Flux of impacts in Jupiter: From super bolides to larger scale collisions

R. Hueso[1], A. Sánchez-Lavega[1], S. Pérez-Hoyos[1], A. Wesley[2], C. Go[2], M. Tachikawa[2], K. Aoki[2], M. Ichimaru[2], M. Delcroix[2] and J.C. Moreno[2]

[1] University of the Basque Country, Bilbao (Spain)

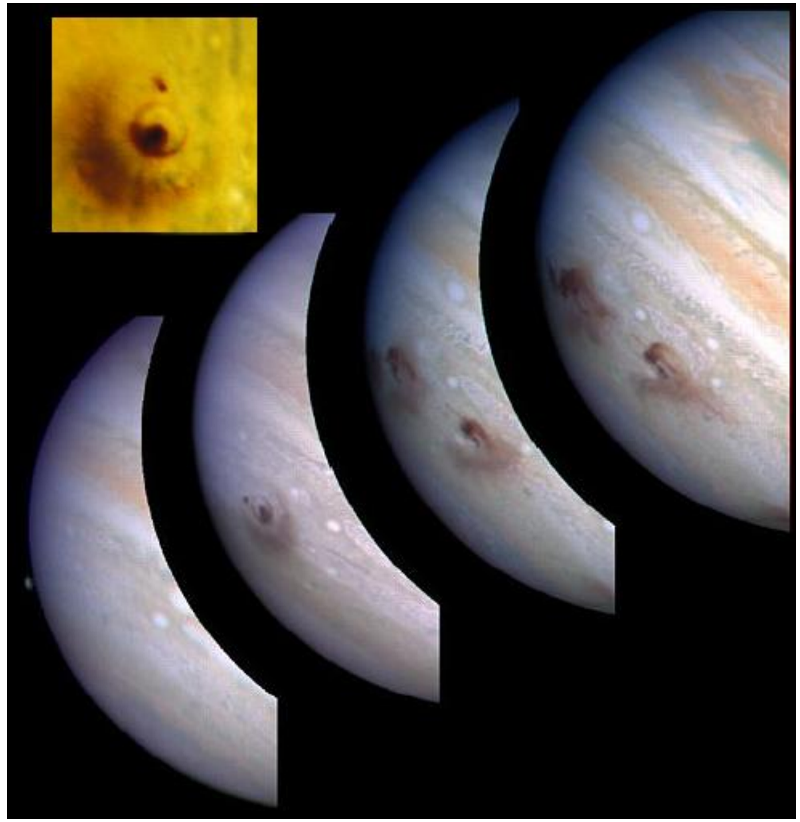
[2] Amateur observers from Australia, Philippines, Japan, France & Spain

Jupiter impacts

Shoemaker-Levy 9 July 1994

A "once in a lifetime event"

Jupiter Family Comet fragmented by gravitational tides



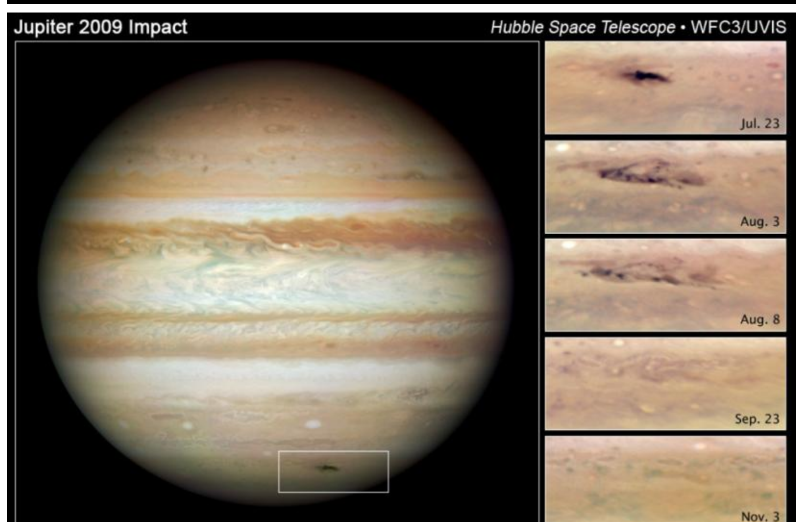
Unexpected 0.5 km   July 2009

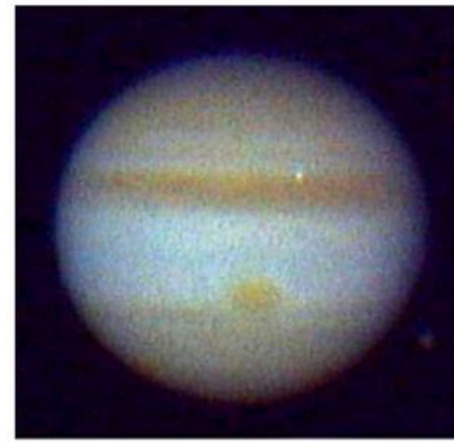
Discovered by Anthony Wesley (australian amateur astronomer) hours after the impact.

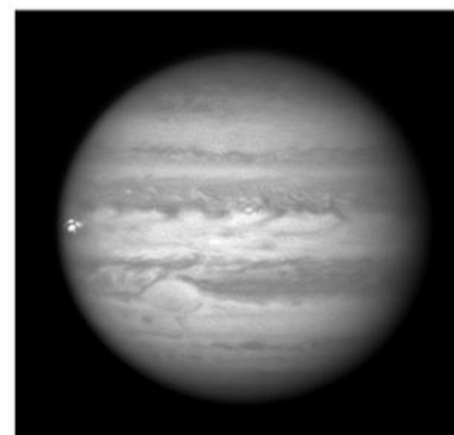
Completely unexpected.
Debated asteroidal nature

See report by
Sánchez-Lavega et al. ApJL (2010)

See poster PDC13-05-04P by Sánchez-Lavega et al.



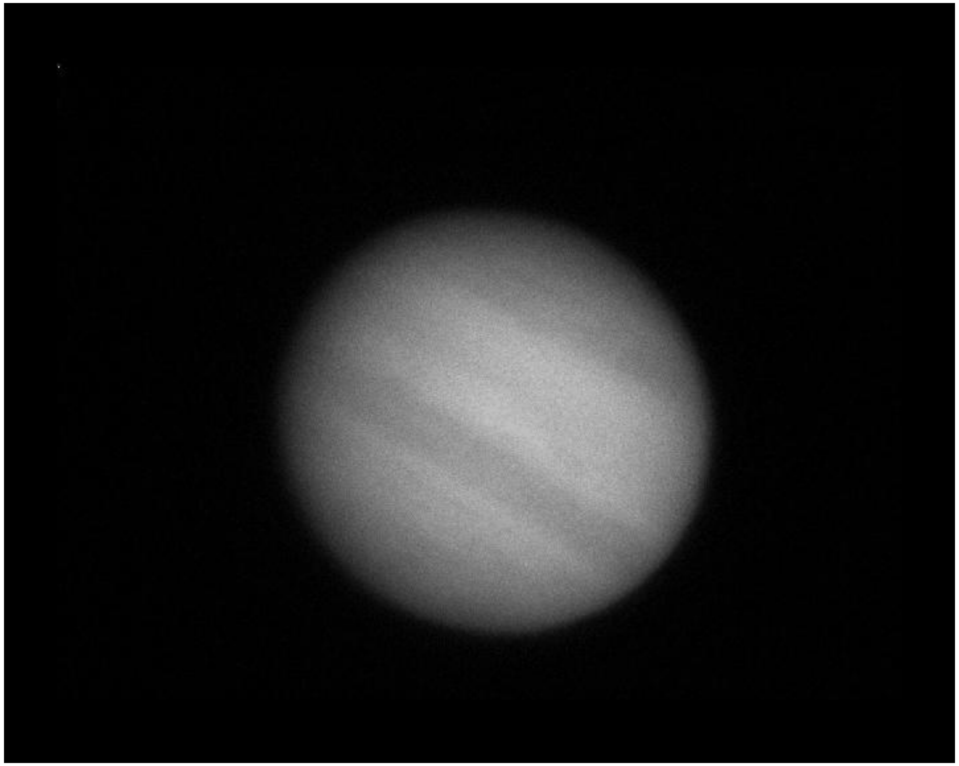




A fireball in Jupiter's atmosphere:
Video data in red wavelengths by A. Wesley (New South Wales, Australia)

Data obtained during a normal Jupiter observing session on June 3, 2010 at 20:31:20 UT

Video data from Anthony Wesley (Australia)



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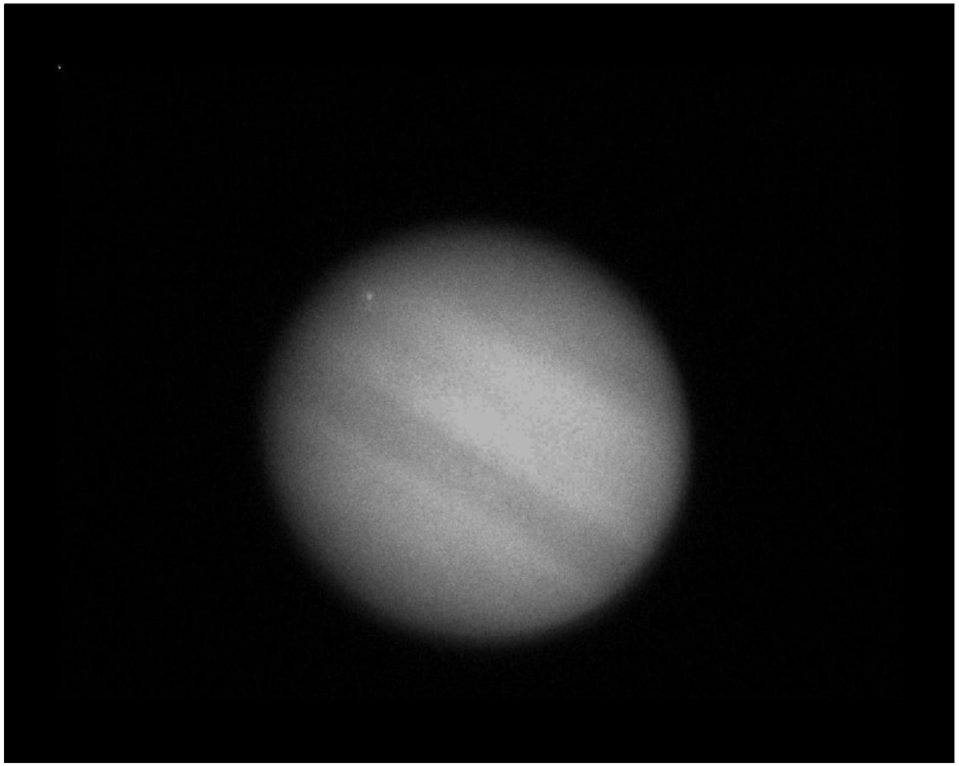

