Small impacts on the Giant Planet Jupiter

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49th Meeting of the AAS Division for Planetary Sciences
Shoemaker-Levy 9 July 16-23, 1994

A Jupiter family comet (~ 2 km in diameter) fragmented by gravitational tides resulting in 16 fragment impacts (6 large impacts).

At the time this was coined as “a once in a lifetime event”


July 19, 2009:
Anthony Wesley discovers an impact scar in Jupiter

Size of the impact object: 0.5-1.0 km

Possible asteroidal nature: Orton et al. Icarus (2011)


(Background: HST image of the G impact site)
2010: A fireball in Jupiter’s atmosphere!

June 3, 2010 at 20:31:20 UT. Casual Jupiter observation by A. Wesley with a 15” telescope, a 60fps camera & a red filter. The second impact in Jupiter found by a single person!

Flash ~ 1/6000 Jupiter brightness
Equivalent to a +6.5 magnitude star
Time duration about 1 s

Flash simultaneously observed by an amateur in Phillipines (Christopher Go) using a 11” telescope, similar camera and a blue filter.

Fast campaign to detect a debris field in the atmosphere (HST, VLT, Gemini, Keck, IRTF, ...). No debris found!

Analysis of both light-curves and lack of observable debris →
Flash caused by an impact of a **8-13 m object** releasing 1.5 - 3.0x10^{13} J of luminous energy

... since then... 4 more flashes (11 videos & 12 observers) in 8 years

June 3, 2010
Anthony Wesley (Australia)
Christopher Go (Phillipines)

August 22, 2010
Masayuki Tachikawa,
Kazuo Aoki,
Masayuki Ishimaru (Japan).

September 10, 2012
Dan Petersen – visual alert and accurate magnitude estimation!
Video by George Hall (USA).

2013-2015
--- No detections ---

March 17, 2016
Gerrit Kernbauer (Austria)
John McKeon (Ireland).

May 26, 2017
Sauveur Pedranghelu (France),
Thomas Riessler (Germany),
Andre Fleckstein (Germany).

Diversity of telescopes (from 6” to 14”), cameras, speeds, filters, seeing,...
Analysis of flashes light-curves

Differential photometry + Image calibration using Jupiter integrated flux as a reference

Impacts of objects of sizes: 5-15 m releasing energies of 45-450 kTns

(Chelyabinsk impact-like)

Impact on May 26, 2017@19:25UT - Lightcurves examples

**Original image**

**Differential photometry**

“Average” impact location

Impact location adjusted &
Aperture photometry with background substraction (over an outer ring)

+ Light-curves in RGB channels in both observations

+ Additional light-curve from A. Fleckstein video observations (IR)

(all with lower quality and detail)

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**Sauveur Pedranghelu: Video at 61.79 fps**

- Photometric line (Average 7 frames)
- Full duration: 1.10-1.39 seconds
- Visual duration: 0.70 s
- Integrated light: 36244 DNs in 1.39 s
- Faint increase and first flash: 25% of the total
- Central flash: 54% of the total
- Faint tail: 21% of the total

**Thomas Riessler video at 30.78 fps (lower quality than the previous video)**

- Photometric line (Average 7 frames)
- Full duration: 0.88 s
- Only a part of the flash is recovered

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**Relative frame number**

**Total Excess DNs**

**Noise level**
Impact on May 26, 2017@19:25UT - Energy calibration

1) Integrated photometry of Jupiter disk + Solar constant at Jupiter’s distance: 45.77 W/m²

2) Convolution of Solar Spectrum+Camera response+Jupiter spectrum

3) Integrate light-curve (5-20% error) & Geometric correction → Detected Luminous energy

4) Computing the total luminous energy
   “Detected energy” into total luminous energy from the deconvolution of Placnk’s black body law with filter and camera responses

   \[ T_{BB} = [3500-8500] \text{ K} \rightarrow \text{Factor of 2 uncertainty in energy calculation} \]

   Earth’s fireballs, SL9 impacts, 2010 Jupiter fireball in R/B filters

5) From luminous energy to kinetic energy of the impactor

   \[ \eta = 0.12 E_0^{0.115} \]

   Efficiency factor converting kinetic energy to luminous energy where \( E_0 \) = luminous energy in ktn (based on observations of Earth bolides). Adapted from Brown et al. Nature (2002)
### Results: Energies, Masses & Sizes of all Jupiter fireballs

#### Assumptions on the collision

- **Impact velocity:** \( v \approx 60 \text{ km/s} \)
- **Luminous efficiency:** \( \eta \approx 0.16 - 0.22 \)
- **Density:** \( \rho \approx 2.0 \text{ g/cm}^3 \)
- **Density:** \( \rho \approx 0.6 \text{ g/cm}^3 \)

