The 2009 impact on Jupiter

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A report of the Jupiter Section (Director: J. H. Rogers)

On 2009 July 19 a new impact site appeared on Jupiter, similar to one of the mid-sized impacts of comet Shoemaker–Levy 9 (SL9), fifteen years earlier. It was a single, unpredicted event, which appeared as a very dark spot in the South Polar Region, and was bright in methane-band images. It retained a nearly black core for 12 days, then rapidly dispersed and fragmented, although dark streaks remained visible for more than two months after the impact.

During the week of the 25th anniversary of the first manned moon landing, Jupiter was bombarded by a comet. On the eve of the 40th anniversary, another impact occurred. This was noticed by Anthony Wesley at his home observatory just outside Murrumbateman, New South Wales, Australia, during regular imaging of the planet. He saw a new, unnaturally dark spot, resembling the SL9 impact scars, in the normally featureless South Polar Region (see Figure 1 and his web link).[1] With the excitement of the discovery compensating for the freezing temperatures, he immediately reported this apparent impact site to the astronomical community by e-mail. The spot was also recorded at about the same time by several observers in Japan.

The new impact site was in the South Polar Region, at 57ºS. In Wesley's images, it was first detected right at the limb at 14:02 UT. (It would then have been centred 74º from the CM.) It had a nearly-black oval core (5000km long), and a diffuse patchy fringe on the NW side (~9000km in radius) which no doubt represented the ejecta arc, indicating that the impactor came from that direction. It is possible that the ejecta became more arc-shaped during this first passage across the disk, either due to real evolution or due to the change in viewing angle.

The impact region had been virtually featureless up to that time. There was no visible scar on the previous rotation (images from the USA by Rich Jakiel, Paul Rix, and Fred Locklear), so the impact occurred on the dark side some time between 07:40 and 14:00 UT on July 19.

On its second rotation, early on July 20, various European observers took images confirming the impact site, which was also seen visually. Most importantly, Antonio Cidadão and Damian Peach both obtained methane-band images, which showed the impact site as a bright spot, confirming its very high altitude (Figure 3). The impact site was slightly less dark in near-infrared images. Subsequent observations confirmed these characteristics, and showed that the site remained undimmed right up to the limb (in visible or methane-band images) (Figure 3). All these were characteristics of the SL9 impact sites,[2–8] and not shown by any meteorological feature, as experienced observers all agreed.

Professional astronomers quickly turned infrared telescopes on Mauna Kea towards the impact site (Figure 1). Infrared observations on July 20 at the NASA-IRTF by Drs Glenn Orton and Leigh Fletcher not only confirmed the high-altitude cloud, they also detected a real 'smoking gun': '...evidence for high temperatures at the impact location, and suggestions of ammonia and aerosols that had been carried high into the atmosphere.'[9] Also on Mauna Kea on July 22, at the Gemini-North telescope, Dr Imke de Pater and colleagues found: 'The

