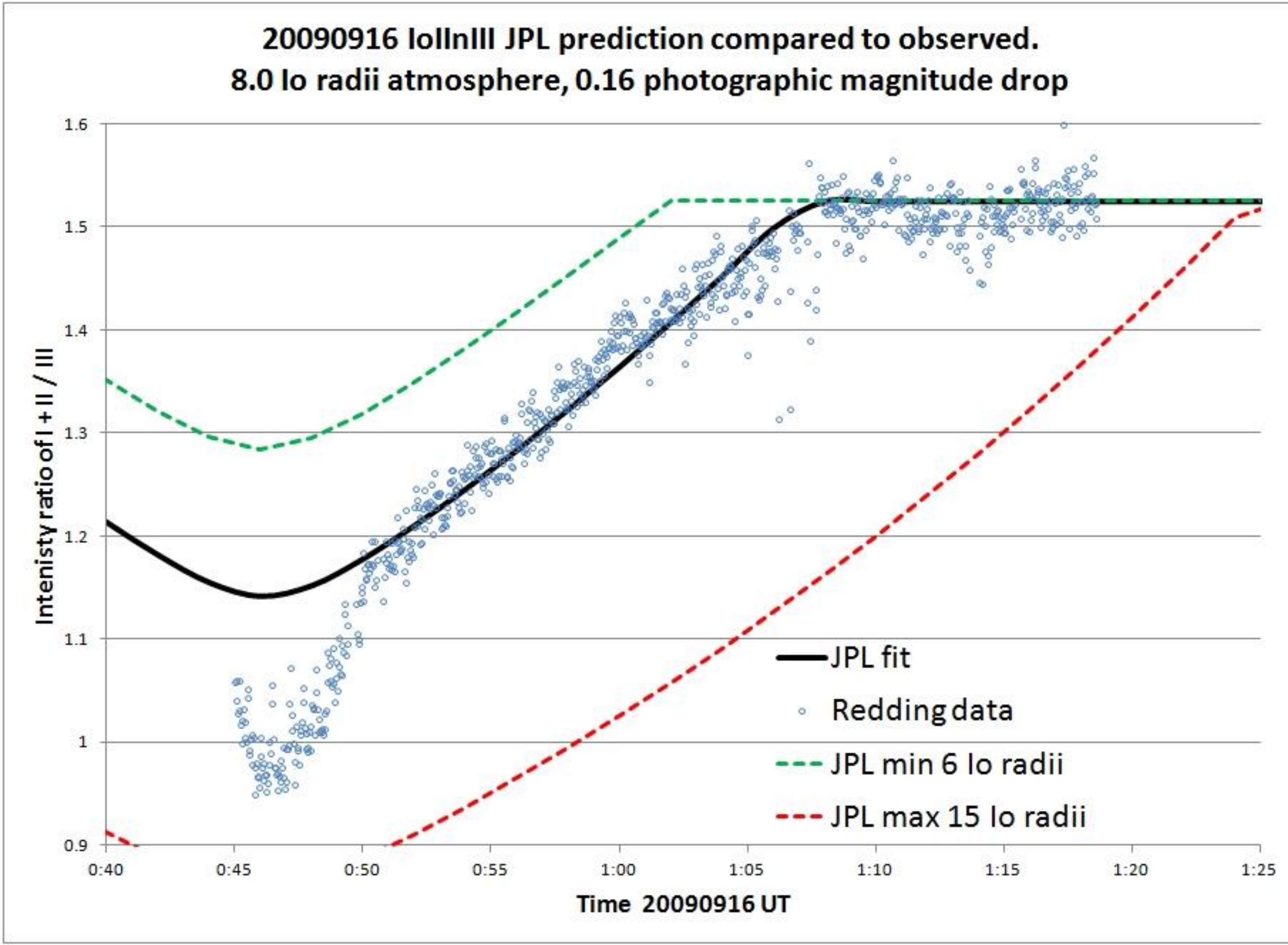

2009-Sep-01 IoIInIII S. Degenhardt Data
Anomalous dimming surrounding occultation repeated
Time 2009-Sep-01 UT
1:00
1:15
1:30
1:45
2:00
2:15
2:30
2:45
3:00
3:15
3:30
4.30
4.40
4.50
4.60
4.70
4.80
4.90
5.00
photographic magnitude of I+II normalized to III
Sample JEE lightcurve
Using JPL data we can create an O-C comparison
Stnd dev = 0.016 mag
Io occults
Europa


2009-Sep-01 IoIInIII JPL ephemeris prediction envelope
6 to 15 Io radii atmosphere, 0.1 to 0.5 mag drop
Time 2009-Sep-01 UT
1:00
1:15
1:30
1:45
2:00
2:15
2:30
2:45
3:00
3:15
3:30
photographic magnitude of I+II
4.30
4.40
4.50
4.60
4.70
4.80
4.90
5.00
This is a sample “envelope” of extinction based on published atmospheric model size for Io. There are no published values for extinction, so we used a range of 0.1 to 0.5 magnitude loss due to extinction overlaid on the JPL ephemeris.

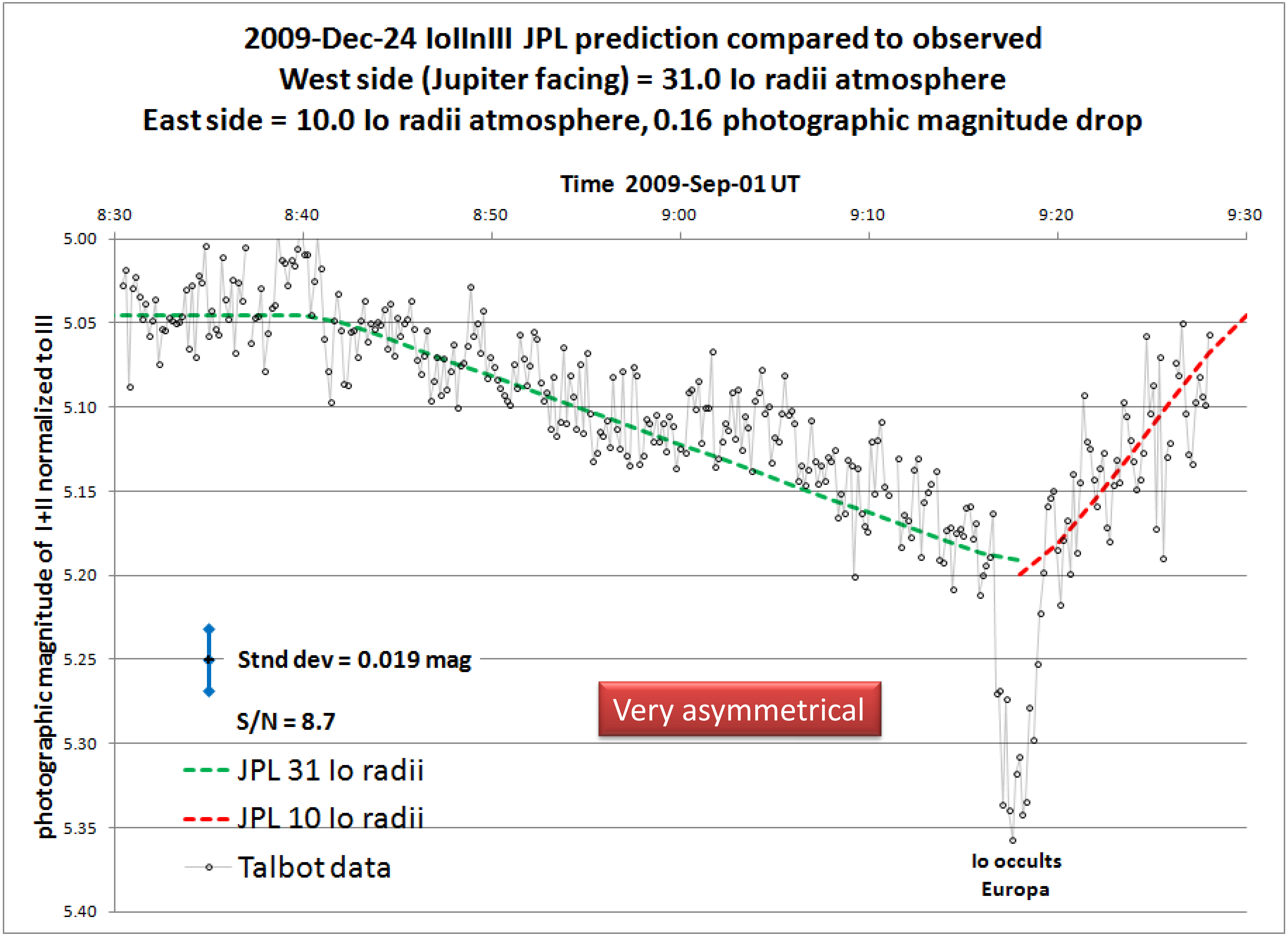


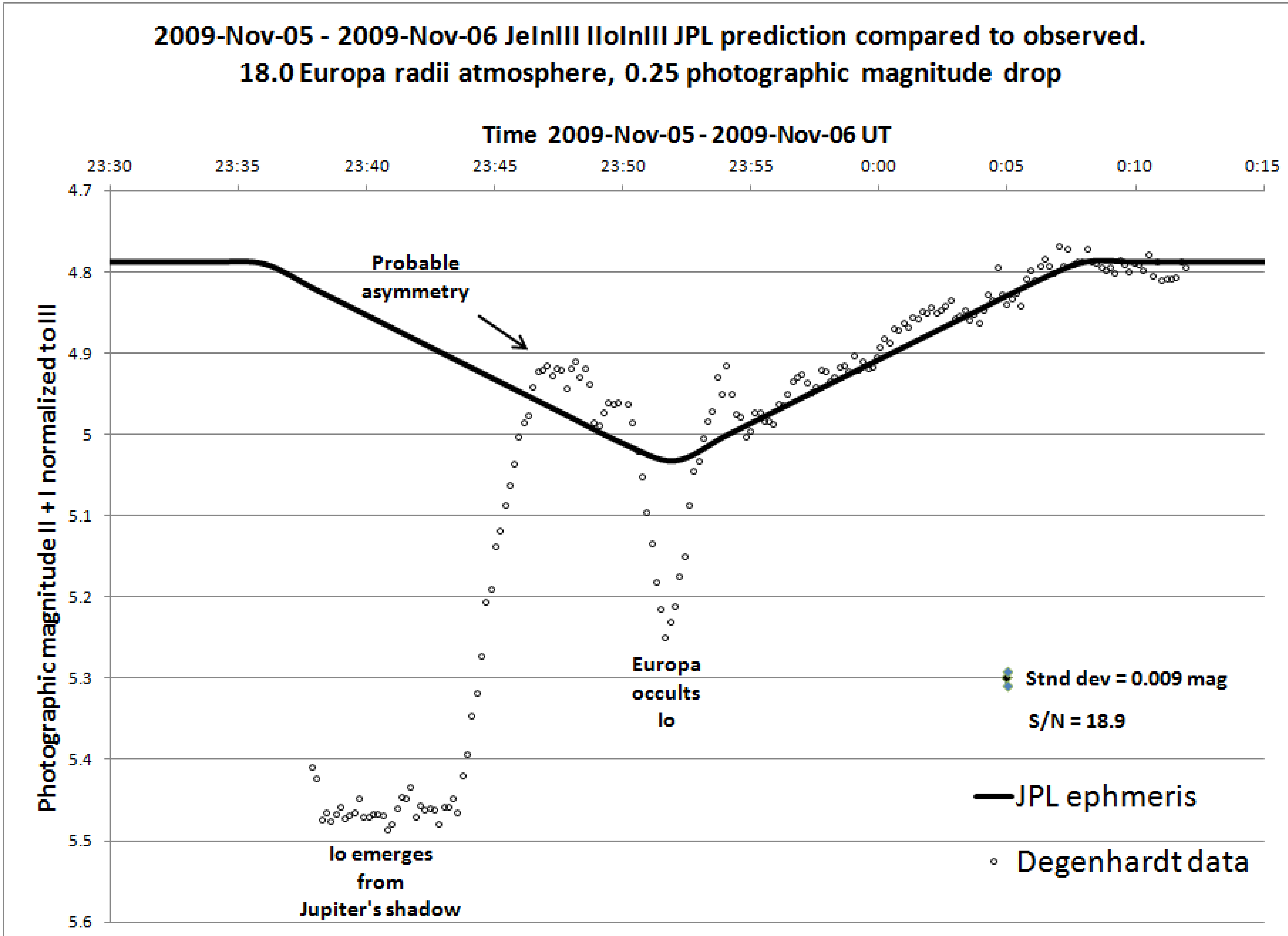
2009-Sep-01 IoIInIII JPL prediction compared to observed.
fit = 8.0 Io radii atmosphere, 0.18 photographic magnitude drop
Time 2009-Sep-01 UT
1:00
1:15
1:30
1:45
2:00
2:15
2:30
2:45
3:00
3:15
3:30
4.30
4.40
4.50
4.60
4.70
4.80
4.90
5.00
photographic magnitude of I+II normalized to III
The JEE data is in the envelope, a fit is then performed using JPL ephemeris
Stnd dev = 0.016 mag
S/N = 9.8
Io occults
Europa
JPL fit
JPL 6 Io radii
JPL 15 Io radii
Degenhardt data