#### Impacts reported in Hueso et al. 2013

<table>
<thead>
<tr>
<th>Date</th>
<th>Energy</th>
<th>Mass</th>
<th>Size (diameter)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>June 3, 2010</strong></td>
<td>( 1.9 - 14.0 \times 10^{14} \text{ J} )</td>
<td>( 46 - 350 \text{ ktn} )</td>
<td>( D \approx 4.7 - 9.1 \text{ m} )</td>
</tr>
<tr>
<td></td>
<td>( 3.7 - 11.0 \times 10^{14} \text{ J} )</td>
<td>( 88 - 260 \text{ ktn} )</td>
<td>( D \approx 7.0 - 14 \text{ m} )</td>
</tr>
<tr>
<td><strong>August 20, 2010</strong></td>
<td>( 8.7 - 13 \text{ m} )</td>
<td>( 205 - 610 \text{ Tn} )</td>
<td>( D \approx 5.8 - 8.4 \text{ m} )</td>
</tr>
<tr>
<td><strong>Sept. 10, 2012</strong></td>
<td>( 9.0 - 17.0 \times 10^{14} \text{ J} )</td>
<td>( 215 - 405 \text{ ktn} )</td>
<td>( D \approx 7.8 - 9.7 \text{ m} )</td>
</tr>
<tr>
<td><strong>May 26, 2017</strong></td>
<td>( 1.3 - 2.3 \times 10^{14} \text{ J} )</td>
<td>( 32 - 55 \text{ ktn} )</td>
<td>( D \approx 4.1 - 5.0 \text{ m} )</td>
</tr>
<tr>
<td><strong>March 17, 2016</strong></td>
<td>( 5.6 - 11.2 \times 10^{14} \text{ J} )</td>
<td>( 135 - 270 \text{ ktn} )</td>
<td>( D \approx 6.7 - 8.4 \text{ m} )</td>
</tr>
<tr>
<td></td>
<td>( 310 - 620 \text{ Tn} )</td>
<td>( D \approx 10.0 - 12.6 \text{ m} )</td>
<td></td>
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<td><strong>March 17, 2016</strong></td>
<td>( 5.6 - 11.2 \times 10^{14} \text{ J} )</td>
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#### Latest Jupiter impacts

- **Chebyalinsk-like events [450 ktn] and 5-60 times less energetic than Tunguska (3000-5000 ktn)**
- **1-3x10^{-6} less than the combined SL9 impacts (300.000 kTn)**
How large must an object be to leave a visible feature on the planet?

**HST observations of SL9 impact debris**

**Galileo light-curves of SL9 fragment impacts**

**Extensive numerical simulations**

Fragment N had an estimated size of 45 m with a mean density of 0.25 g/cm³

Crawford, Annals of the NY Academy of Science, 1997

**SL-9 fragment N:** 14 times more massive than the largest possible mass for the flash detected in September 2012 or 180 times more massive than the smallest flash detected in May 2017.
How representative are these flashes of similar undetected impacts in Jupiter?

Statistical analysis of amateur images contributed to the PVOL2 database [http://pvol2.ehu.es](http://pvol2.ehu.es) (17643 images since 2010)

The efficiency of detecting impacts by the amateur community increases with oppositions moving towards summer in the north hemisphere.

### Jupiter oppositions

- **2010 Sept. 21**: Australia, Philippines
- **2011 Oct. 29**: Japan
- **2012 Dec. 3**: USA
- **2014 Jan. 5**: Austria, Ireland
- **2015 Feb. 6**: France, Germany
- **2016 March 8**: South Africa
- **2017 April 7**: Brazil

### Geographical location of observers

- **Good weather (North hemisphere)**
  - Spring-Summer North hemisphere
- **Bad weather (North hemisphere)**
  - Autumn-Winter North hemisphere

### Image Statistics

- # Images from Low latitudes: 21%
- # Images from North latitudes: 65%
- # Images from South latitudes: 16%
Increasing the numbers: DeTeCt 2.1 & DeTeCt 3.0 | Software tools for amateurs

1000’s of Terabytes of Jupiter’s observations in the hard-drives of the amateur community!

Differential photometry of video observations shows the impacts better than the eye can see.

Marc Delcroix’s DeTeCt 2.1: Largest effort to find more impacts on analysis of video observations


Command line software used by >70 collaborators analyzing >70,000 videos worth 83 days sparsed over a decade

Log files of negative detections are later analyzed

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<th>Observer</th>
<th>Duration</th>
<th>Number of videos</th>
<th>Date range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total: 71 observers</td>
<td>83.636 days</td>
<td>71196 videos</td>
<td>2004/02/29 - 2017/07/16</td>
</tr>
</tbody>
</table>

DeTeCt3.0: UPV/EHU + Marc Delcroix (Funded by Europlanet-2020 RI)

http://pvol2.ehu.eus/psws/jovian_impacts/

But most of the observations are under bad conditions and the software does not find the impacts in the worst observations.
Estimation of the number of comparable Jupiter impacts per year

Global estimate: [5-30]

22-130 “total flux” of 5-20-m size impacts per year

We only observe 9/12 months and 1/3 of the planet

Original estimation in 2013 with 3 flashes from a qualitative assessment of distribution of observations [5-50]

Higher than [4.4] (Detect project)

Monte-Carlo simulations with temporal coverage 25% (longitudinal distribution of observers) + 50% weather + 50% quality or detection capability [5 -15]

2 impacts in 2 months in 2010 require a higher flux of impacts

[4.5-45] (same arguments with 5 impacts in 8 years)

[7.5-45] (correction from bad weather in the Northern hemisphere)

1 impact in 8 years accumulated time of about 400 hrs A. Wesley & C. Go

Improbability of a single observer finding 2 impacts in 9 years (A. Wesley)

2 impacts in 400 hours

Absolute minimum [0.67]

(6 impacts in 9 yrs counting the 2009 impact)
Updated Flux of impacts in Jupiter & Conclusions

- A “huge flash” leaving an observable debris field could be observable in Jupiter every 5-15 years on average when correcting from the time we observe Jupiter.

- An small debris field caused by the impact of a 300-400 m size objects could occur once every 5-10 years and could be detectable once every 7-12 years for about one week for “regular” amateur observers.

- Juno’s continuous motivation of amateur and professional observers will help to find more impacts the next year with a Jupiter opposition on May 9.