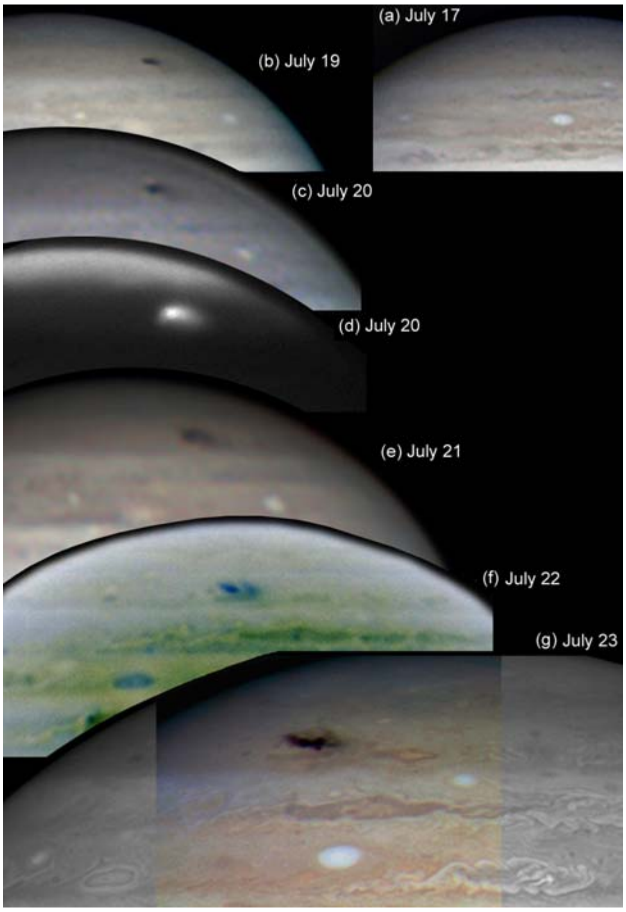

Figure 1. The best images of the impact site on each of the first 4 days.
(a) 2009 July 17, 14:53 UT. *A. Wesley (Australia).*
(b) July 19, 14:11.5 UT. *A. Wesley (Australia).*
(c) July 20, 01:13 UT. *A. Medugno (Italy).*
(d) July 20, ~12h UT. Infrared image at 1.65µ (the impact site appears bright). *Dr Glenn Orton & colleagues (NASA-IRTF, Hawaii).*
(e) July 21, 07:15 UT. *D. C. Parker (Florida).*
(f) July 22, ~13:30 UT. Infrared false-colour image at 8.7 and 9.7 microns, shown in negative. *I. de Pater (UC Berkeley), H. B. Hammel (Space Science Inst.), & T. Rector (U. of Alaska Anchorage). (Gemini-N Obs., Hawaii).*
(g) July 23, ~19h UT. Hubble Space Telescope WFC3. *(NASA, ESA, H. Hammel (Space Science Inst.), and the Jupiter Impact Team).*

Table 1. Observers

Imaging observers:

Australia: Trevor Barry, Stefan Buda, Paul Haese, John Kazanas, Darryl Pfitzner Milika, David Pretorius, Zac Pujic, Mike Salway, Matt Watson, Anthony Wesley. *Brazil:* Fabio Carvalho. *China:* Daniel Chang. *France:* Marc Delcroix, Michel Jacquesson, Christophe Pellier, Jean–Jacques Poupeau, Jean–Pierre Prost. *Germany:* Bernd Gährken, Torsten Hansen. *Iran:* Sadegh Ghomizadeh. *Ireland:* Carl O'Beirnes. *Italy:* Cristian Fattinnanzi, Paolo Lazzarotti, Raffaello Lena, Antonello Medugno, Tiziano Olivetti, Sergio Saltamonti, Andrea Tasselli. *Japan:* T. Mishina, S. Yoneyama, and others via the ALPO-Japan. *Namibia:* Jean Dijon. *The Netherlands:* Richard Bosman, Ralf Vandebergh. *New Zealand:* Maurice Collins. *The Philippines*: Tomio Akutsu, Chris Go. *Portugal:* Paulo Casquinha, Antonio Cidadao. *Puerto Rico:* Efrain Morales Rivera. *Spain:* Jaume Castella, Alan Fitzsimmons, Francisco San Emeterio, Jesus R. Sanchez, Jose A. Soldevilla. *USA:* Brian Combs, Ed Grafton, Richard Jakiel, David Kolb, Daniel Llewellyn, Paul Maxson, Larry Owens, Donald Parker, Jim Phillips, Michael Phillips, Theo Ramakers, Paul Rix, Sean Walker, Joel Warren, and others via ALPO. *UK:* David Arditti, Pete Lawrence, Bill Leatherbarrow, Damian Peach, Ian Sharp, Dave Tyler.

Visual observers in the UK:

Paul Abel, David Arditti, Peter Grego, Lee Macdonald, Andrew Robertson, John Rogers, Steve Ringwood, Dave Storey.

(Details of observers' locations and equipment will be given in the Jupiter Section's final report for 2009, to be posted on-line.)

impact site is clearly much warmer than its surroundings.'[10] The heating and the ammonia in the upper atmosphere could only have come from an explosion due to impact.

The Hubble Space Telescope was also quickly recruited, and produced superb images using the newly installed Wide Field Camera 3, whose calibration was interrupted to take these images.

Visual observers saw the impact site as a very dark spot which reminded them of the mid-sized SL9 impact sites. It was independently noticed by visual observers in the UK on its second rotation early on July 20, including David Arditti, Dave Storey, and Andrew Robertson ('not quite as dark as Io's shadow; it did also appear elongated'). On July 22/23 it was observed visually by John Rogers, Paul Abel, and Steve Ringwood (133mm refractor: 'much darker than any other feature on the disk, although not as dark as a moon shadow'). On July 24/25 it was drawn by three observers,[11] and visual observers continued to follow it until August 8 (Peter Grego).