Brightest frame:

Flash ~ 1/6000 Jupiter brightness
Equivalent to a +6.5 star

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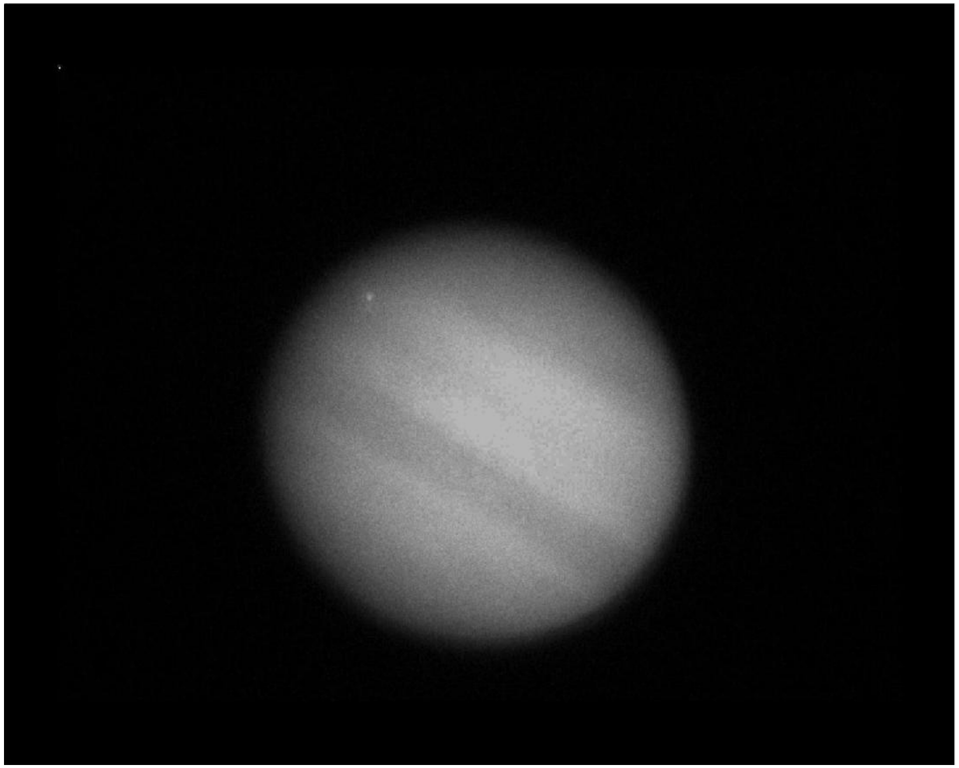
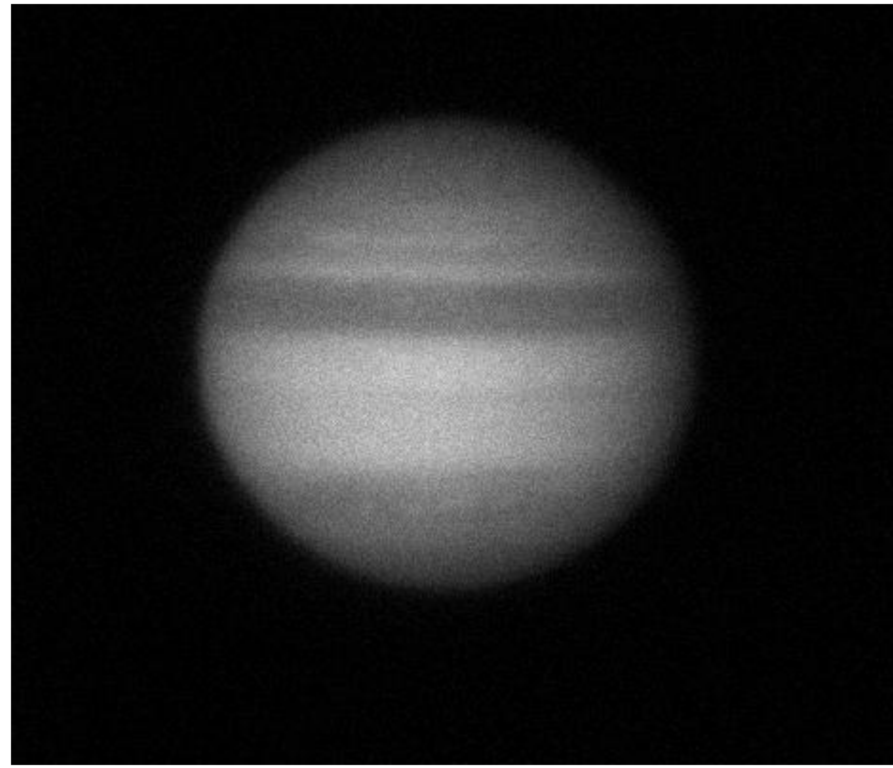


Confirmation from Christopher Go (Phillipines)



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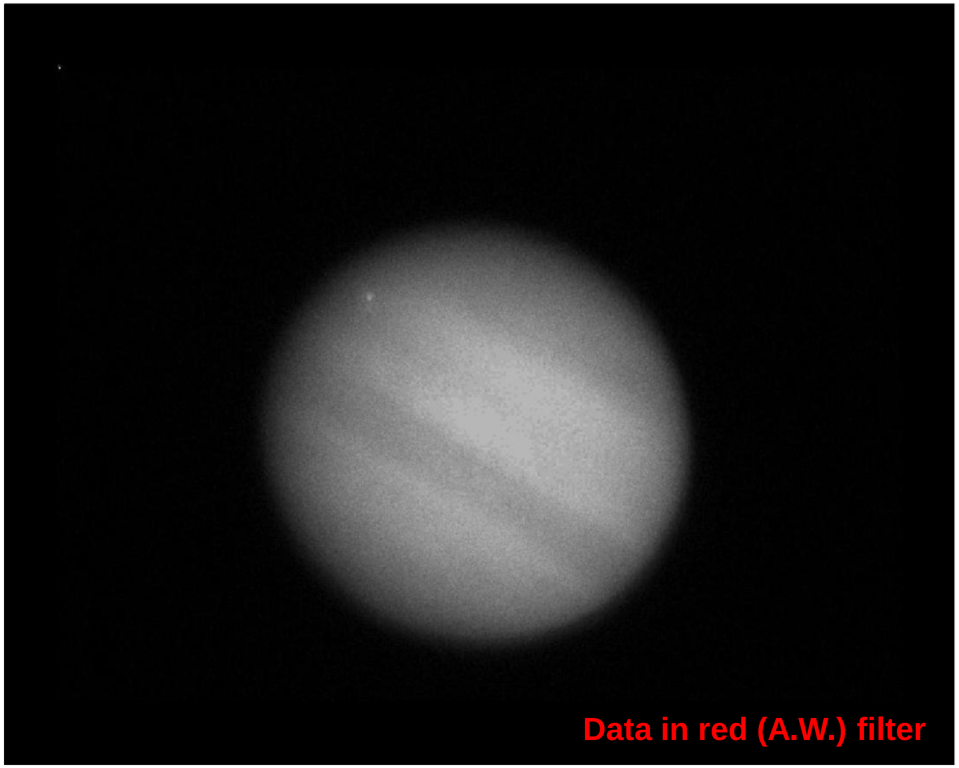