2009-Aug-07 IeIInIII IoIInIII JPL prediction compared to observed.
8 Io radii atmosphere, 0.18 photographic magnitude drop
Time 2009-Aug-07 UT
4:59
5:04
5:09
5:14
5:19
5:24
5:29
5:34
5:39
5:44
5:49
4.3
4.4
4.5
4.6
4.7
4.8
4.9
Photographic magnitude I + II normalized to III
eclipse
occultation
JPL fit
JPL min 6 Io radii
JPL max 15 Io radii
Degenhardt data



20090916 IoIInIII JPL prediction compared to observed.
8.0 Io radii atmosphere, 0.16 photographic magnitude drop
Intenisty ratio of I + II / III
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0:40
0:45
0:50
0:55
1:00
1:05
1:10
1:15
1:20
1:25
Time 20090916 UT
JPL fit
Redding data
JPL min 6 Io radii
JPL max 15 Io radii


2009-Dec-24 IoIInIII JPL prediction compared to observed
West side (Jupiter facing) = 31.0 Io radii atmosphere
East side = 10.0 Io radii atmosphere, 0.16 photographic magnitude drop
Time 2009-Sep-01 UT
8:30
8:40
8:50
9:00
9:10
9:20
9:30
5.00
5.05
5.10
5.15
5.20
5.25
5.30
5.35
5.40
photographic magnitude of I+II normalized to III
Stnd dev = 0.019 mag
S/N = 8.7
Very asymmetrical
JPL 31 Io radii
JPL 10 Io radii
Talbot data
Io occults
Europa



2009-Nov-05 - 2009-Nov-06 JeInIII IIoInIII JPL prediction compared to observed.
18.0 Europa radii atmosphere, 0.25 photographic magnitude drop
Time 2009-Nov-05 - 2009-Nov-06 UT
23:30
23:35
23:40
23:45
23:50
23:55
0:00
0:05
0:10
0:15
Photographic magnitude II + I normalized to III
4.7
4.8
4.9
5
5.1
5.2
5.3
5.4
5.5
5.6
Probable asymmetry
Europa occults Io
Io emerges from Jupiter's shadow
Stnd dev = 0.009 mag
S/N = 18.9
JPL ephmeris
Degenhardt data

Discovery of an extended sodium atmosphere around Europa - Mozilla Firefox

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Discovery of an extended sodium atmos... +

file:///D:/Astro/JEE/Europa/25 radii Europa paper.html

letters to nature

Nature **380**, 229 - 231 (21 March 1996); doi:10.1038/380229a0

Discovery of an extended sodium atmosphere around Europa

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EUROPA, one of the satellites of Jupiter, has long been thought to be a dormant icy body[1], unlike its volcanically active neighbour, Io. Europa lies deep within Jupiter's magnetosphere, however, and is continuously bombarded by energetic ions, which modify the surface ices[2] and are probably responsible for creating Europa's tightly bound oxygen atmosphere[3,4]. Here we report the discovery of an atmosphere of atomic sodium that extends to at least 25 times Europa's radius. We suggest that this sodium is originally released by Io's volcanoes, after which it is ionized in the magnetosphere and implanted into Europa's surface ice; subsequent sputtering of the ice by magnetospheric ions releases the sodium to form the extended atmosphere. Although sodium is a minor constituent of Europa's atmosphere, it traces the distribution of the major atmospheric components which are not themselves directly observable. The sodium and oxygen could represent the extremes of the distribution of the atmospheric components, with only the heaviest molecules (such as the oxygen) being tightly bound; alternatively the sodium might be in the form of an extended corona, analogous to Io's atmosphere.

References

1. Clark, R. N., Fanale, F. P. & Gaffey, M. J. in *Satellites* (eds Burns, J. A. & Matthews, M. S.) 437–491 (Univ. Arizona Press, Tucson, 1986). | ChemPort |
2. Johnson, R. E., Nelson, M. L., McCord, T. B. & Gradie, J. C. *Icarus* **75**, 423–436 (1988). | Article | ChemPort |
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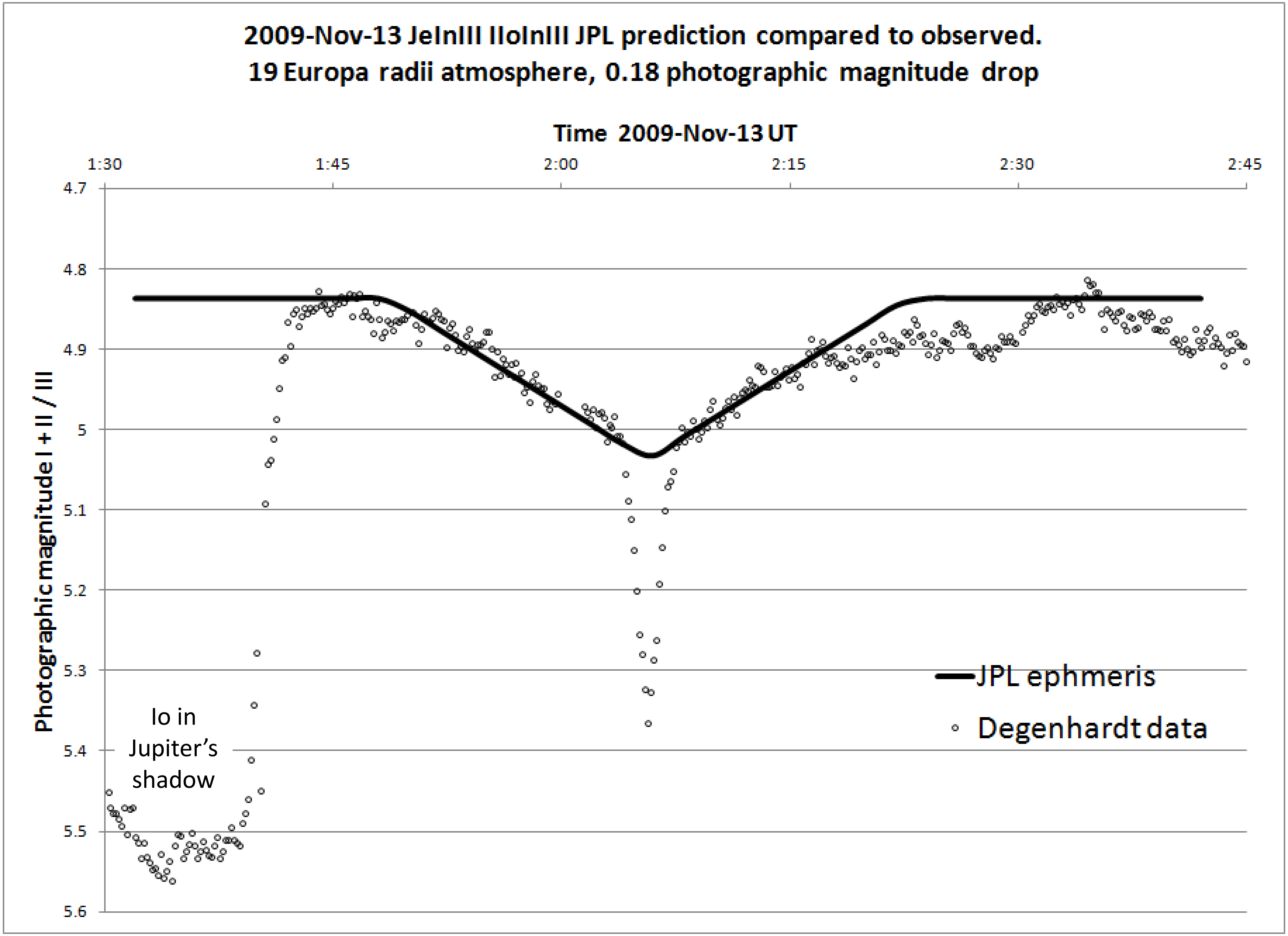
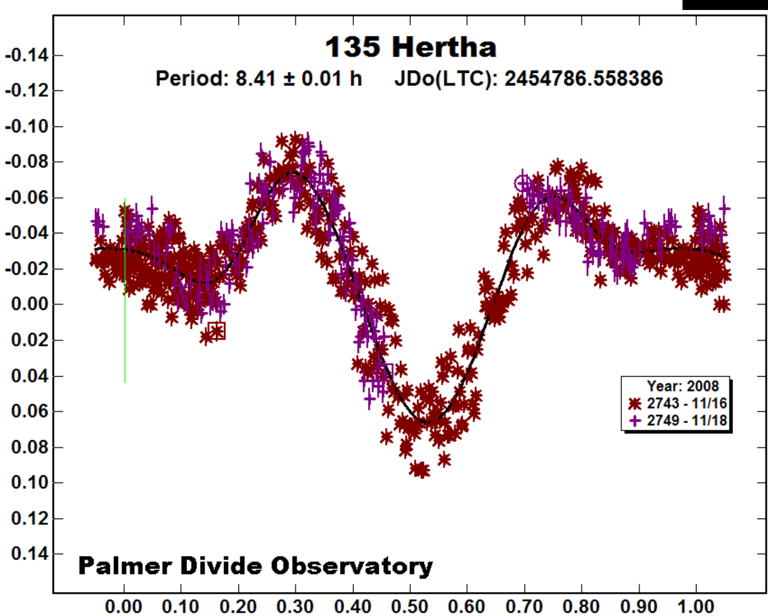
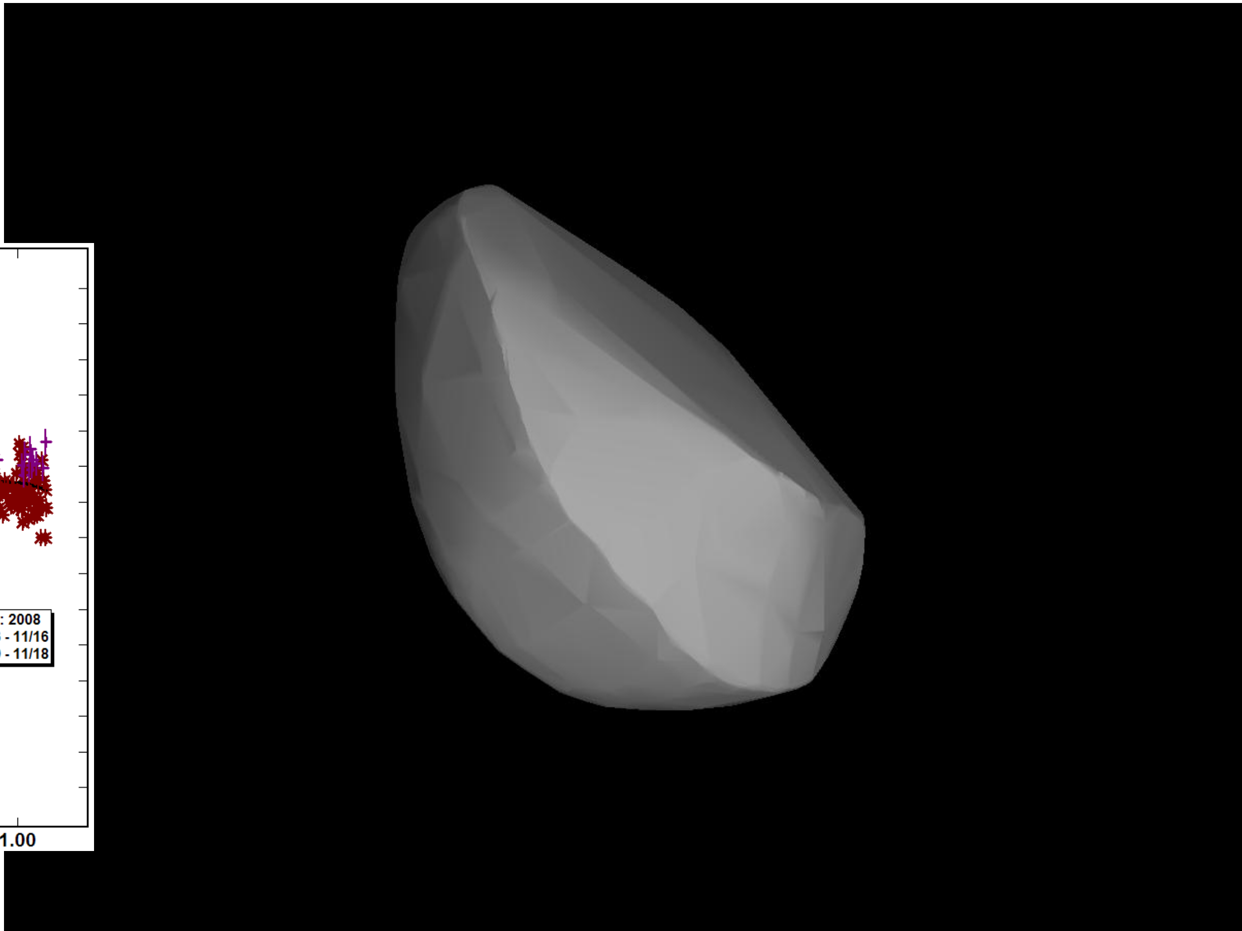
8. Bagenal, F. *J. geophys. Res.* **99**, 11043–11062 (1994). | Article |