The impact soon became known as the 'Bird Strike', since Wesley's nickname is Bird. After a week, it had shown only modest changes, but was visually even more impressive than on its first rotation. The core remained nearly black, and became more elongated. The ejecta arc quickly became blurred, appearing as a smaller but darker fan or patch following the core. But from July 29 onwards, the site started to spread out quite rapidly (Figures 3 and 4). (More extensive compilations of images are on the Jupiter Section website.[12])

Because this event occurred in a region undisturbed by weather systems or by other impacts, it provided an excellent probe of the atmospheric currents. At the impact latitude of 57ºS, spacecraft data show that the cloud-top mean wind speed is weakly retrograde: it lies mid-way between prograding jets at 53ºS and 61ºS. As with the SL9 events, the scar was expected to have two components:

1) The nearly-black core, where the impactor exploded below the cloud-tops; black smoke convects upwards from below the clouds, as well as lying in the stratosphere.

2) A more extensive layer of smoke in the stratosphere, initially deposited from the ejecta 'splash-back'.

The drift and latitude measurements are displayed in Table 2 and Figure 5; Figure 5c compares them with the mean east-west wind speeds measured by the *Cassini* spacecraft.[13] The core of the site remained almost stationary (initial L2= 216; 57ºS; July 19–27), though elongating gradually to E and W. This early nearly-black spot may have been larger than the true core beneath, which became apparent from July 29 onwards with retrograding motion. The motion of the true core is probably best represented by the retrograding motion of the following (W) end of the site (DL2= +7º/month; 56.5ºS; July 20–Aug.12). This is not quite as rapidly retrograding as the local wind speed (+12º/month), suggesting that the impact core may be in a more sluggish current below the cloud-tops. It is very similar to the mean speed for the cores of the SL9 sites (–2º/month), although the latter were situated at a different latitude.[3]

A small dark streak detached from the NW end and prograded rapidly eastward (July 29 to Aug 9). At 54ºS, it was close to the prograding jet-stream at 52.5ºS, and was probably a cloud of smoke from the core which was caught in this current. On Aug 1–3 it apparently curled southwards again so that the impact cloud encircled a light oval, although this was not a persistent feature. Meanwhile the S edge of the site

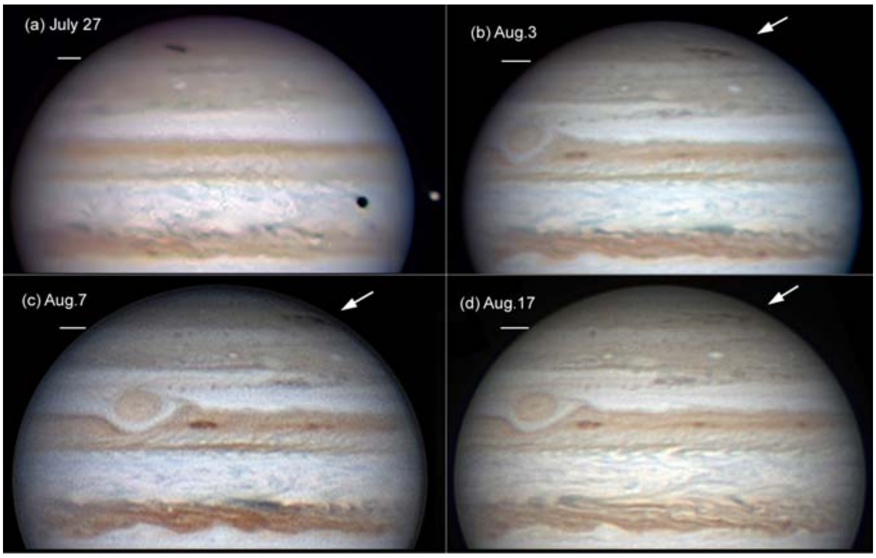

Figure 2. Some of the best images showing the later evolution of the impact site (arrowed). White line indicates the SPRn edge which lies along the prograding jet at ~52.5°S.
(a) July 27, 03:15 UT. *Paulo Casquinha (Portugal),* 356mm Celestron-14. Compare impact site with shadow of Io.
(b) Aug 3, 12:36 UT. *Anthony Wesley (Australia),* 370mm Newtonian.
(c) Aug 7, 15:15 UT. *Darryl Pfitzner Milika (Australia)*, 280mm C11.
(d) Aug 17, 13:53 UT. *Trevor Barry (Australia).*