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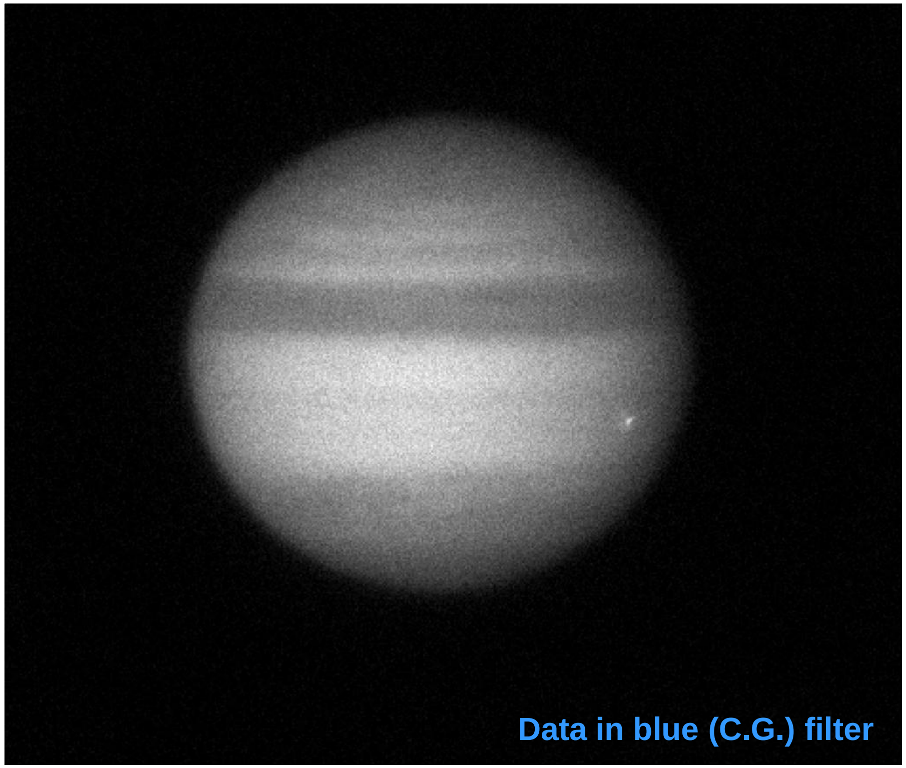
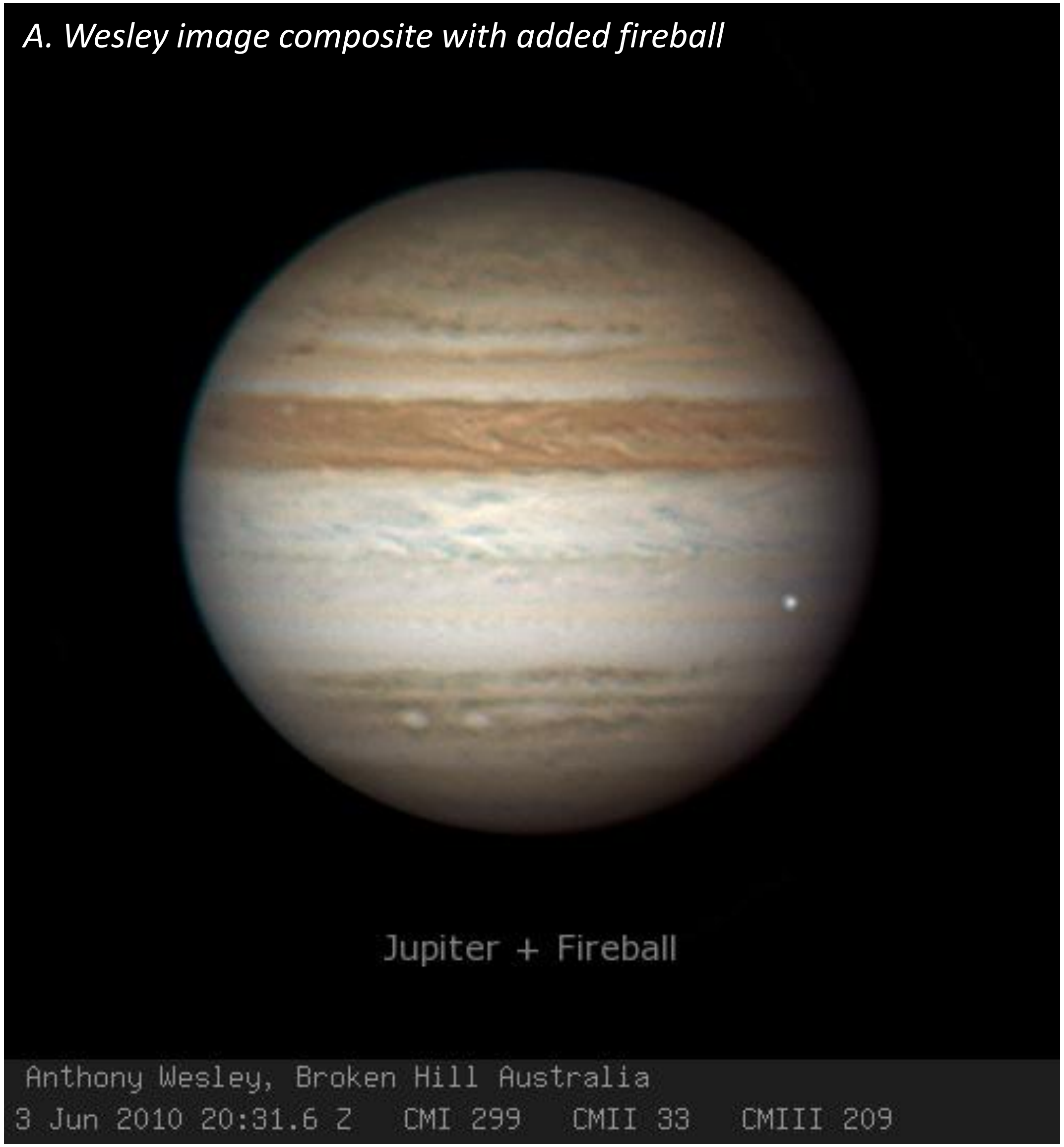


Fireball location: 159ºW (System III)
15.6ºS (Planetographic)

Short 2 s flash
SN Ratio = 5

In both videos the flash brightness in the most intense frame is approximately 1/5000 that of Jupiter (equivalent to a star of magnitude +6.8)

A fireball in Jupiter's atmosphere

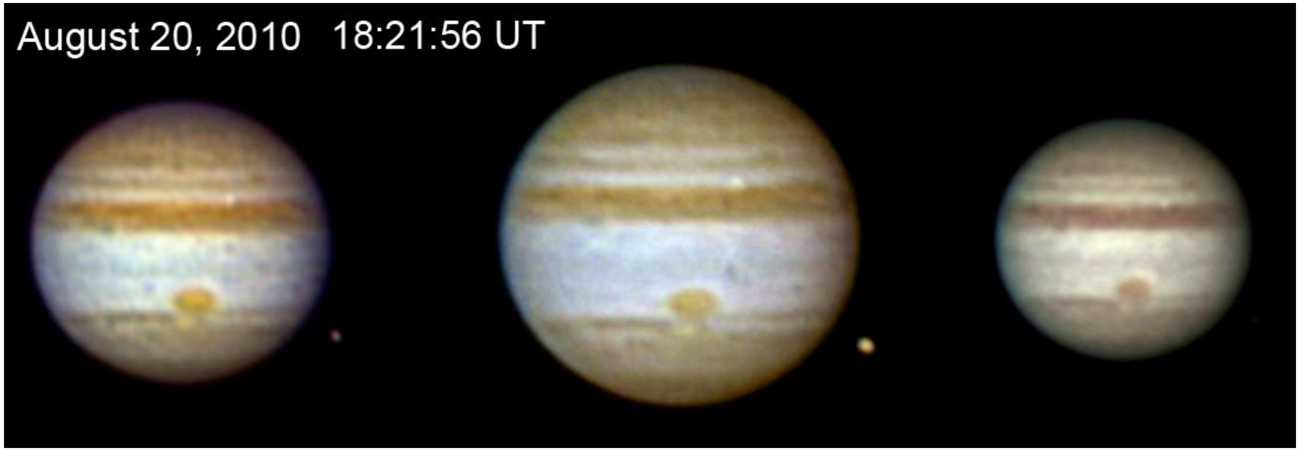


A. Wesley Equipment:
15'' telescope (37 cm)
Point Grey Flea3 camera,
ICX618AQA chip
Red filter from Astrodon
60 fps

C. Go Equipment:
11'' Celestron (28 cm)
Point Grey Flea3 camera,
ICX618AQA chip
Blue filter from Edmund Scientific.
55 fps

Hueso et al. ApJL (2010):
8-13 m impact

Two additional fireballs in Jupiter's atmosphere "captured" by several amateurs



Masayuki Tachikawa, 6'' telescope
Kumamoto City (Japan)
Phillips Toucam (RGB webcam)

Kazuo Aoki, 9.25'' telescope
Tokyo
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Masayuki Ichimaru, 6'' telescope
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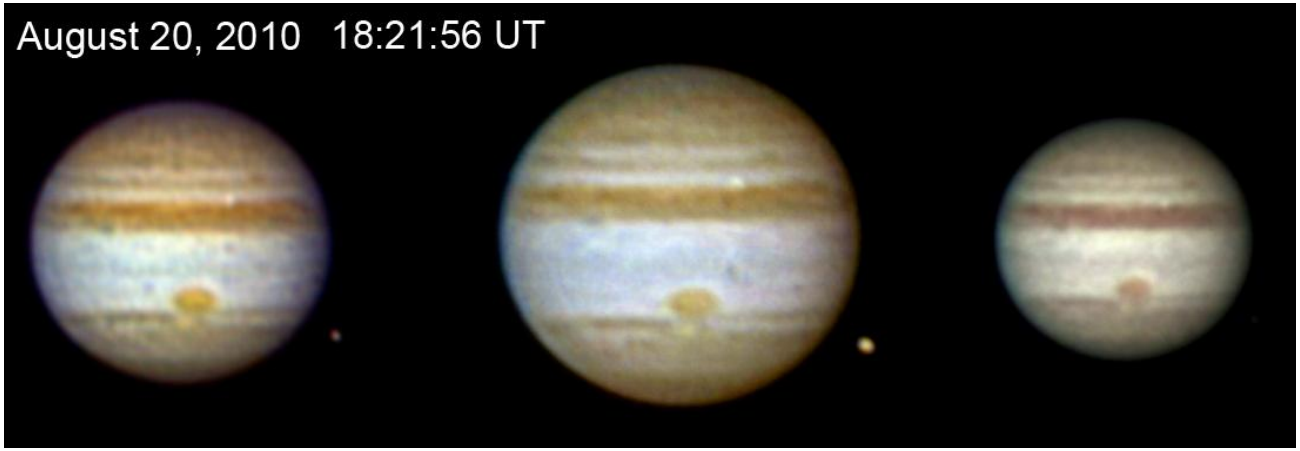