2009-Nov-13 JeInIII IIoInIII JPL prediction compared to observed.
19 Europa radii atmosphere, 0.18 photographic magnitude drop
Time 2009-Nov-13 UT
1:30
1:45
2:00
2:15
2:30
2:45
4.7
4.8
4.9
5
5.1
5.2
5.3
5.4
5.5
5.6
Photographic magnitude I + II / III
Io in Jupiter's shadow
JPL ephmeris
Degenhardt data

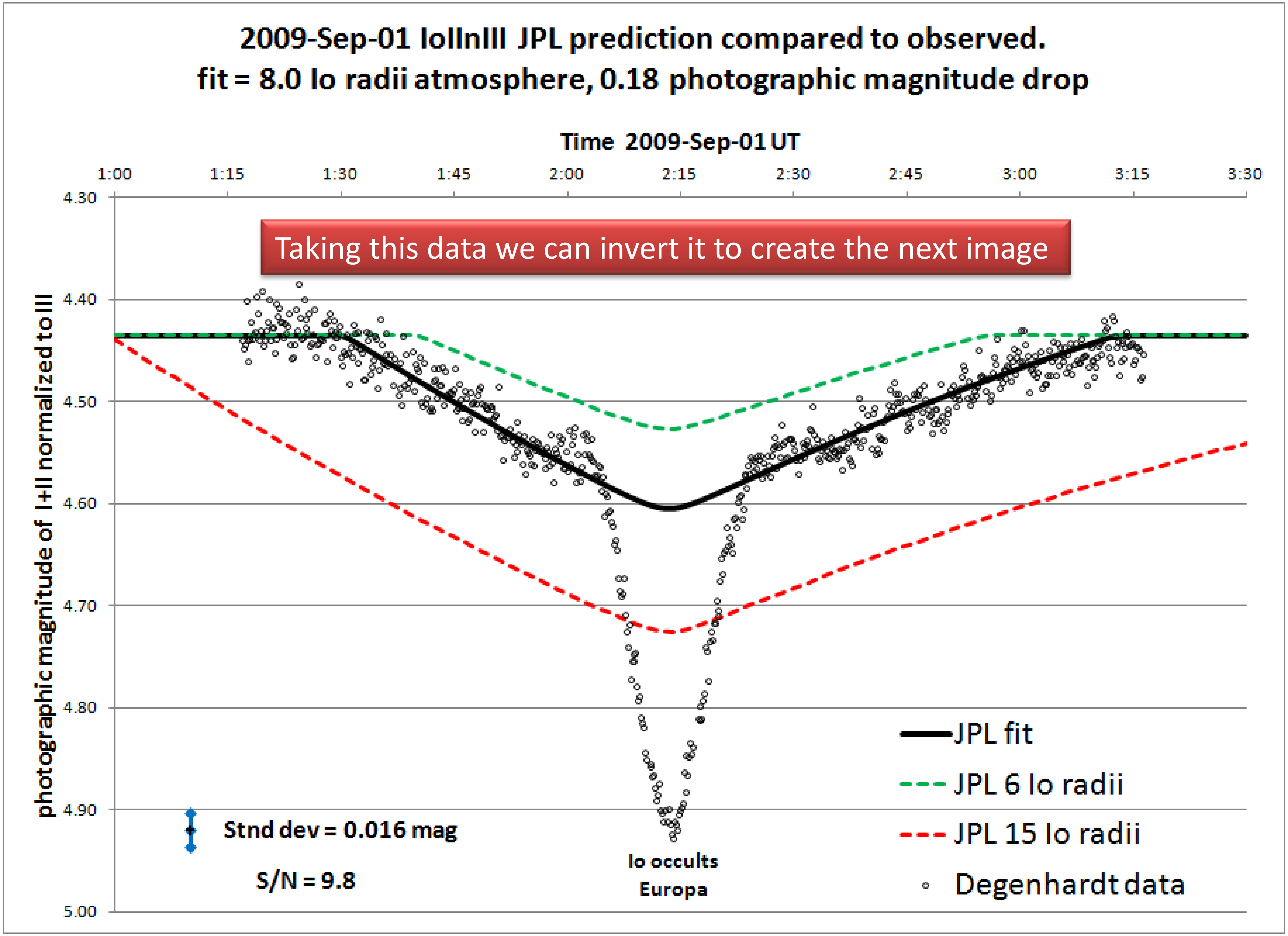
In asteroid work multiple reflected lightcurves are combined and inverted to create a 3D model





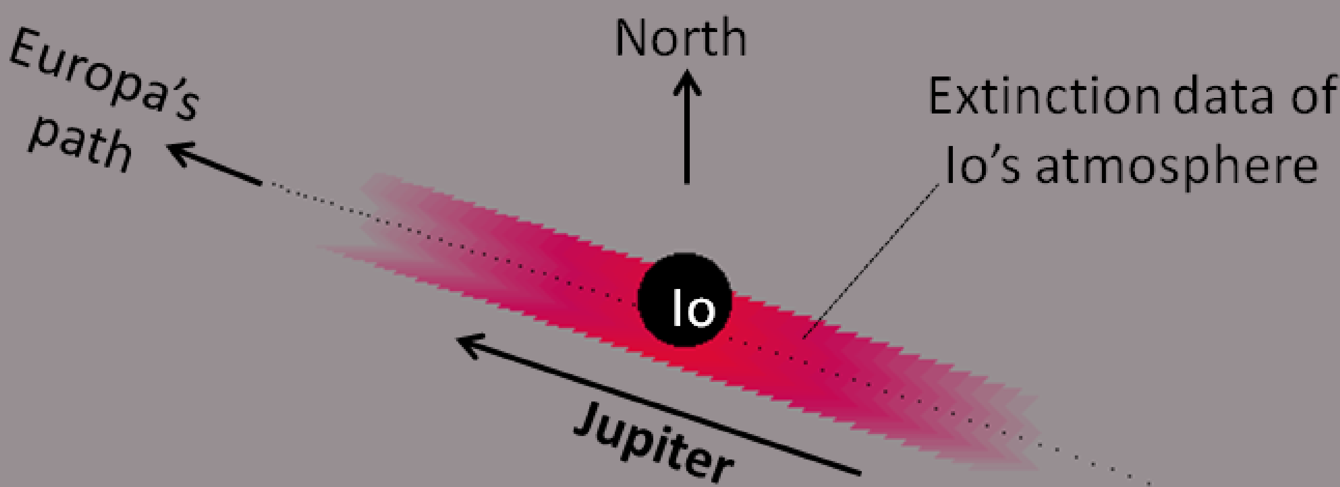
“Inverting” a JEE Lightcurve

- Using JPL ephemeris and our extinction data we have developed a means of overlaying the intensity loss data onto the JPL ephemeris of the accurate moon locations during the JEE event.
- These inversions are turned into an image that can aid in deriving geometrical data of the extinction event.
- We expect multiple JEE events inverted together into a single image will eventually lead to 3D models of the Jovian dust and gas similar to asteroidal models.