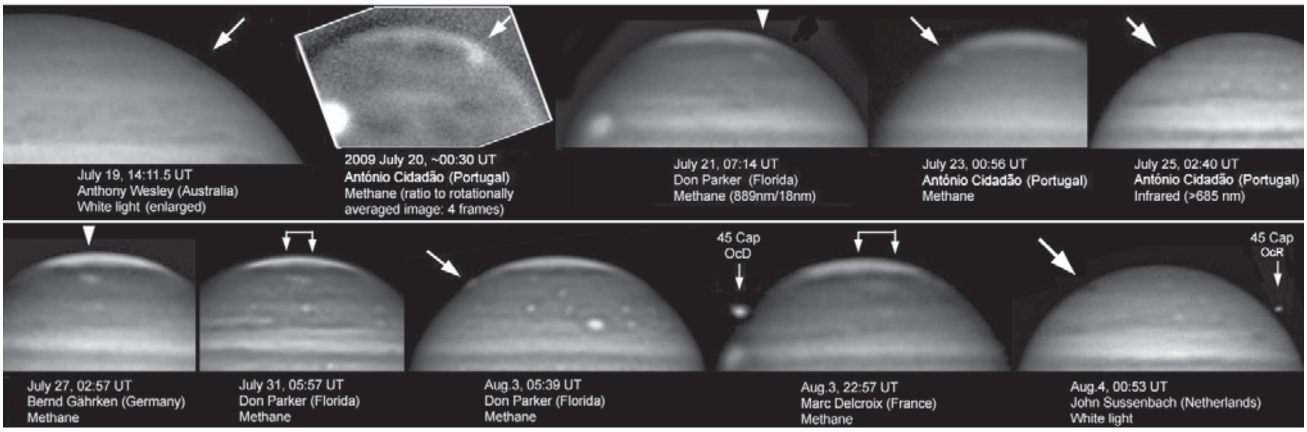

Figure 3. Set of methane-band and near-limb images, showing that the impact debris was at very high altitude. The bright cloud in methane-band images was co-extensive with the dark cloud in visible light. These images were taken with filters centred at 889nm, width 18nm (except Gährken, 12nm). Several images are included to show the impact cloud very near the limb, both in methane-band and visible light: in these images the elongation was 68° on July 19 (it was actually detected at 14:02, elongation 74°); 74° on Aug 3, and 51–57° on other dates. The last two images also show the occultation of the star 45 Cap.

elongated rapidly eastwards (–22º/mth, July 20 to Aug 13, 58.5ºS). The mean speed at this latitude is close to zero, so the prograding drift may be special to the stratosphere, as was the case with the extended dark clouds around the SL9 impact sites (mean speed –18º/mth).[3]

The impact site was still nearly black up to August 1, but observers noted it was fainter on August 2 as it stretched out. From Aug 5–11 the site was an oblique dark streak, breaking up into three parts including the core at the NW end which remained the darkest. All the parts except the core had similar prograding drift (Figure 5). By Aug 11–12, it covered >30° longitude, and was still detectable right up to the E or W limb, showing that it was still in the stratosphere. On Aug 12, it was fragmenting much more, forming seven or eight small clouds which rapidly dispersed. By Aug 17 these were dispersed from L2~183–230. However they remained confined between latitudes 53–59ºS throughout. By then, they were no darker than many spots elsewhere on the planet, but they were still detectable right up to the limb in both visible and methane images on Aug 24. Two of the darkest fragments persisted in late August, distorted into oblique streaks, indicating that their Np. ends were again being accelerated by the prograding jet at 52.5°S. Meanwhile the albedo boundary that marks this jet developed notable waves preceding the impact site, from about Aug 7 onwards (Figure 2: jet marked by white lines); such waves had been weaker or absent before the impact.