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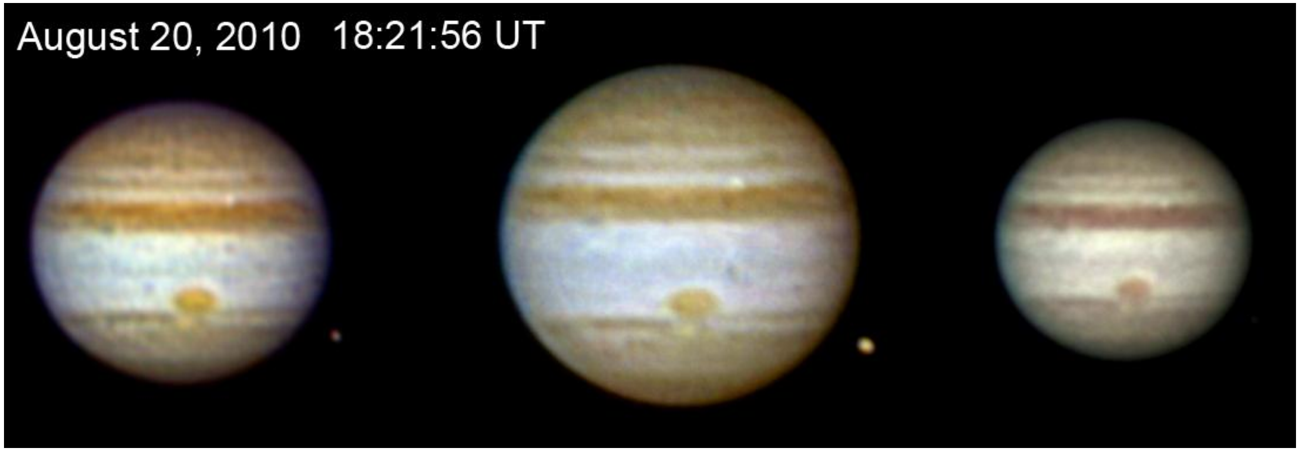

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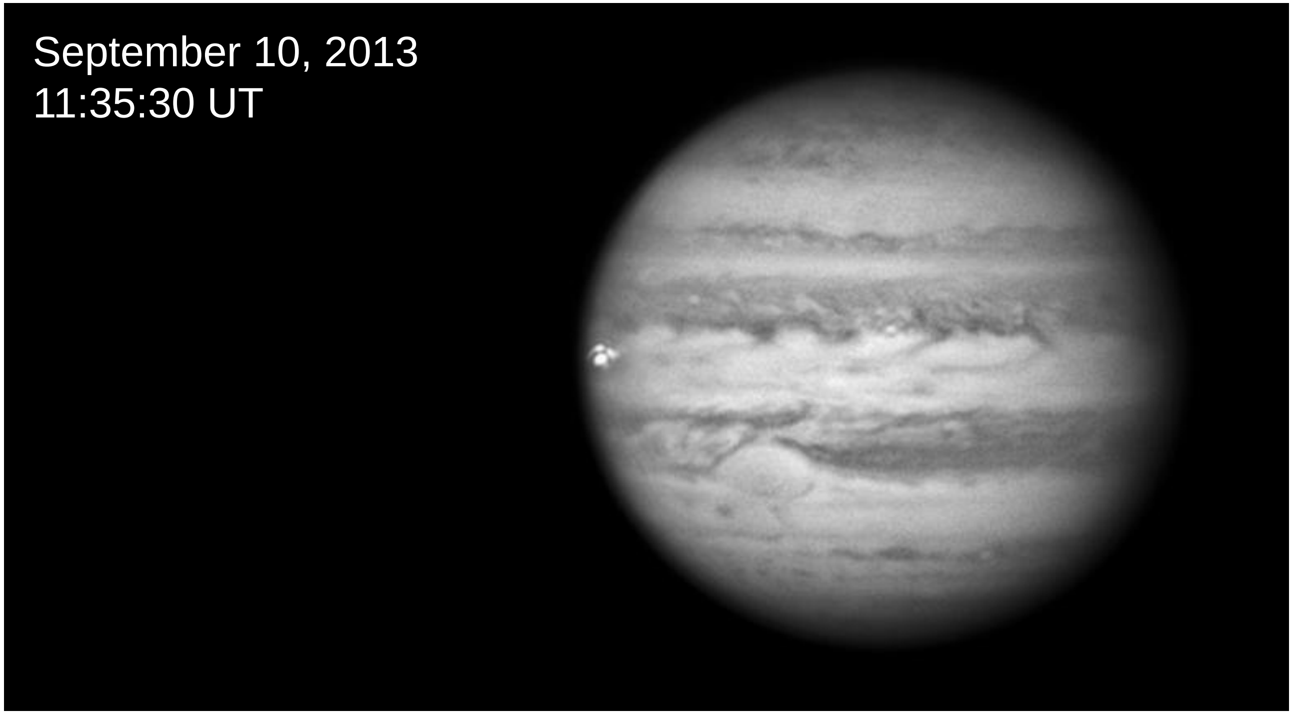
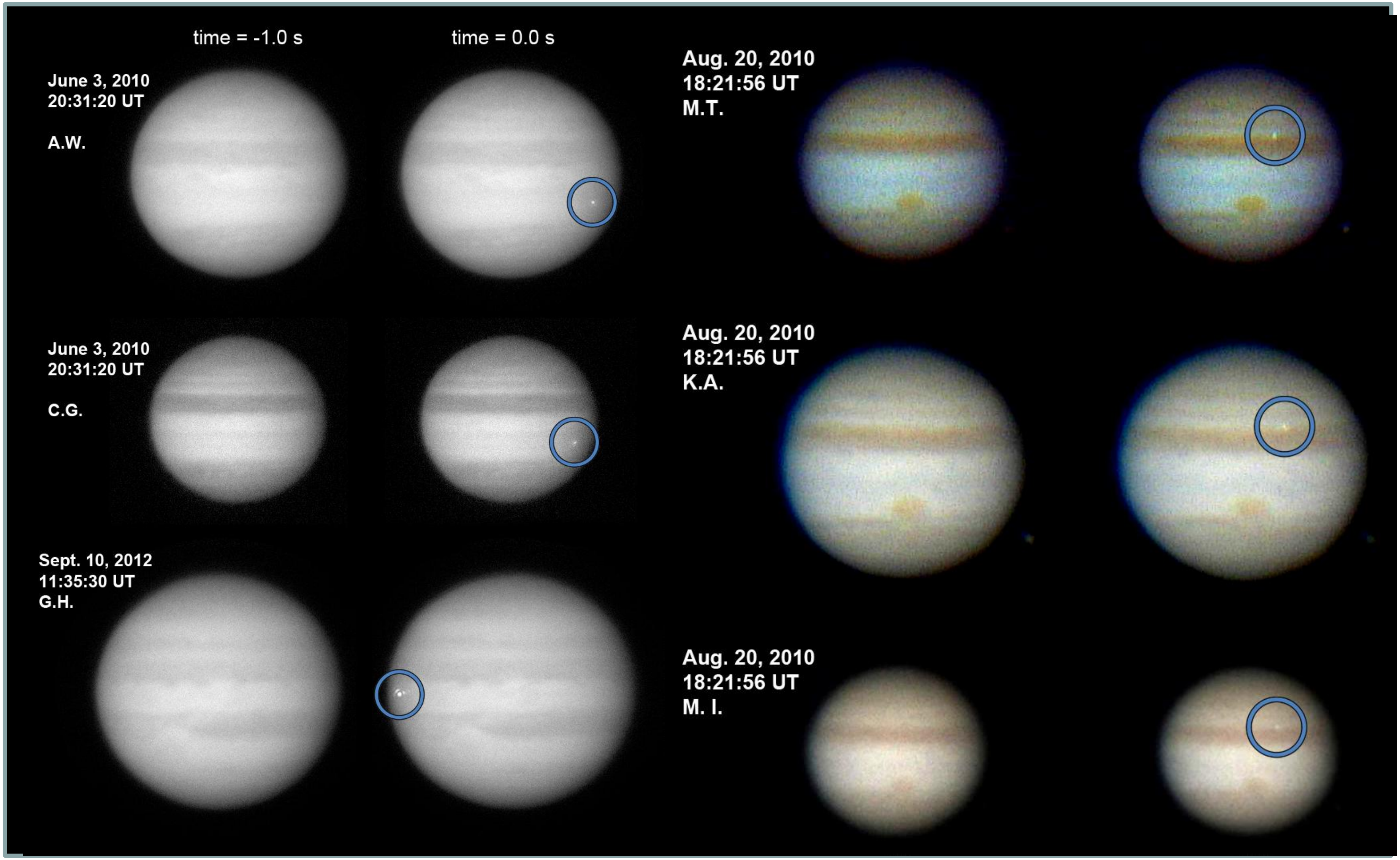


Dan Petersen, 12'' telescope
(Racine, Wisconsin)
visual observation
Estimation of magnitude +6.0

George Hall, 12'' telescope
(Dallas, Texas)
Point Grey Flea3 camera
ICX618AQA chip
Red filter (Astronomik Type 2c)
15 fps

How difficult is to detect 1-2 second flashes?