2009-Sep-01 IoInIII JPL prediction compared to observed.
fit = 8.0 Io radii atmosphere, 0.18 photographic magnitude drop
Time 2009-Sep-01 UT
1:00
1:15
1:30
1:45
2:00
2:15
2:30
2:45
3:00
3:15
3:30
4.30
4.40
4.50
4.60
4.70
4.80
4.90
5.00
photographic magnitude of I+II normalized to III
Taking this data we can invert it to create the next image
JPL fit
JPL 6 Io radii
JPL 15 Io radii
Degenhardt data
Stnd dev = 0.016 mag
S/N = 9.8
Io occults
Europa

S. Degenhardt 2009-Sep-01Extinction data
JEE lightcurve inversion overlaid on JPL ephemeris

Europa's extinction passing behind Io

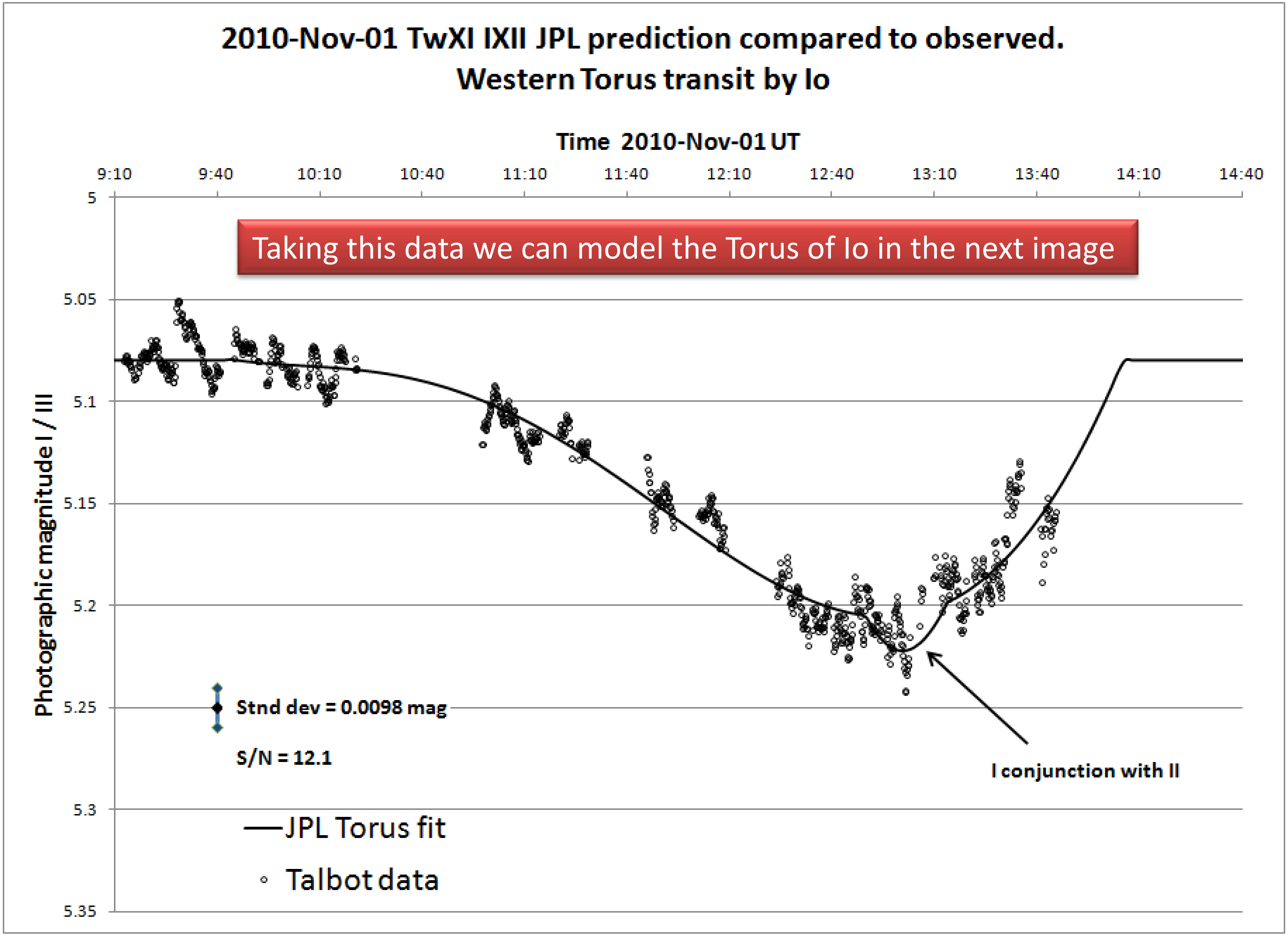


Using Europa to probe Io's atmosphere:

Io atmospheric extinction out to ~ 8 Io radii

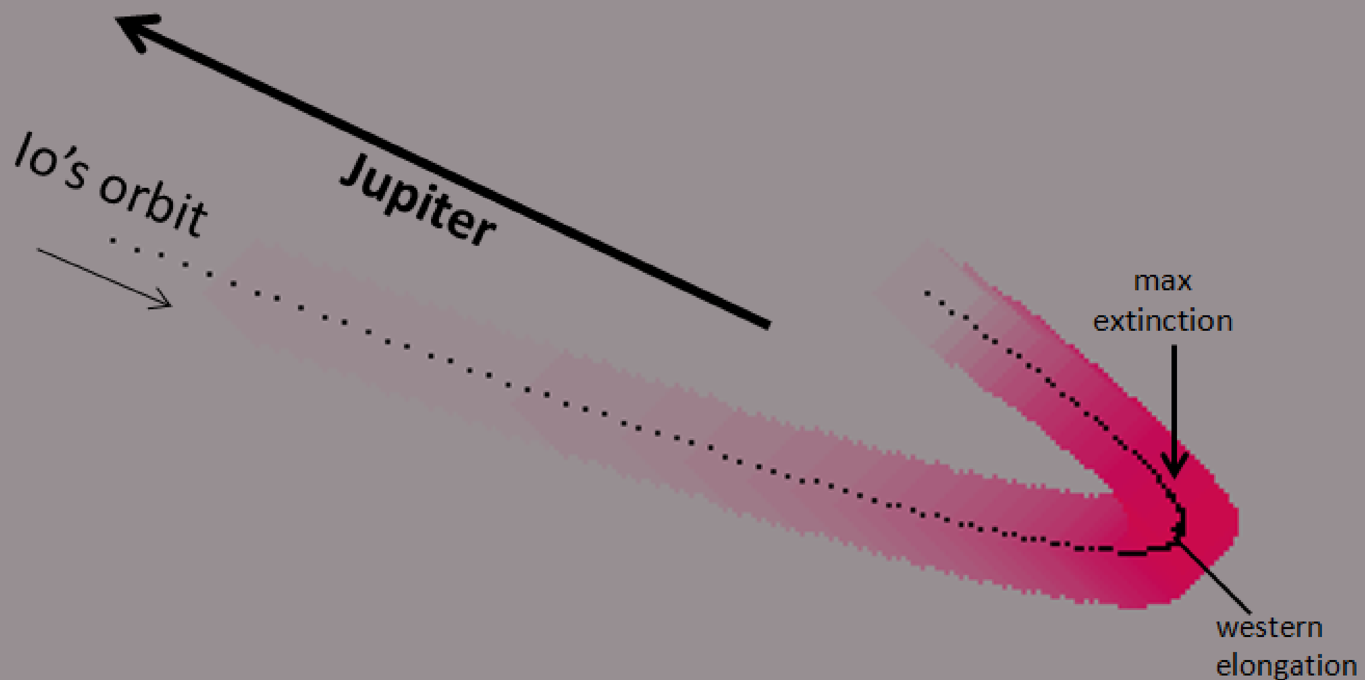
Max extinction magnitude = ~ 0.18 photographic magnitude

Column depth at max extinction = ~ 29 km


2010-Nov-01 TwXI IXII JPL prediction compared to observed.
Western Torus transit by Io
Time 2010-Nov-01 UT
9:10
9:40
10:10
10:40
11:10
11:40
12:10
12:40
13:10
13:40
14:10
14:40
Photographic magnitude I / III
5
5.05
5.1
5.15
5.2
5.25
5.3
5.35
Taking this data we can model the Torus of Io in the next image
Stnd dev = 0.0098 mag
S/N = 12.1
I conjunction with II
JPL Torus fit
Talbot data