The development of the scar is best displayed in polar projection images (Figure 4). Theo Ramakers (ALPO) has put these into an animation showing vividly the progression of the scar.[14] Another dramatic rendition of the event was posted on *YouTube*.[15]

Overall, the appearance and behaviour of this impact site were very similar to those of the medium-sized SL9 fragments (E, H or Q1), which became larger over the first few days and remained visible for several weeks. It particularly resembled E in both initial appearance[6] and timecourse of dispersal.[3] The ejecta arc of this impact was rather small and faint relative to its dark core, but that was also the case for both the smaller and the later SL9 impacts, so it may be a sensitive function of the depth of the terminal explosion and/or the angle of impact. Slight differences could also give clues to the density and the

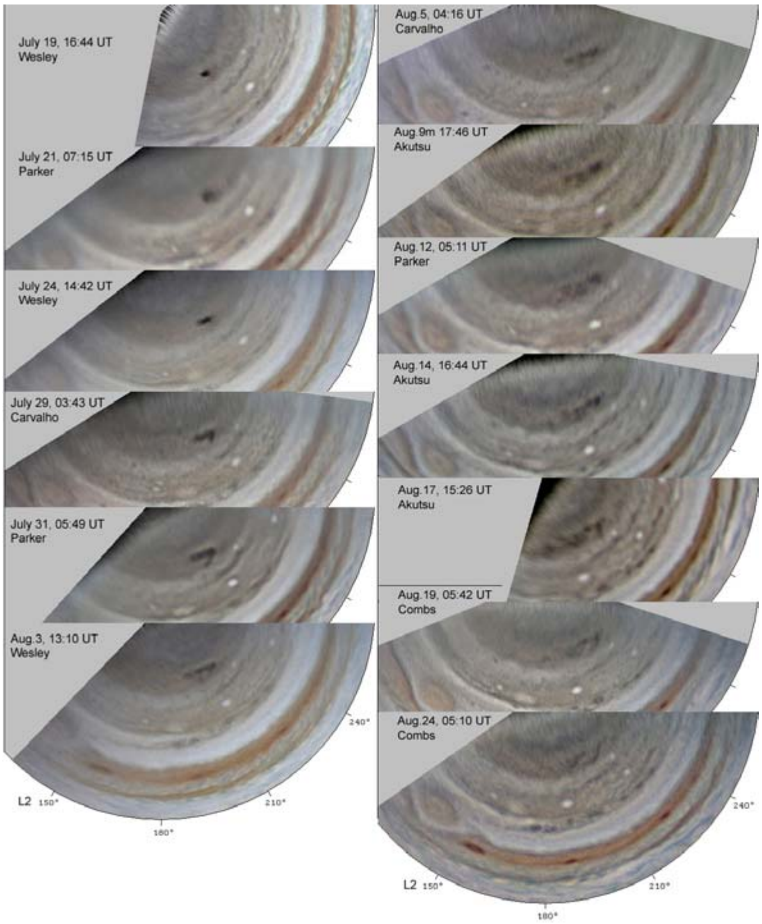

Figure 4. Polar projection maps, made by H–JM and the *JUPOS* team, from images by A. Wesley, D. C. Parker, F. Carvalho, T. Akutsu and B. Combs. These are mapped onto a stereographic polar projection using *WinJUPOS*. Longitudes in System 2. Note that bright strips flanking the dark impact site (especially on the southern side), on the images and on these maps, are probably artefacts caused by image processing. Also see an animated version of the whole series.[14]

speed of the impactor, which could both be higher for a single extraneous object than for the SL9 fragments which had reassembled in orbit around Jupiter.

One clear difference was in the angle of approach: the SL9 fragments came from the SE, this one from the NW. This clarifies our observations of the rapid dispersal of the debris clouds to the E: as the drift rates were similar for both SL9 and this impact, these drifts probably relate to material drifting out from the dark core, not the ejecta arc, which on this occasion was a short-lived feature to the NW. The present impact however has not dispersed in latitude as much as some SL9 sites. Cloud streams from the large SL9 impacts, although initially at lower latitude, reached 66°S – probably derived from the large stratospheric ejecta arcs, which were much more extensive in those cases.[3,16]

What of the impactor itself? It is most likely to have been a comet nucleus (which would probably be inactive at that distance from the Sun), or it could have been a stray asteroid. If it was similar in size to a mid-sized SL9 fragment, it would only have been ~200–400m across.[4] Therefore it is not surprising that it was not detected before the impact: this would hardly be possible for such a small object, as even the smallest known satellites of Jupiter are 1–2km in diameter. SL9 was only detected because it had been disrupted while orbiting Jupiter, vastly increasing its brightness.

Nothing on the scale of the larger SL9 impacts had been seen in the previous 300 years,[3] and this is consistent with estimated frequencies of comets of this size. Therefore it might seem surprising that the present impact occurred only 15 years later. But impacts like this are smaller and likely to be more frequent. Although there are no definite records of such an impact before 1994, they could have been missed during times of poor coverage, or mistaken for normal weather systems if they occurred at lower latitudes. They are much more likely to be detected now that there is very frequent and high resolution coverage of the planet.