Observations after the first June 2010 impact: Searching atmospheric debris

3 June 20:31UT
Several hours of observations
2 s Flash
A. Wesley
C. Go

June 4, 03:44 UT – Fattinanzi
04:27 UT – *Damian Peach*, *Bakingsley*

2010-06-04 15:00 UT

- *Keck/NIRC2*
  Near IR obs. 2.17 μm
  Aerosols &Clouds
- *IRTF/TEXES (Mid IR obs.)*
  Thermal & NH3 chemistry
- *Gemini N/NIRI*
  Near IR obs. 2.12, 2.17 μm
  Aerosols &Clouds

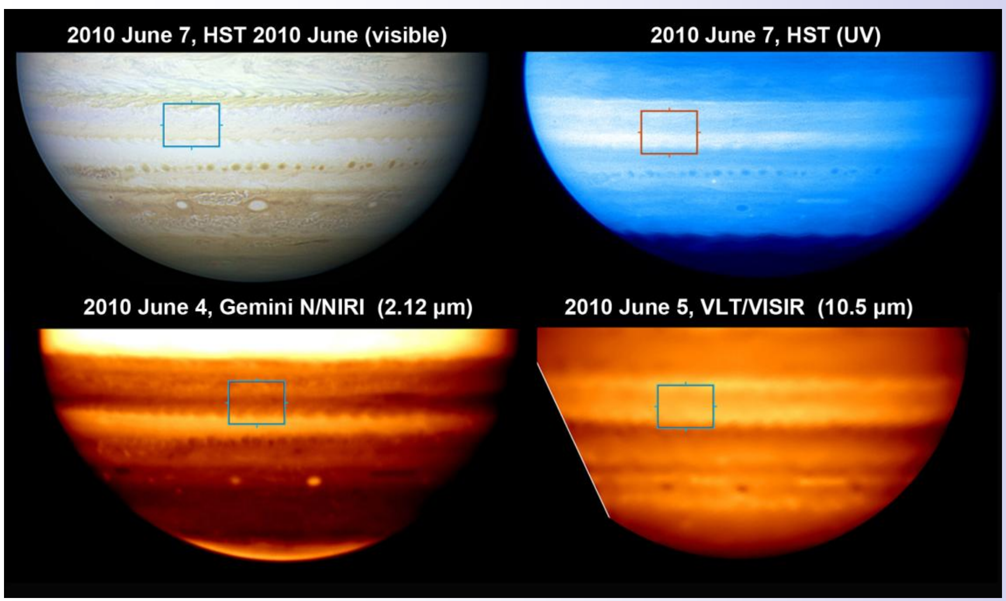
2010-06-05 10:30 UT

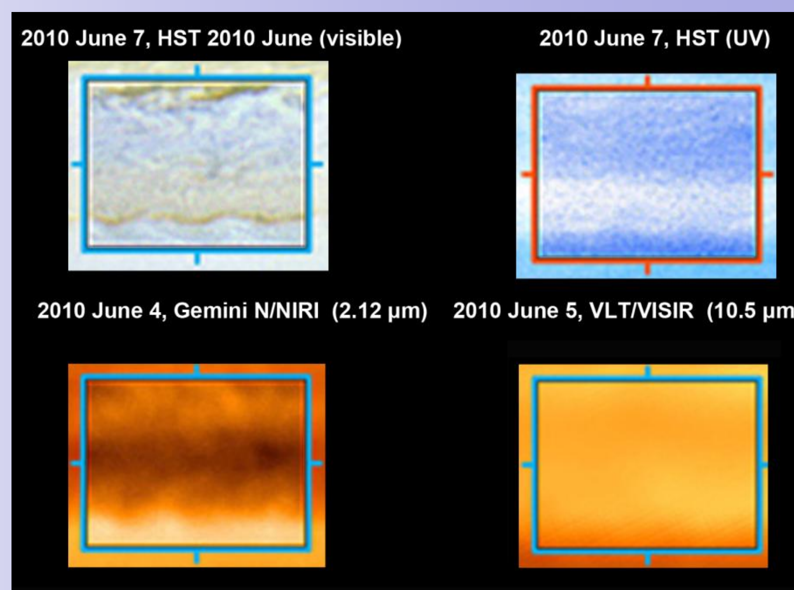
- *Gemini S/T-ReCS*
  Mid IR obs.
  Thermal, NH3, chemistry & Aerosols
- *VLT/VISIR*
  Mid IR obs.
  Thermal, NH3, chemistry & Aerosols

2010-06-07 10:30UT

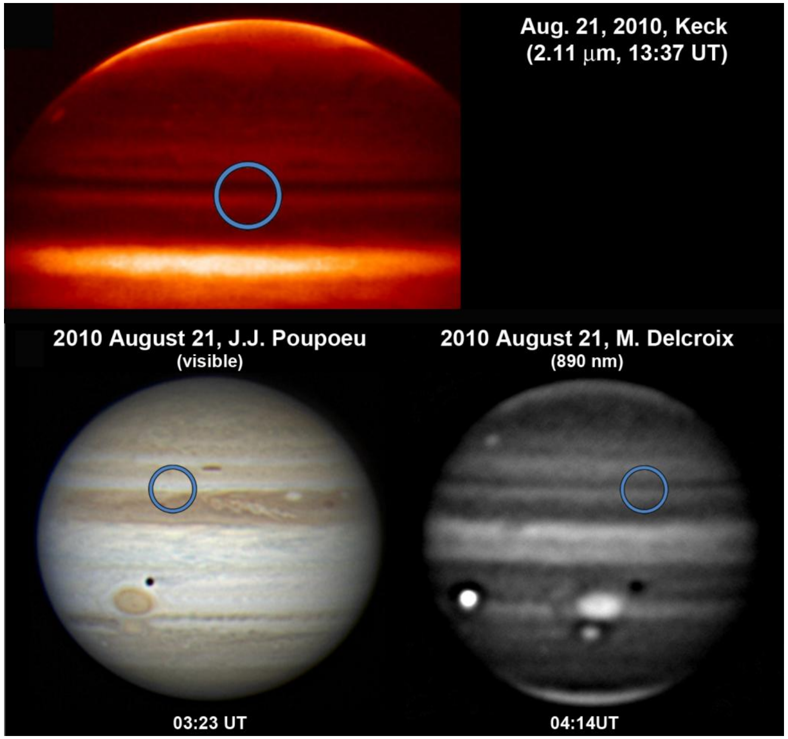
- *HST WFPC3*
  890nm, UV
  Aerosols
  Visible
  Clouds

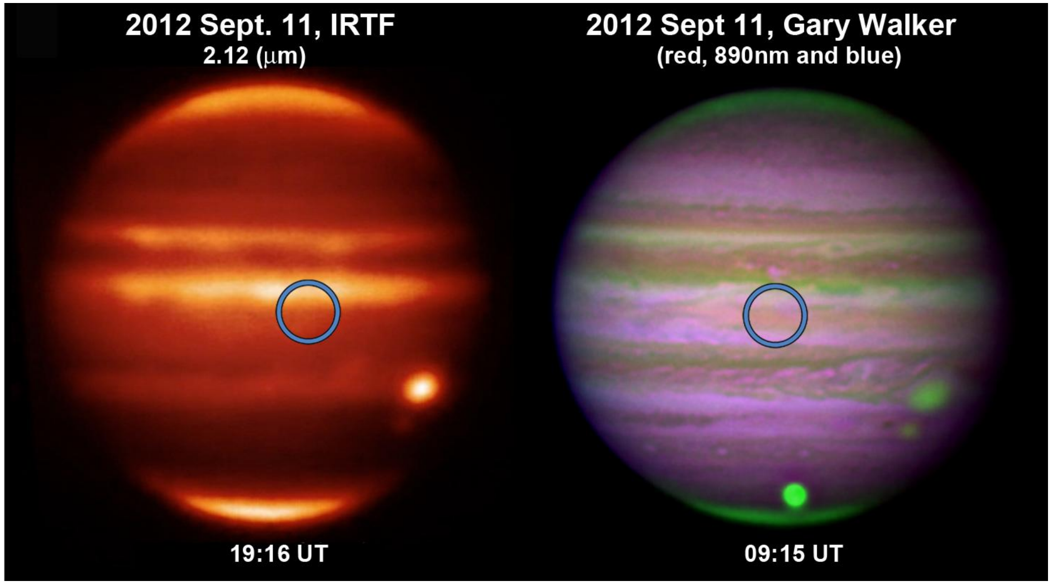
… resulting in negative results (spatial resolution of ~ 300 km)



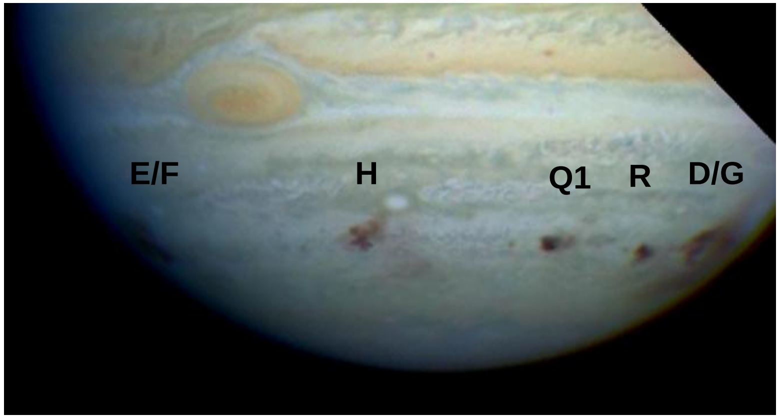


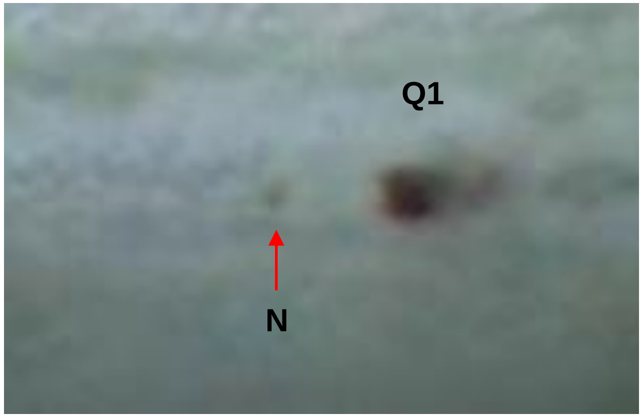
No debris either in the August 21, 2010 impact or the September 10, 2011





How large must an object be to leave a visible feature on the planet?





Fragment N had an estimated size of 50 m with a mean density of 0.25 g/cm^3 from the light-curve of its impact in the planet.