J. Talbot 2010-Nov-01 Extinction data
JEE lightcurve inversion overlaid on JPL ephemeris

Io's extinction through western Torus tip

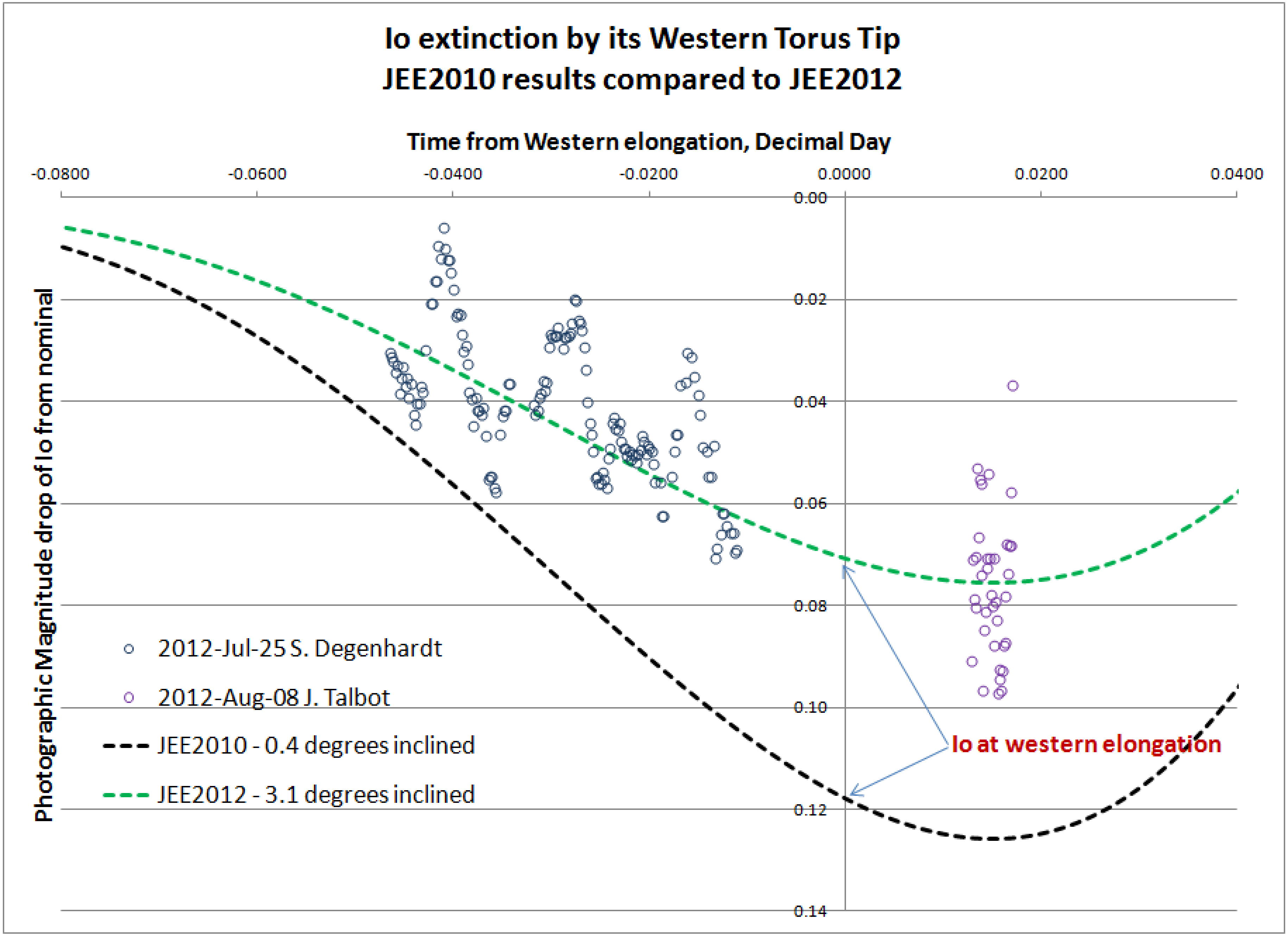


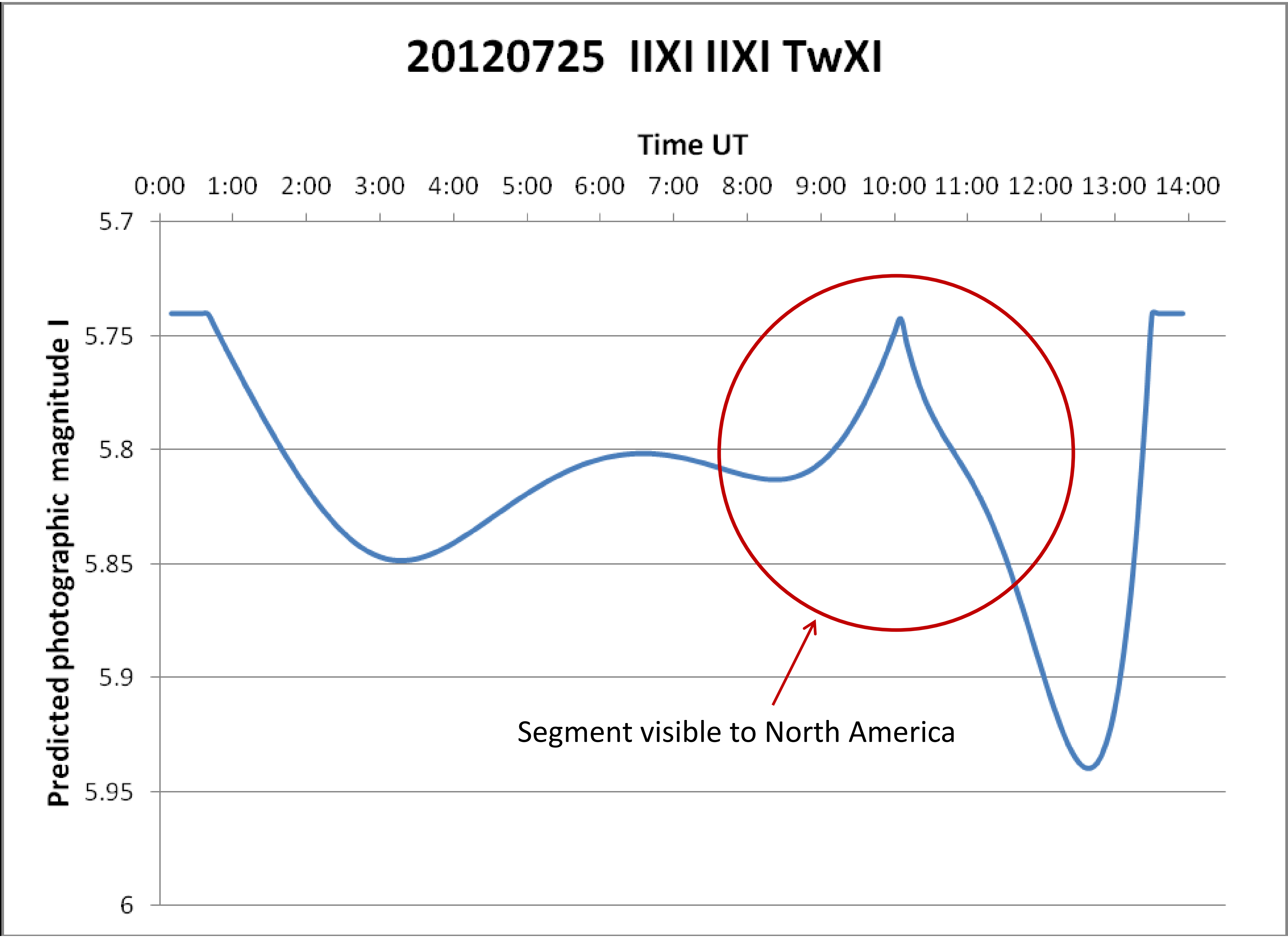
Using Io to probe Io's Torus tip:

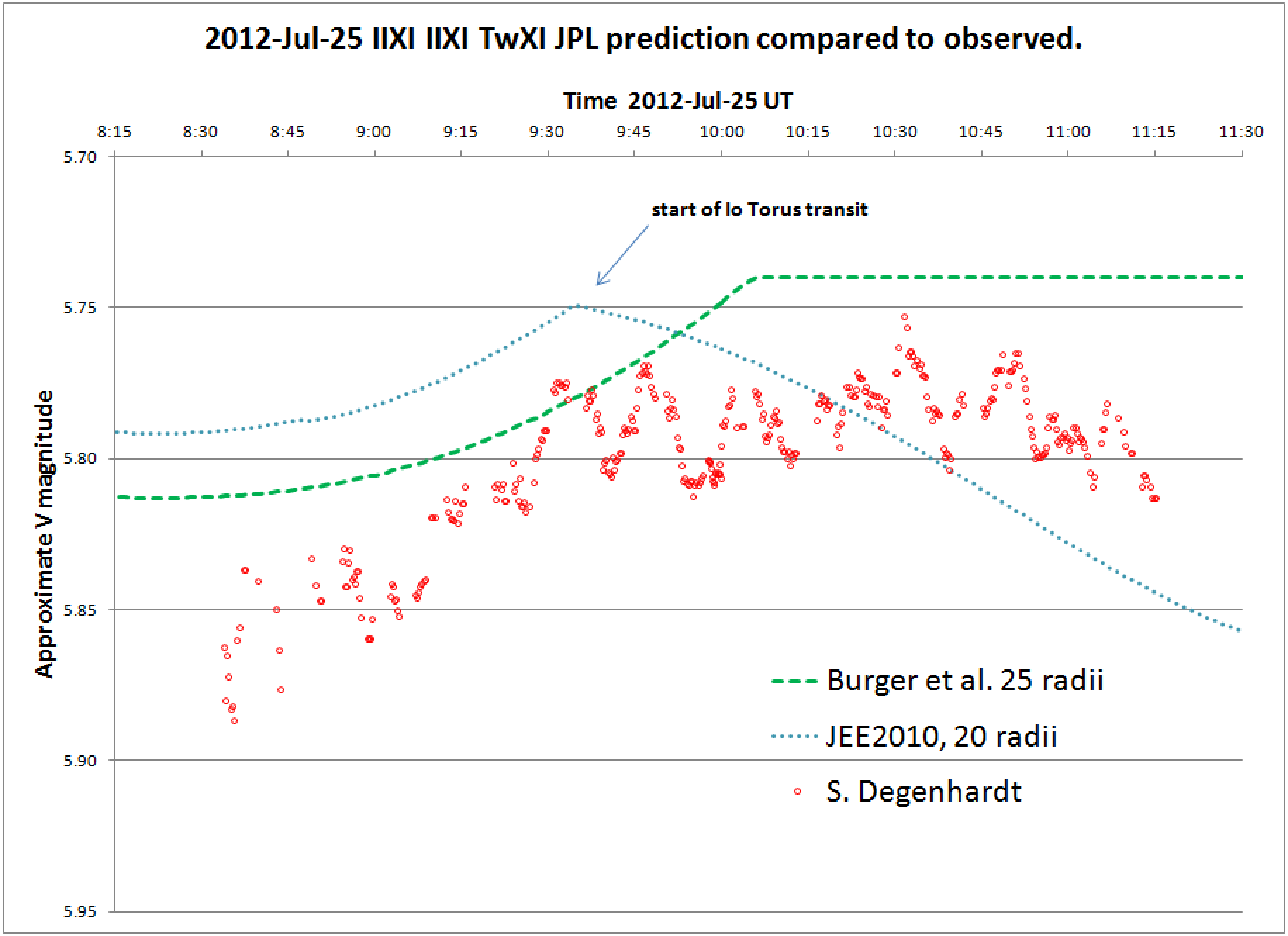
Line of sight max extinction column depth = ~ 40 Io radii
Max extinction magnitude = ~ 0.13 photographic magnitude
Column depth at max extinction = ~ 73 km

Preliminary JEE2012 Observing Campaign Results

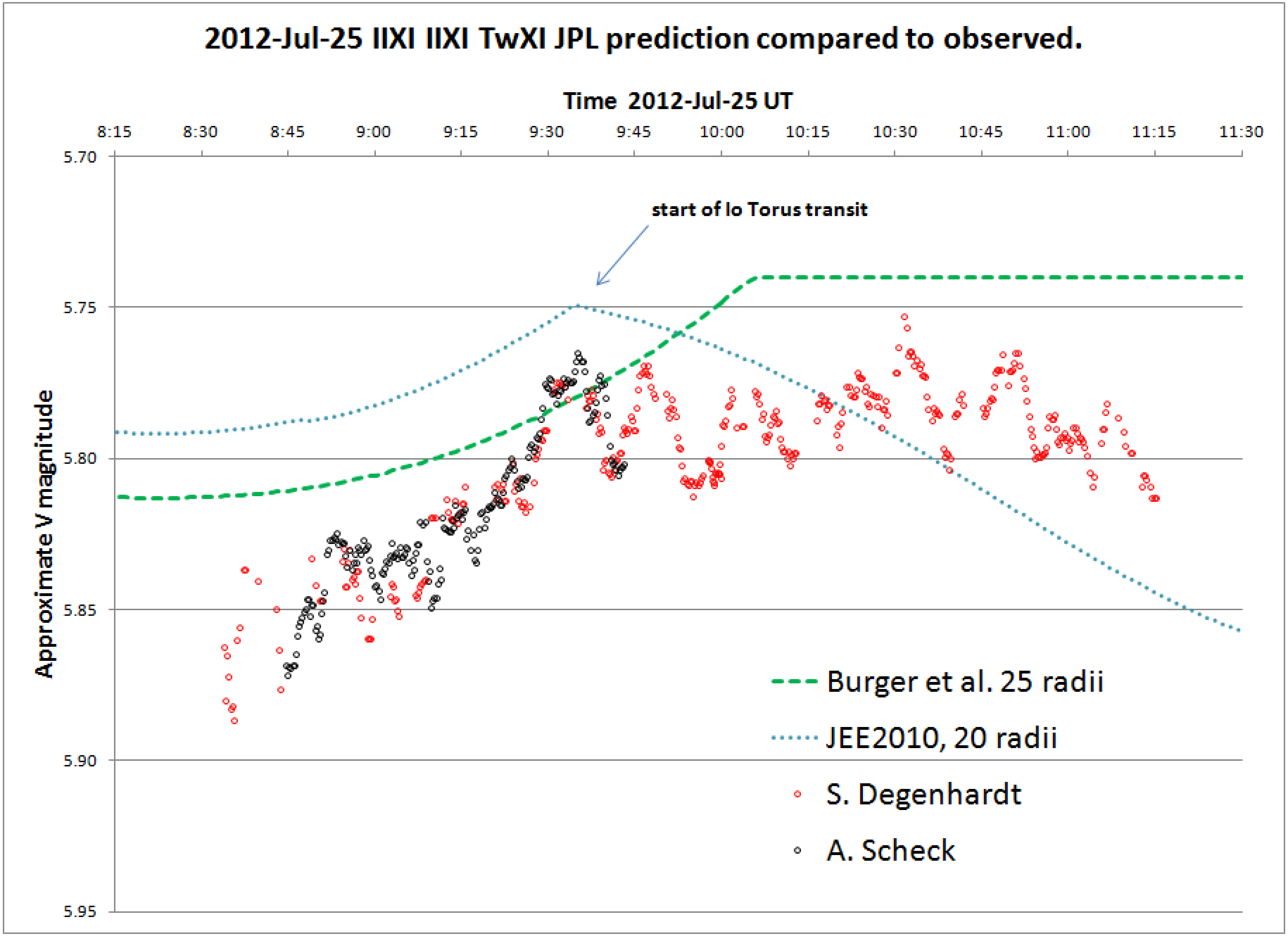
- New discoveries have once again taken us by surprise!
- Multi-wavelength data sets have been submitted by AAVSO, USA and foreign observers and are being processed. German observer Bernd Gährken is regularly observing in the methane band.
- Lesson learned: let the data speak for itself! Give up preconceived ideas of what it should say.
- Future predictions should be presented as "Windows of Opportunity" of JEE.