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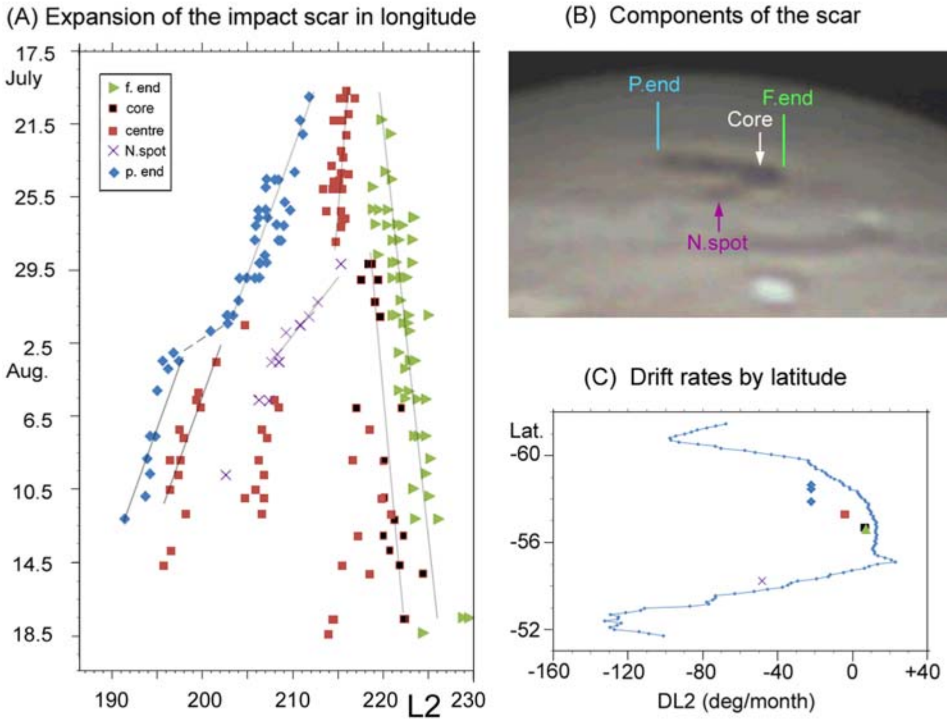

Figure 5. Expansion of the impact scar, from *JUPOS* measurements of longitude (System 2) and latitude (zenographic): data summarised in Table 2.
(A) Expansion of the impact scar in longitude.
(B) Components marked on an image of the impact site (July 31, 05:49 UT, D. C. Parker).
(C) Drift rate vs. latitude for the different components, compared with the mean zonal wind speeds from *Cassini* spacecraft images.[13]

Table 2. Latitudes and drift rates for components of the impact scar

Component	*Dates*	*Lat.*	*SD*	*DL2 (°/mth)*	*μ (m/s)*	*N*	*DL2 (Cassini)*
Centre	July 19–27	−57.3	0.29	−4	−1.1	30	10
F. end	July 21–Aug 12	−56.5	0.45	7	−4.2	48	13
Core	July 29–Aug 17	−56.7	0.51	6	−3.9	23	13
C. of p. patch	Aug 1–10	−58.4	0.16	−22	3.7	11	−1
P.end	July 20–27	−57.9	0.71	−22	3.8	22	7
P.end	July 29–Aug 1	−58.5	0.65	−22	3.7	15	−1
P.end	Aug 3–13	−58.4	0.49	−22	3.7	15	−1
N. spot	July 29–Aug 9	−54.2	0.43	−48	11.7	13	−29

Derived from data in Figure 5. Columns are: Component of impact scar; Dates measured; Latitude (zenographic); standard deviation for latitude; drift rate in System 2 (DL2, degrees per 30 days); equivalent speed in System 3 (m/s); number of observations used; mean zonal wind speed (DL2, degrees per 30 days) at the same latitude as measured from *Cassini* images.[13]

Note added in proof

Although the impact site was inconspicous after August, it was still detectable as an ill-defined dark streak in the original latitude, especially when near the limb, at least up to Sept 28. In October, while a faint diffuse trace may still be suspected in a few images, it cannot be clearly distinguished from a normal appearance. – *JHR, 2009 Nov 4*

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