Automatic extraction of light-curves with differential photometry

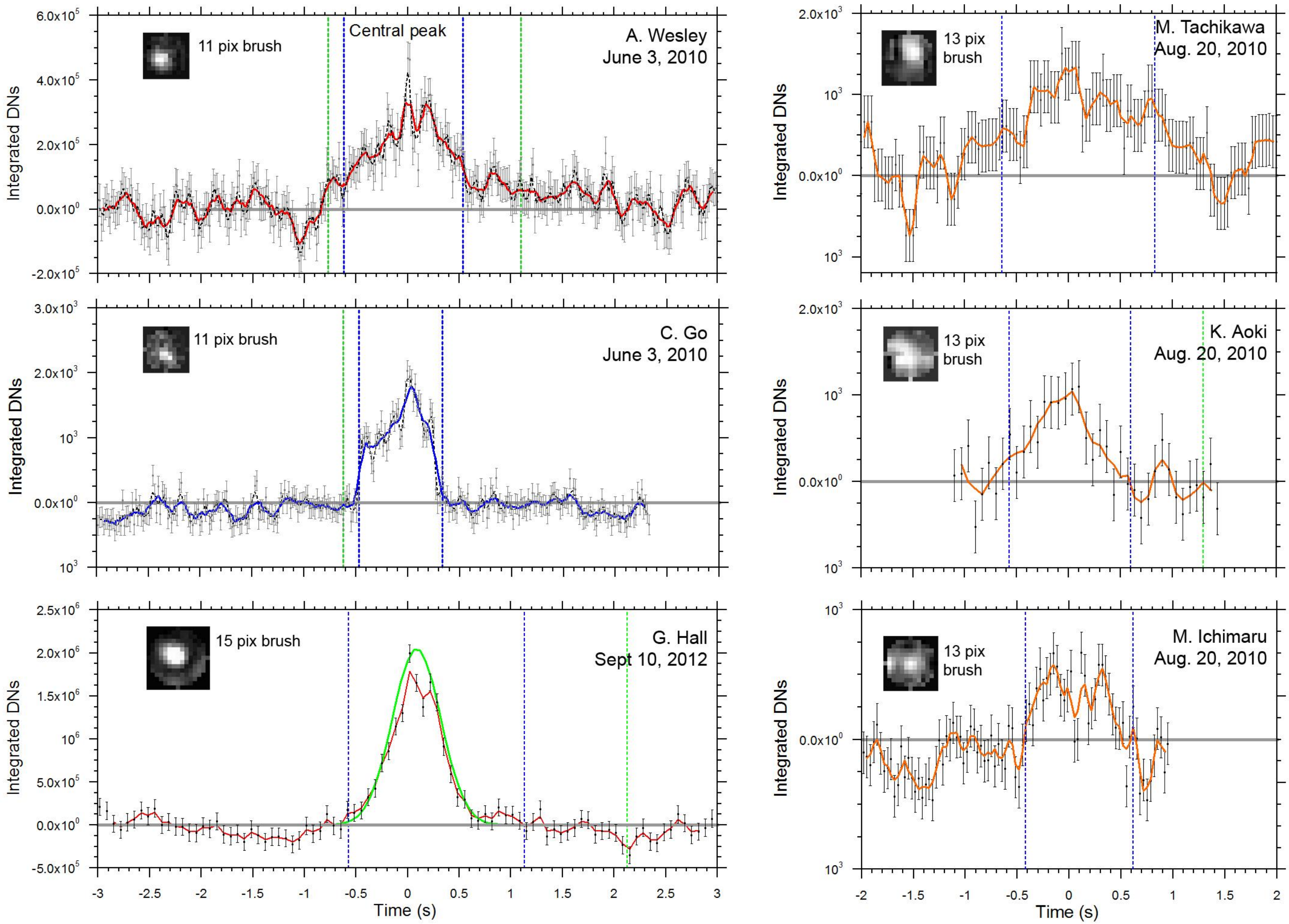
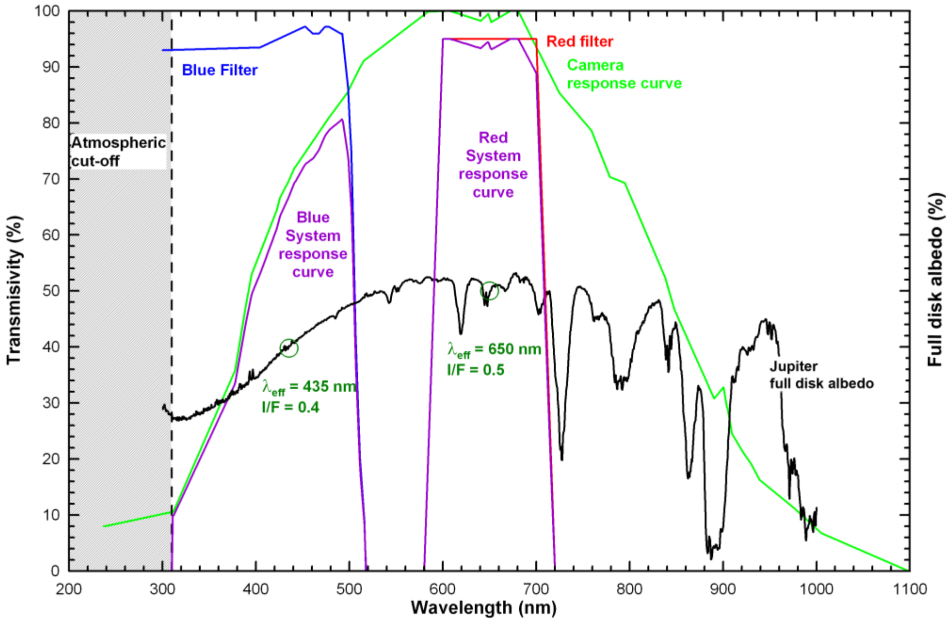


Image and light-curve calibration (example with the first impact)



We take into account the Solar spectrum, filter and camera responses. Only a portion of the solar energy arriving at Jupiter is detected in each filtered observation

Anthony Wesley observation (red filtered)

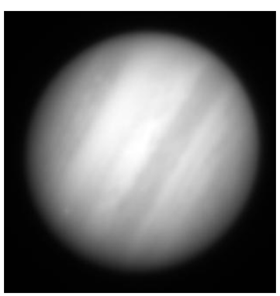
S_R=6.6 W/m2 I/F = 0.5 → Total DNs =5.30x10^{16} W
Exposure: 1/60 s

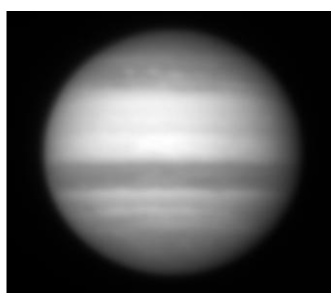
1DN = 3.5x10^5 J

Christopher Go observation (blue filtered)

S_B=6.2 W/m2 I/F = 0.4 → Total DNs =3.98x10^{16} W
Exposure = 1/55 s

1DN = 1.2x10^8 J





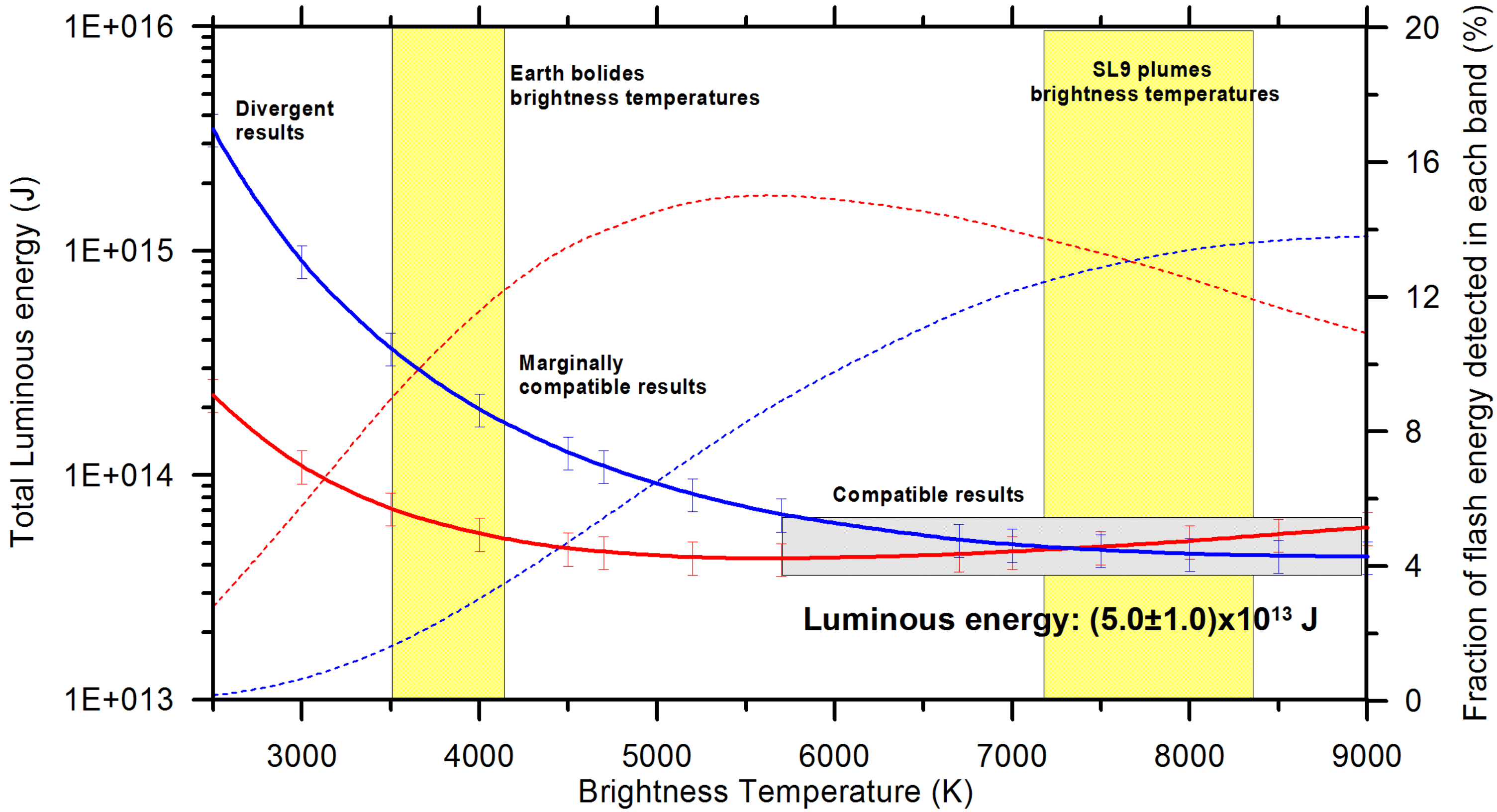
DNs corresponding to the impact

Detected ENERGY = (6.4 +/- 2.0) x 10^{12} J Wesley

Detected ENERGY = (6.0 +/- 1.0) x10^{12} J Go

This energy is only the fraction of energy detected from the total luminous energy and depends on the brightness temperature of the impact