Io extinction by its Western Torus Tip
JEE2010 results compared to JEE2012
Time from Western elongation, Decimal Day
-0.0800
-0.0600
-0.0400
-0.0200
0.0000
0.0200
0.0400
0.00
0.02
0.04
0.06
0.08
0.10
0.12
0.14
Photographic Magnitude drop of Io from nominal
2012-Jul-25 S. Degenhardt
2012-Aug-08 J. Talbot
JEE2010 - 0.4 degrees inclined
JEE2012 - 3.1 degrees inclined
Io at western elongation


20120725 IIXI IIXI TwXI
Time UT
0:00
1:00
2:00
3:00
4:00
5:00
6:00
7:00
8:00
9:00
10:00
11:00
12:00
13:00
14:00
5.7
5.75
5.8
5.85
5.9
5.95
6
Predicted photographic magnitude I
Segment visible to North America

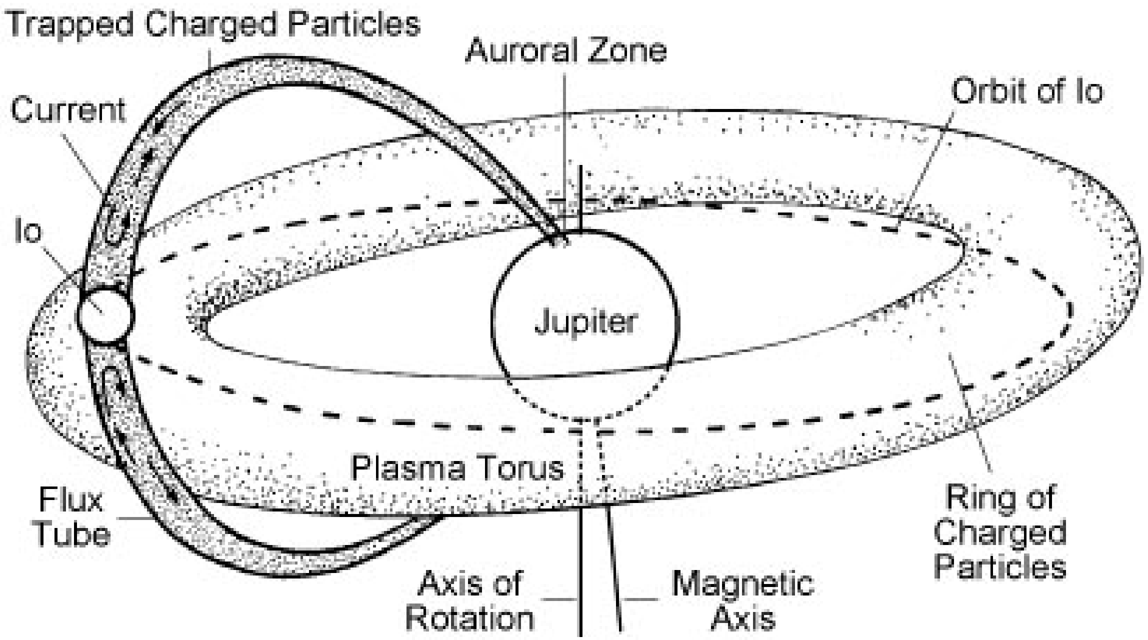


2012-Jul-25 IIXI IIXI TwXI JPL prediction compared to observed.
Time 2012-Jul-25 UT
8:15
8:30
8:45
9:00
9:15
9:30
9:45
10:00
10:15
10:30
10:45
11:00
11:15
11:30
5.70
5.75
5.80
5.85
5.90
5.95
Approximate V magnitude
start of Io Torus transit
Burger et al. 25 radii
JEE2010, 20 radii
S. Degenhardt