Total luminous energy & Total kinetic energy



Largest uncertainties come from unknown brightness temperature and unknow efficiency η in the transformation from kinetic to luminous energy

$$T_{BB} = 3500 - 9000K$$

$$\eta = 0.12 E_0^{0.115}$$

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)

Energies, Masses & Sizes

Assumptions on the collision

$T_{BB} = 3500 - 8500K$ $\eta \approx 0.16 - 0.22$

Impact velocity: $v \approx 60km/s$

Density: $\rho \approx 2.0g/cm^3$ Density: $\rho \approx 0.5g/cm^3$

Results

June 3, 2010

$Energy \approx 4.0 - 15.0 \times 10^{14}\ J$
$100 - 350$ ktn

$Mass \approx 200 - 900\ Tn$

Size (diameter) $D \approx 5.5 - 10.0\ m$ / $D \approx 8.7 - 16\ m$

August 20, 2010

$Energy \approx 5.2 - 12.0 \times 10^{14}\ J$
$120 - 300$ ktn

$Mass \approx 300 - 700\ Tn$

Size (diameter) $D \approx 6.5 - 9.0\ m$ / $D \approx 10 - 14\ m$

September 10, 2012

$Energy \approx 12.0 - 32.0 \times 10^{14}\ J$
$320 - 750$ ktn

$Mass \approx 860 - 1500\ Tn$

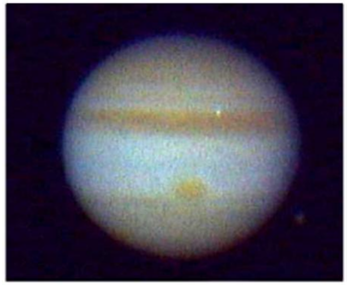
Size (diameter) $D \approx 9.0 - 12\ m$ / $D \approx 14 - 19\ m$

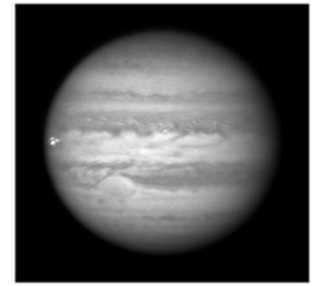
Energy range: 100-750 ktn surrounding Chebyalinsk-like events [450 ktn] and 5-50 times less than Tunguska (3000-5000 ktn).

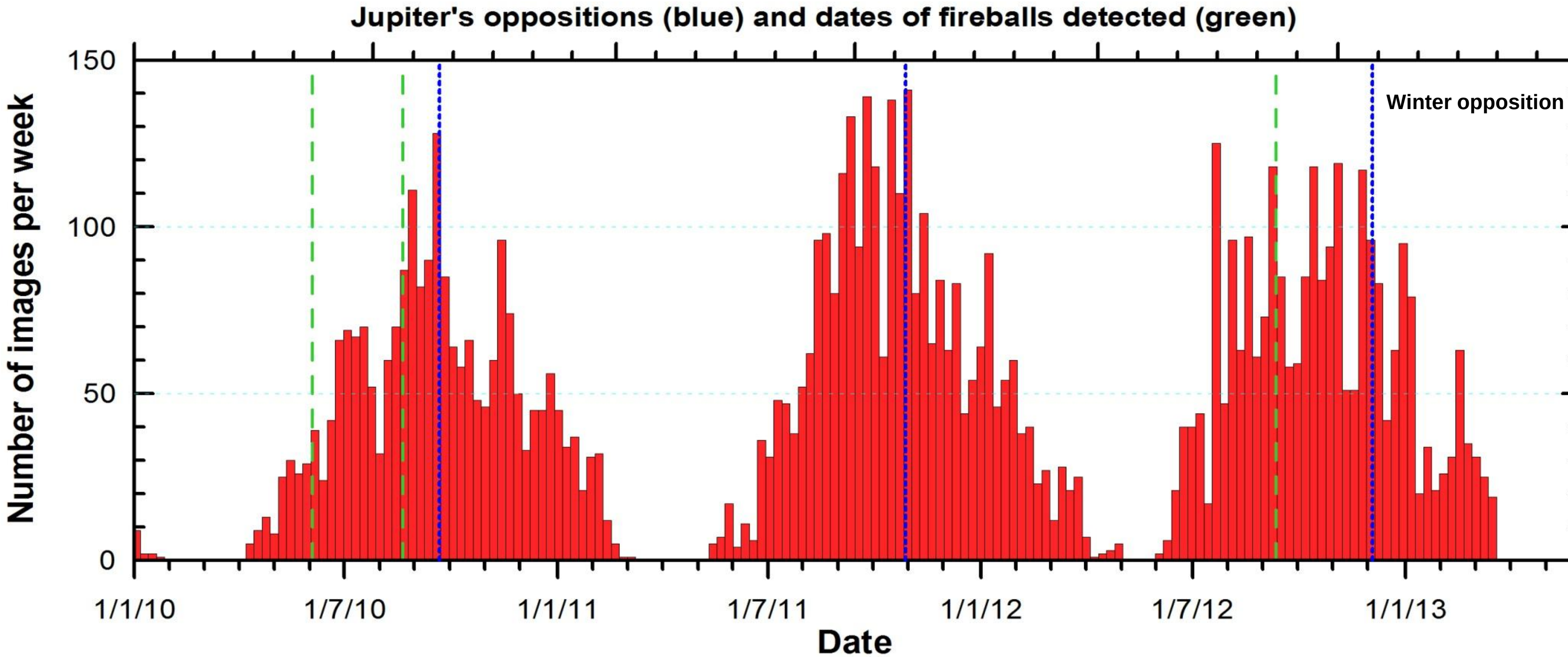
Superbolides with masses 10^5 smaller than the 2009 Jupiter impact (5-50 smaller than the SL9 N fragment)

- *Impacts like this should be much **more common and relatively easy to detect** now that we know what to look for*
- *Smaller impacts (D~4 m could be detected with 40cm telescopes)*
- *Large impacts (D~10 m could also be detected in Saturn)*

Statistical significance

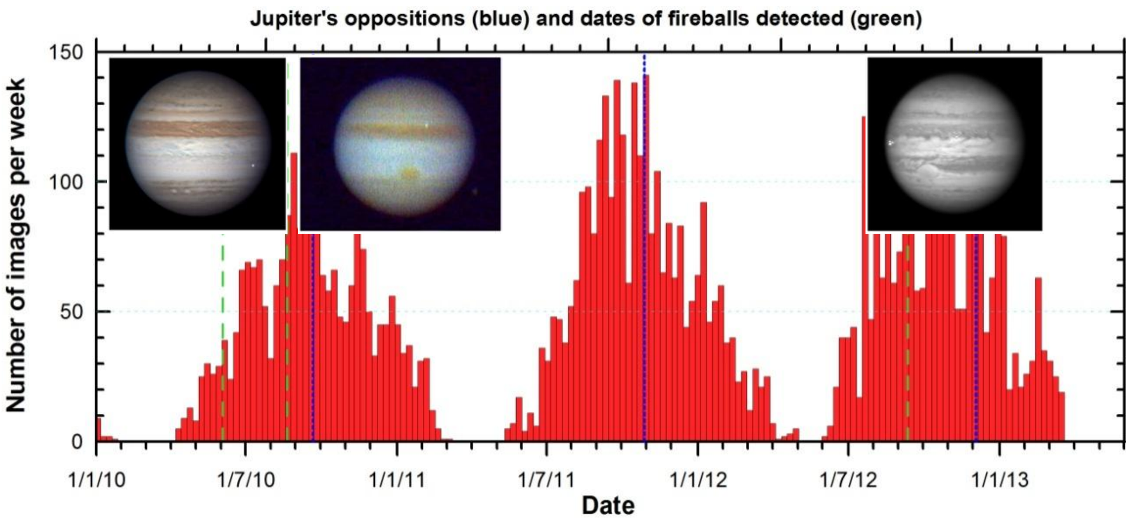






7800 Jupiter images in the International Outer Planets Watch PVOL database for 2010-2013 → Equivalent to a survey efficiency of 5-20% of this period

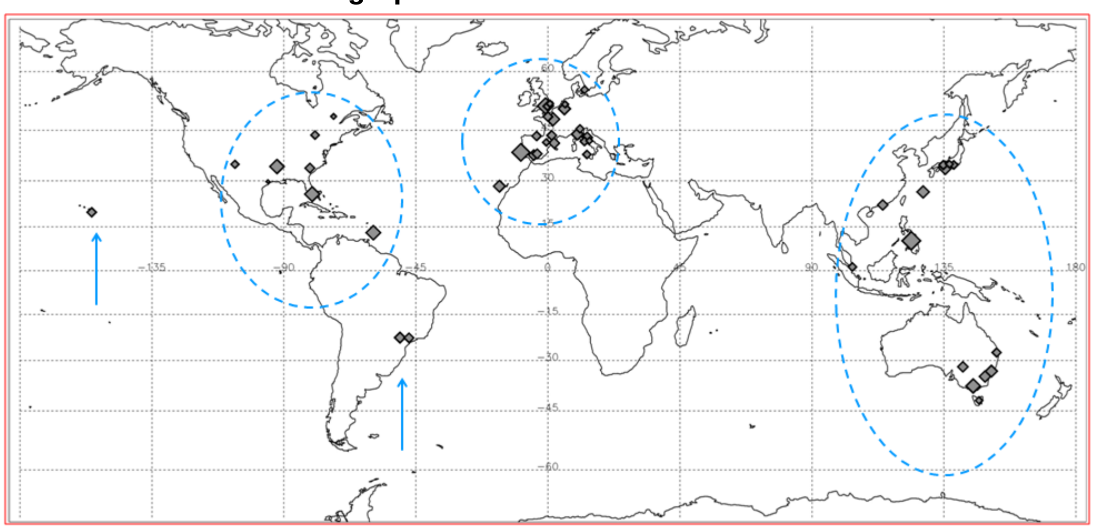
Statistical significance



7800 Jupiter images in the International Outer Planets Watch PVOL database for 2010-2013 **equivalent to 5-20% of this period.**