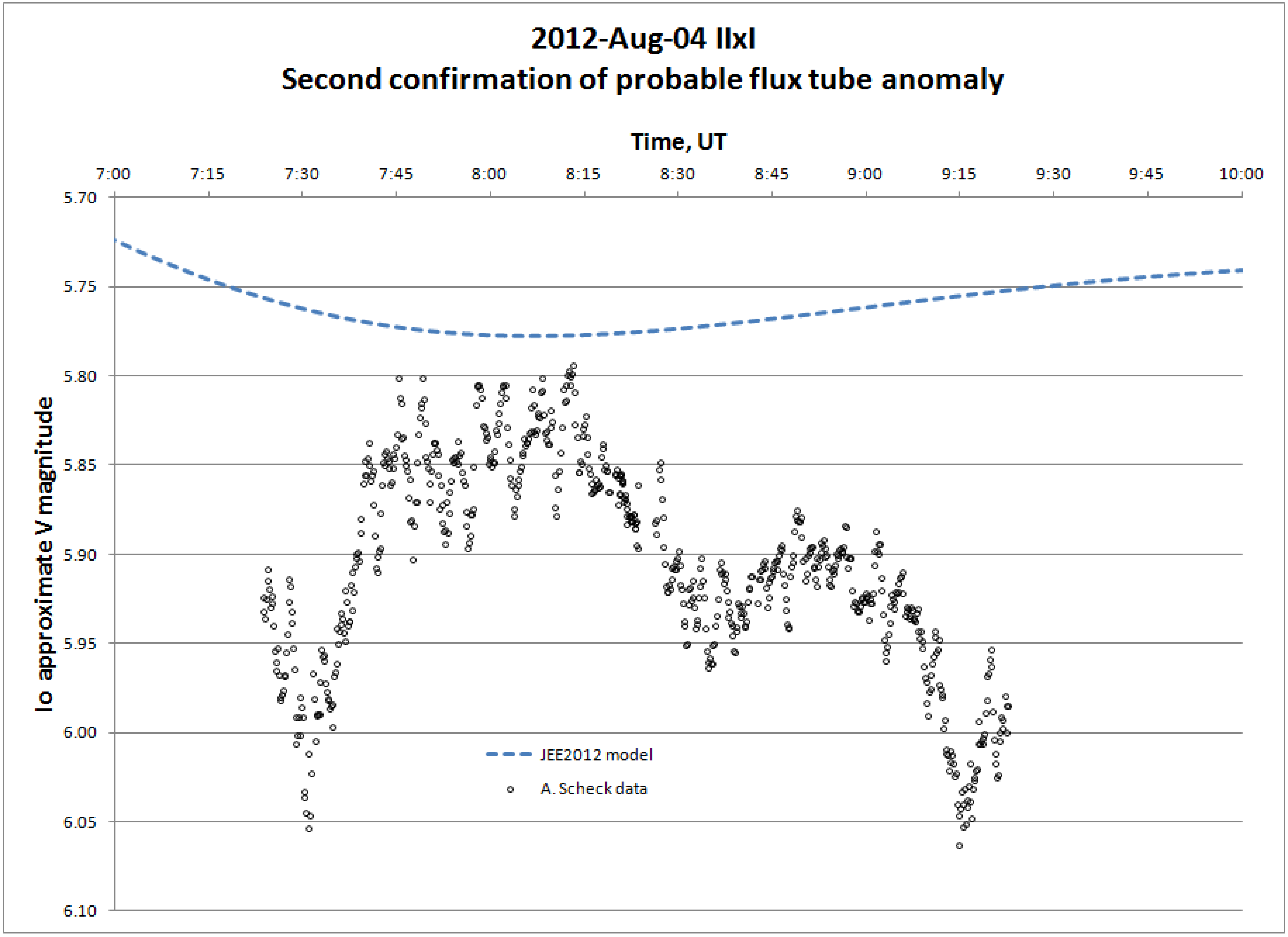


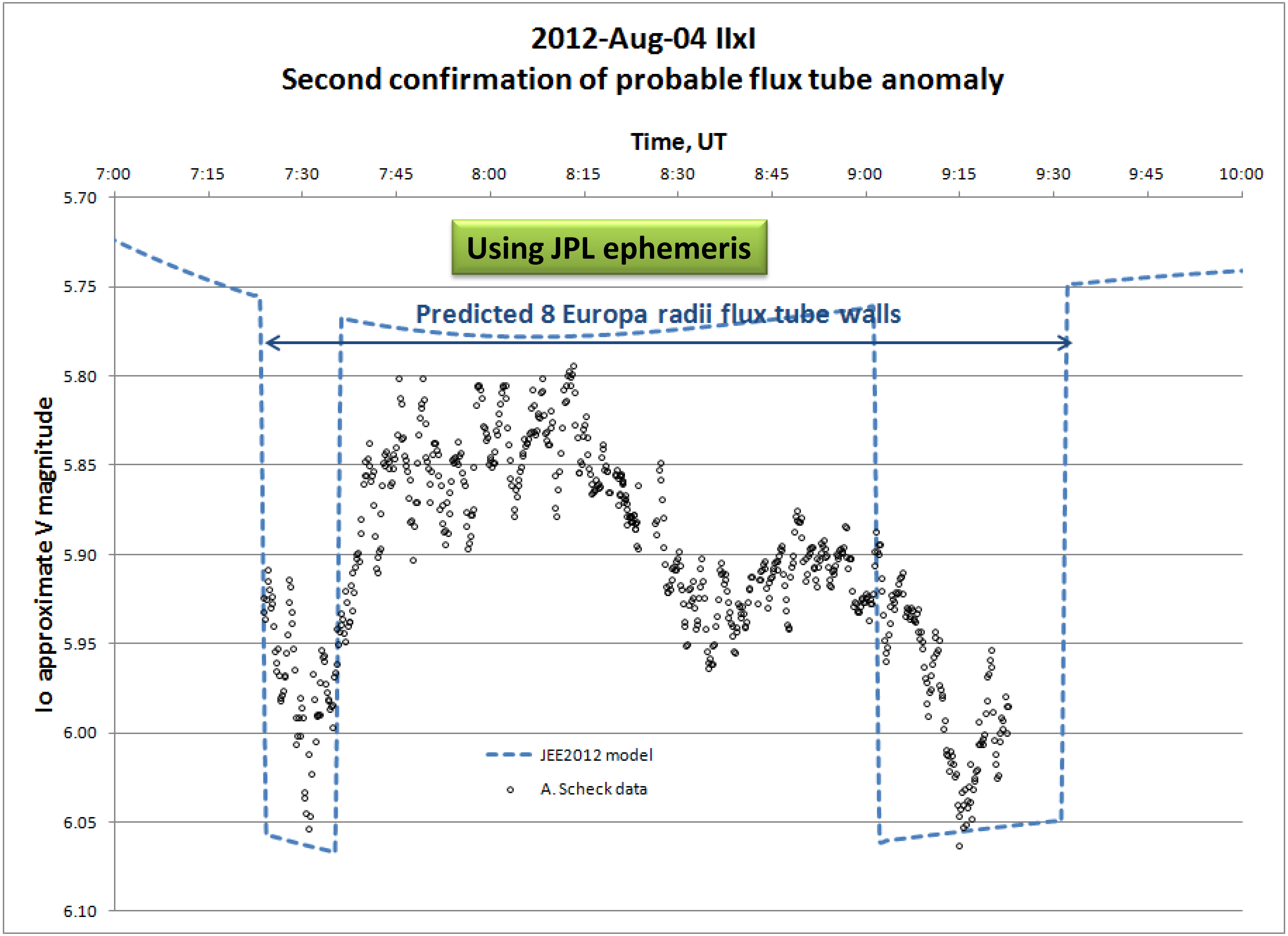
2012-Jul-25 IIXI IIXI TwXI JPL prediction compared to observed.
Time 2012-Jul-25 UT
8:15
8:30
8:45
9:00
9:15
9:30
9:45
10:00
10:15
10:30
10:45
11:00
11:15
11:30
5.70
5.75
5.80
5.85
5.90
5.95
Approximate V magnitude
start of Io Torus transit
Burger et al. 25 radii
JEE2010, 20 radii
S. Degenhardt
A. Scheck

Flux tube and plasma torus



. An electric current of five million amperes flows along Io's flux tube. It connects Io to the upper atmosphere of Jupiter, like a giant umbilical cord. The plasma torus is centered near Io's orbit, and it is about as thick as Jupiter is wide. The torus is filled with energetic sulfur and oxygen ions that have a temperature of about 100 thousand degrees kelvin. Because the planet's rotational axis is tilted with respect to the magnetic axis, the orbit of the satellite Io (*dashed line*) is inclined to the plasma torus.

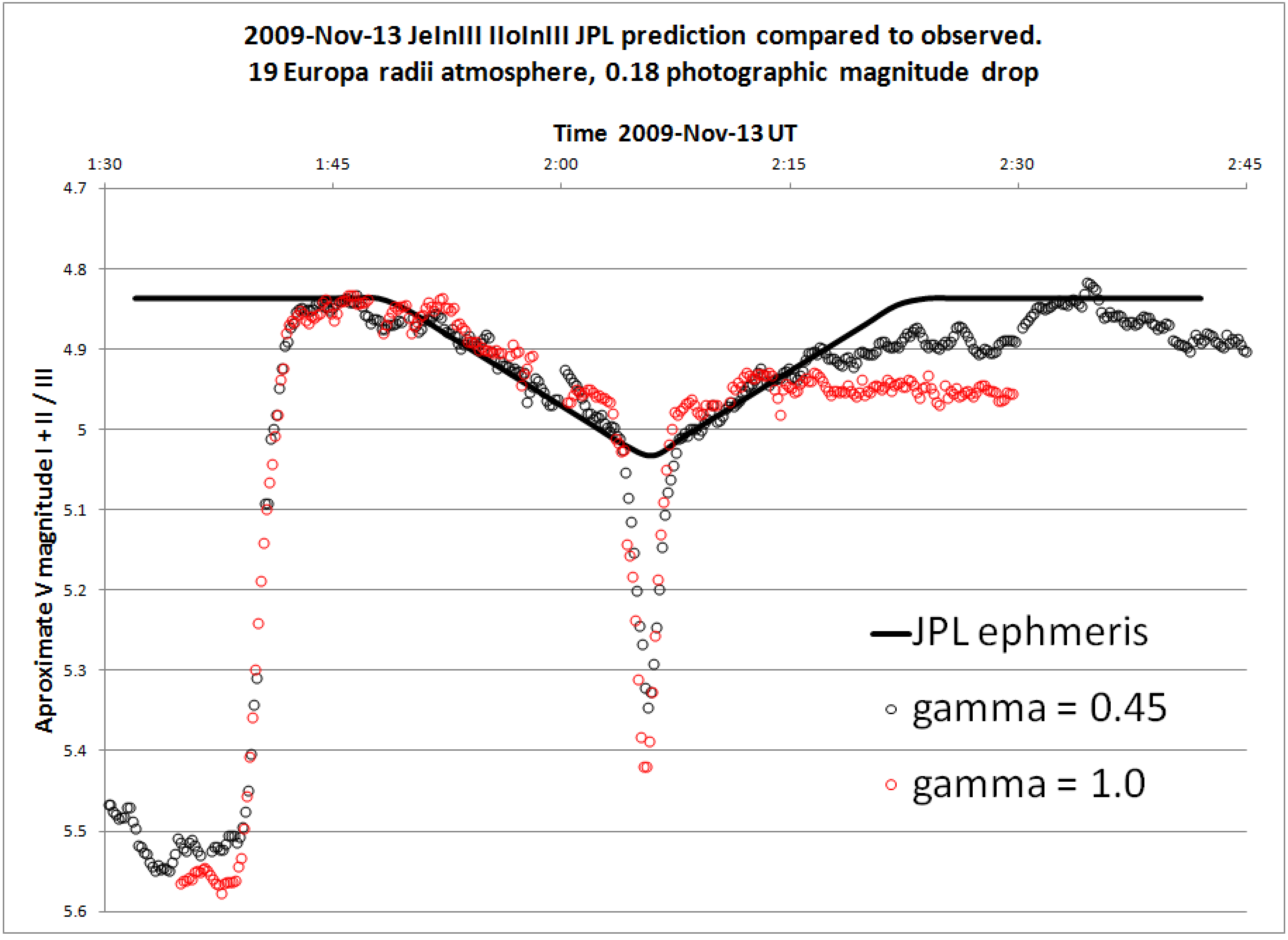

2012-Aug-04 IIxI
Second confirmation of probable flux tube anomaly
Time, UT
7:00
7:15
7:30
7:45
8:00
8:15
8:30
8:45
9:00
9:15
9:30
9:45
10:00
Io approximate V magnitude
5.70
5.75
5.80
5.85
5.90
5.95
6.00
6.05
6.10
JEE2012 model
A. Scheck data



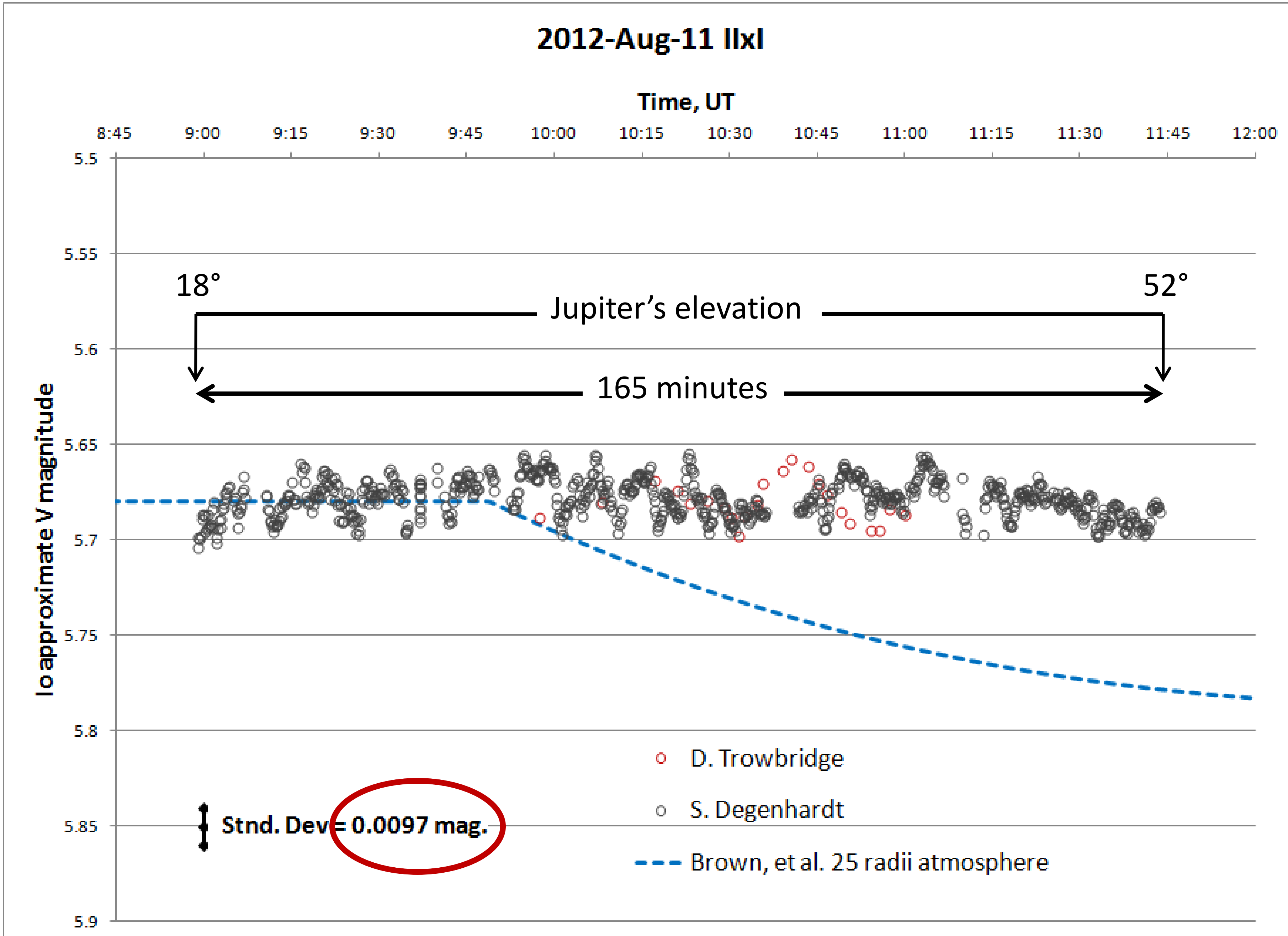
2012-Aug-04 IIxI
Second confirmation of probable flux tube anomaly
Time, UT
7:00
7:15
7:30
7:45
8:00
8:15
8:30
8:45
9:00
9:15
9:30
9:45
10:00
5.70
5.75
5.80
5.85
5.90
5.95
6.00
6.05
6.10
Io approximate V magnitude
Using JPL ephemeris
Predicted 8 Europa radii flux tube walls
JEE2012 model
A. Scheck data