Most of the observations are redundant (at the same time)

Geographical distribution of observers



10-20% of observation efficiency is expected from the global distribution of frequent Jupiter observers

(6-12 hours every day over 6 months assuming good weather somewhere in the three big areas)

270 collaborators in 2010-2013

1/3 impacts discovered by "regular observers"

Statistical significance

3 impacts in 40 months

10-20% of observation efficiency in the temporal sampling of Jupiter

Unknown hability of amateurs to “recognize” an impact in their video observations
Probably < 50% but could be as small as 10%

Impacts can only be detected over a third of Jupiter’s area (excluding the night-side and poles)

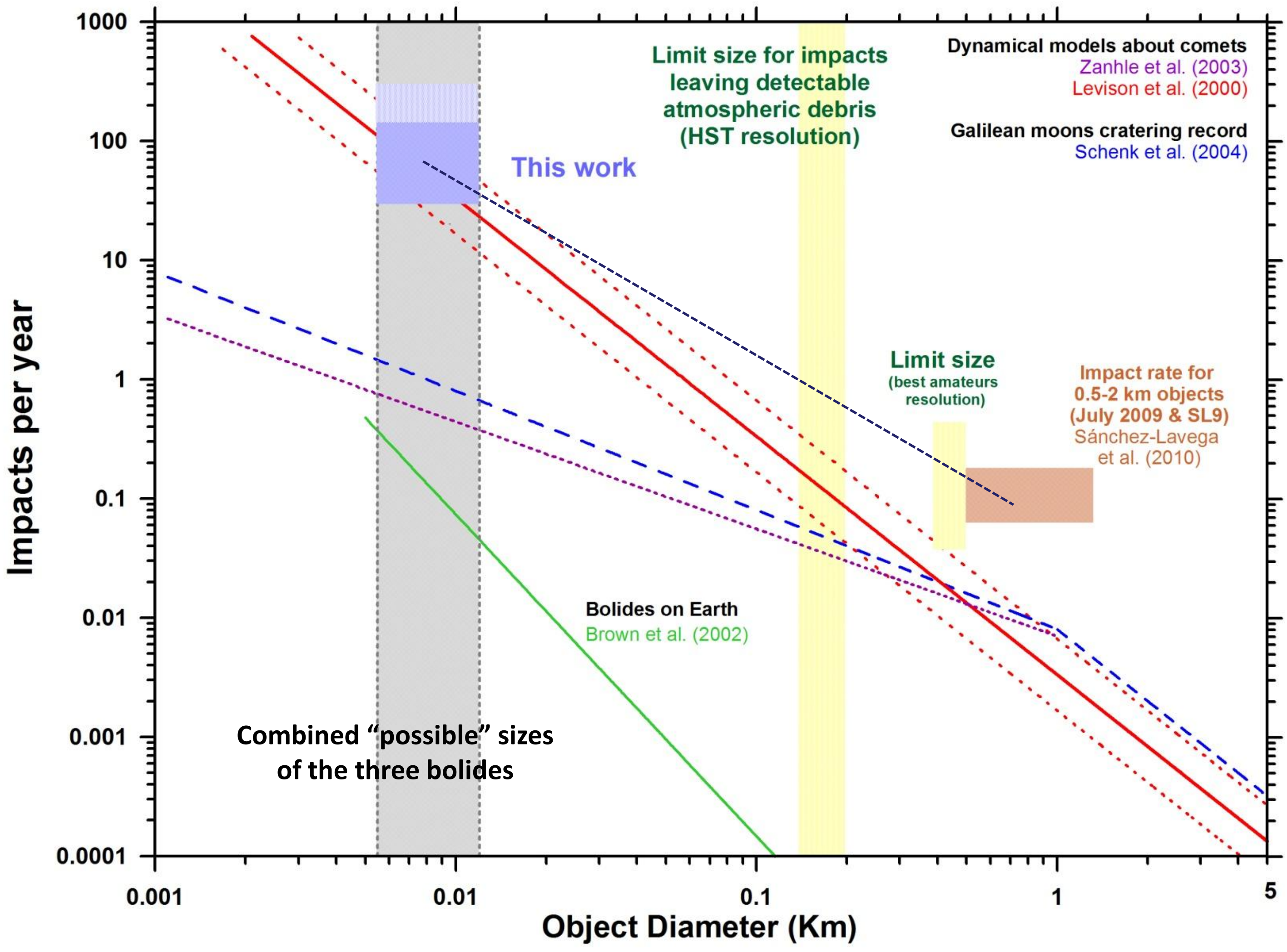
⇨ Expected flux of impacts in the range: 30-300 per year
(only 5-50 detectable in a perfect survey over 9 months a year)

However higher ranges than 150 impacts per year are discarded
by on going searches of impacts by dedicated amateurs

Our best guess: 30-150 impacts per year of 10 m size objects

This requires further observations to be refined

The flux of impacts in Jupiter

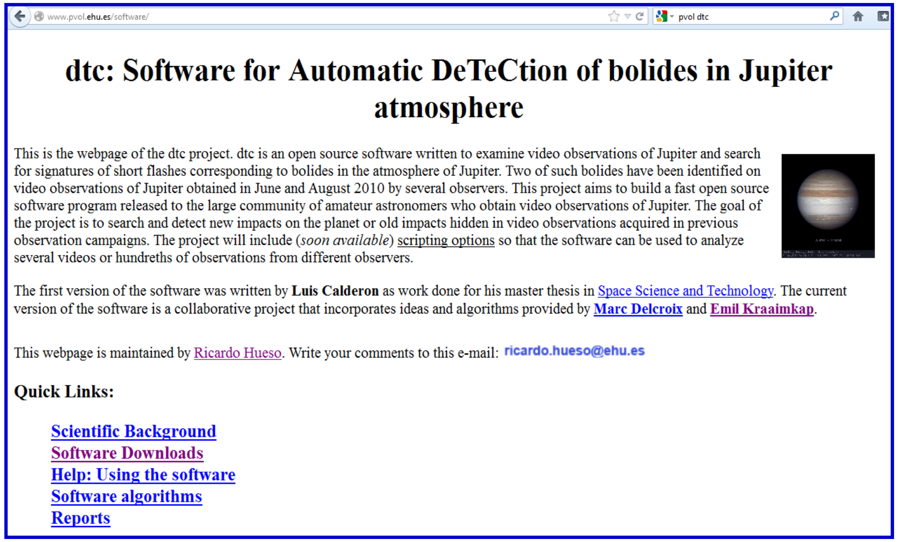


10 m size objects should be detected yearly providing better information about brightness temperatures and their real masses

300-400 m size objects could impact Jupiter once every 2 years and they could be detectable once every 4-5 years for about one week for "regular" observers

Improving statistics: Software & continuing observations

http://www.pvol.ehu.es/dtc *Two software packages for analyzing amateur video observations of Jupiter*


www.pvol.ehu.es/software/

dtc: Software for Automatic DeTeCtion of bolides in Jupiter atmosphere

This is the webpage of the dtc project. dtc is an open source software written to examine video observations of Jupiter and search for signatures of short flashes corresponding to bolides in the atmosphere of Jupiter. Two of such bolides have been identified on video observations of Jupiter obtained in June and August 2010 by several observers. This project aims to build a fast open source software program released to the large community of amateur astronomers who obtain video observations of Jupiter. The goal of the project is to search and detect new impacts on the planet or old impacts hidden in video observations acquired in previous observation campaigns. The project will include (*soon available*) scripting options so that the software can be used to analyze several videos or hundreths of observations from different observers.

The first version of the software was written by **Luis Calderon** as work done for his master thesis in Space Science and Technology. The current version of the software is a collaborative project that incorporates ideas and algorithms provided by **Marc Delcroix** and **Emil Kraaimkap**.

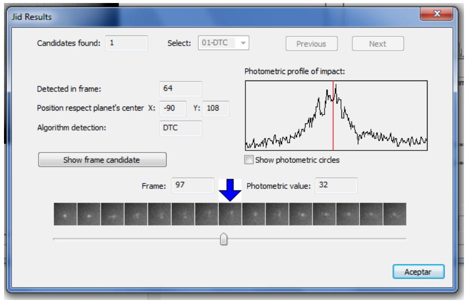
This webpage is maintained by Ricardo Hueso. Write your comments to this e-mail: ricardo.hueso@ehu.es

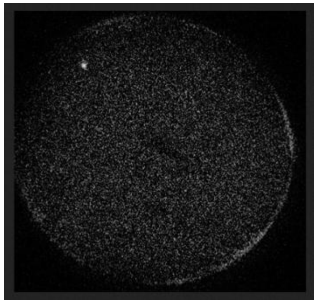
Quick Links:

- Scientific Background
- Software Downloads
- Help: Using the software
- Software algorithms
- Reports

Open Source, multiplattaform, supportinng most video formats and batch mode

✓ Automatic impact detection and light-curve extraction
✓ List of candidates easy to review





Continuing observations

Broad amateur collaboration. Proffesionals should implicate in impact searches. The **largest the telescope aperture the faintest impacts** that could be detected.

A **1-month coordinated campaign** with profesional and amateur collaborators 3 months after **next Jupiter opposition (5 Jan. 2014)** could produce a step forward in the statistics of these objects.

Stay tuned for more "unexpected" jovian impacts