Why video works well with JEEs

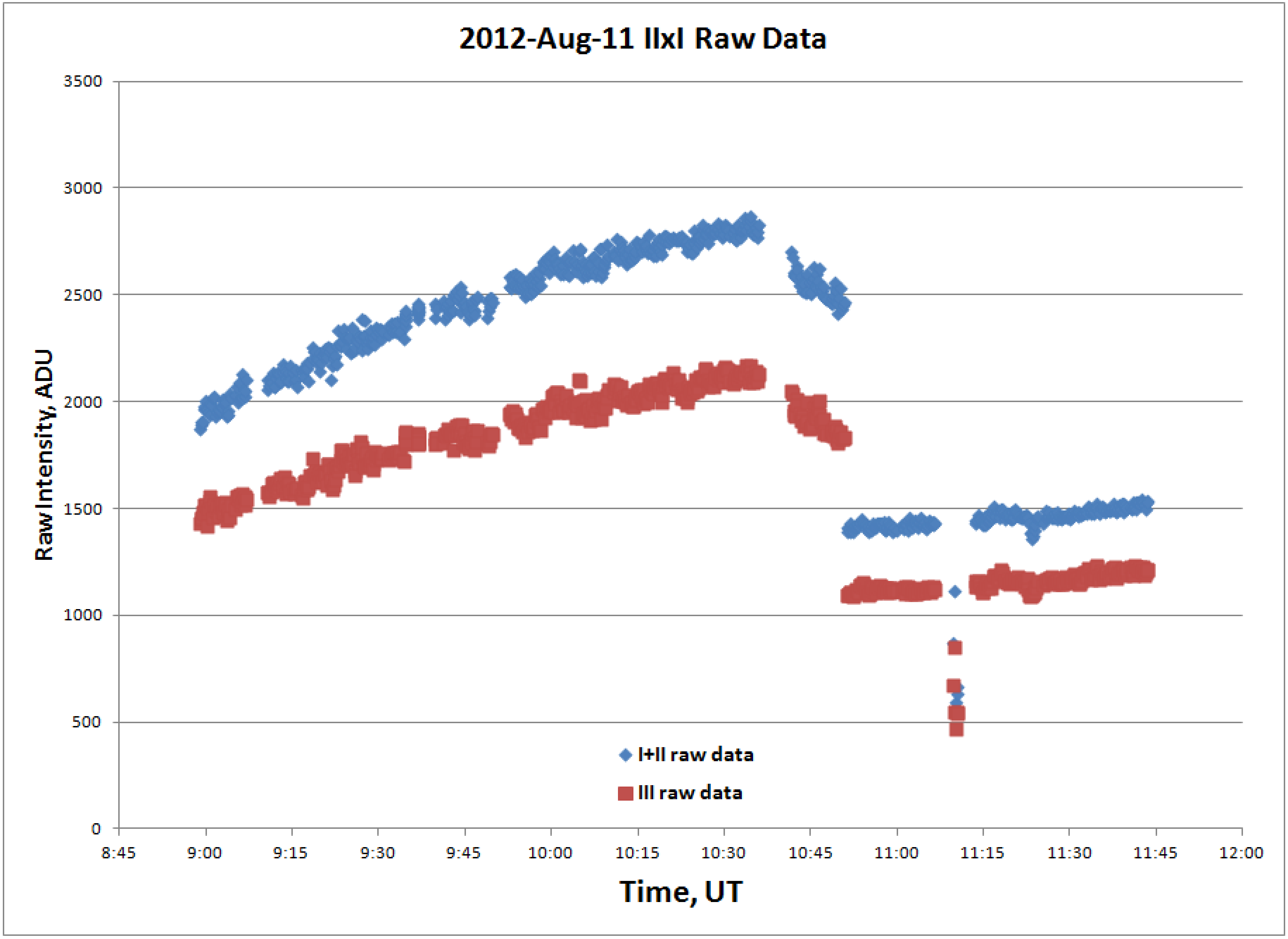
- From day one intensity change/time is our first order priority. Relative magnitude, not absolute magnitude.
- Targets are 5^{th} to 6^{th} magnitude making them accessible to any telescope system.
- The usual photometric reference, one of the other Jovian moons, is of near equal brightness to the target object making effects of gamma and non-linear CCD response minimal.
- The usual photometric reference, one of the other Jovian moons, is within tenths of a degree astrometrically from the target cancelling out earth's atmospheric extinction of the target intensity.
- High imaging rate renders excellent statistics. We first bin ~10 seconds of frames together (for NTSC = 300, PAL = 250) statistically eliminating scintillation effects (Warner, 2006). We then use an approximate 1 minute running average of the binned results increasing S/N even further. Binning large numbers significantly reduces effects of readout noise.
- With most drift in amateur telescope drive systems, non-uniformity in flatness of the CCD is randomized and thus statistically reduced with large binned data.
- With 256 ADU from camera, effective intensity resolution > 2×10^{16} (300*256= 76,800). Typical (Gaussian) standard deviation = 0.010 to 0.015 magnitude.

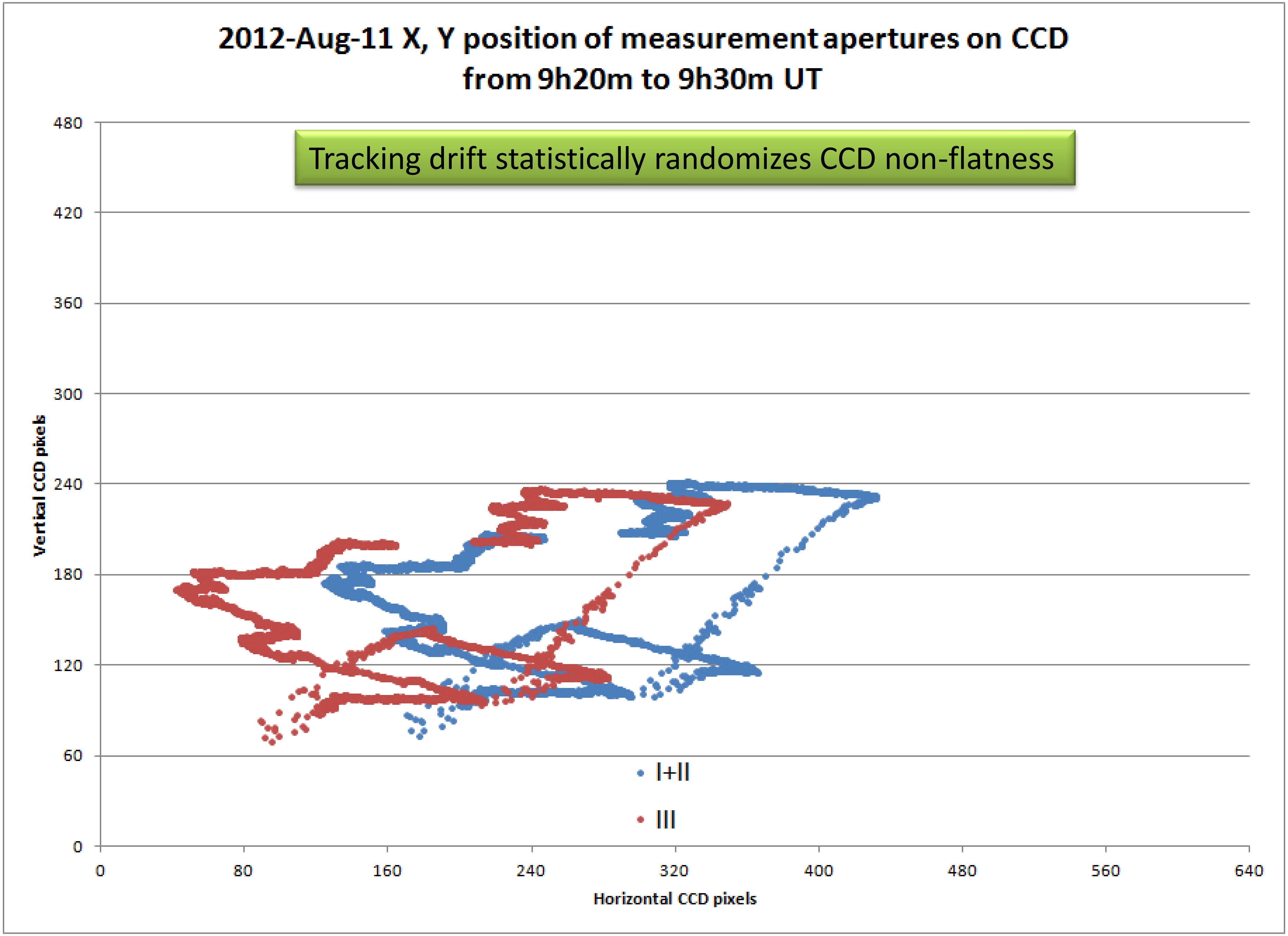


2009-Nov-13 JeInIII IIoInIII JPL prediction compared to observed.
19 Europa radii atmosphere, 0.18 photographic magnitude drop
Time 2009-Nov-13 UT
1:30
1:45
2:00
2:15
2:30
2:45
4.7
4.8
4.9
5
5.1
5.2
5.3
5.4
5.5
5.6
Aproximate V magnitude I + II / III
JPL ephmeris
gamma = 0.45
gamma = 1.0



2012-Aug-11 IIxI
Time, UT
8:45
9:00
9:15
9:30
9:45
10:00
10:15
10:30
10:45
11:00
11:15
11:30
11:45
12:00
5.5
5.55
5.6
5.65
5.7
5.75
5.8
5.85
5.9
Io approximate V magnitude
18°
52°
Jupiter's elevation
165 minutes
Stnd. Dev = 0.0097 mag.
D. Trowbridge
S. Degenhardt
Brown, et al. 25 radii atmosphere


2012-Aug-11 IIxI Raw Data
3500
3000
2500
2000
1500
1000
500
0
Raw Intensity, ADU
8:45
9:00
9:15
9:30
9:45
10:00
10:15
10:30
10:45
11:00
11:15
11:30
11:45
12:00
Time, UT
I+II raw data
III raw data



2012-Aug-11 X, Y position of measurement apertures on CCD
from 9h20m to 9h30m UT
Tracking drift statistically randomizes CCD non-flatness
Vertical CCD pixels
Horizontal CCD pixels
480
420
360
300
240
180
120
60
0
0
80
160
240
320
400
480
560
640
I+II
III

Conclusion

- JEE2012 Observing Campaign started in July 2012, multinational observers have signed up to contribute observations both video and CCD, unfiltered and multi-wavelength . Spectroscopic data sets are still desired.
- JEE2012 has now been extended to include Io Torus Tip JEE (ITTJEE) and Conjunction JEE (CJEE) searching for more flux tube confirmations.
- JPL O-C fits and lightcurve inversions are underway for every lightcurve in our JEE database.
- The JEE Project has many direct measurements of the material in the Jovian system that will be of benefit to the Juno Mission arriving at Jupiter in 434 days. http://www.nasa.gov/mission_pages/juno/main/index.html
- JEE techniques may prove valuable for probing exoplanets, as most are Jupiter like systems.

Observe!

Predictions, results, and discussions available @:

http://scottysmightymini.com/JEE/

(Every one in IOTA already possesses all the equipment necessary to make valuable JEE observations.)

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