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Small impacts on the Giant Planet Jupiter

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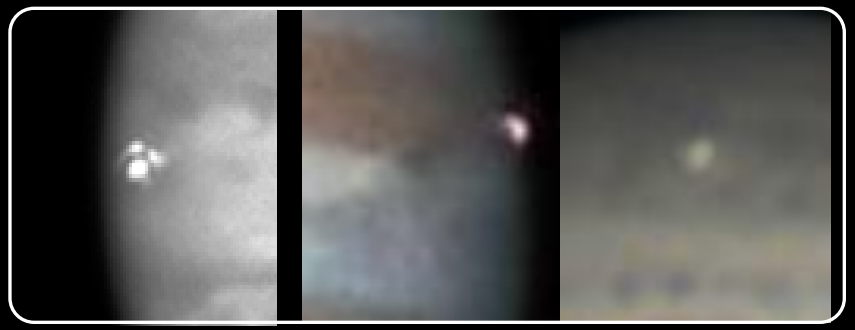


49th Meeting of the AAS Division for Planetary Sciences

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).

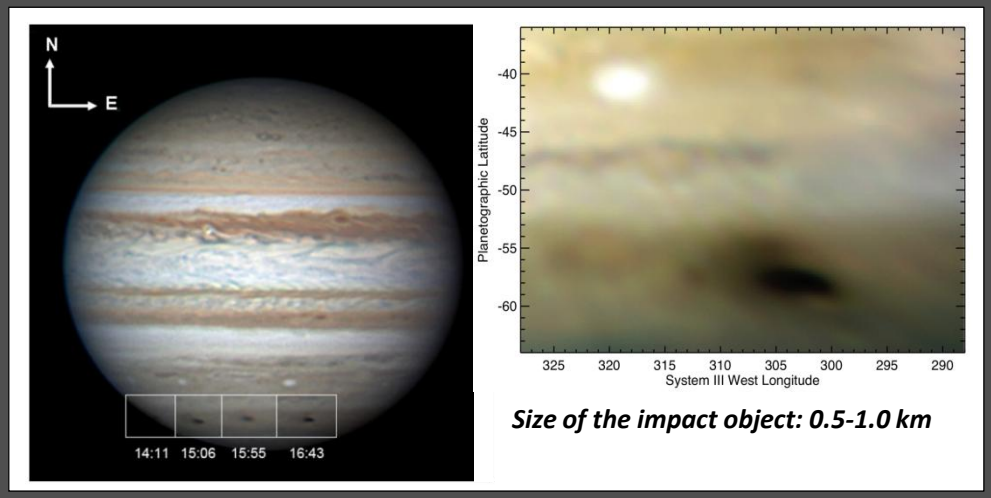
At the time this was coined as "a once in a lifetime event"

Harrington, J., et al. Jupiter book (2004).

(Background: HST image of the G impact site)

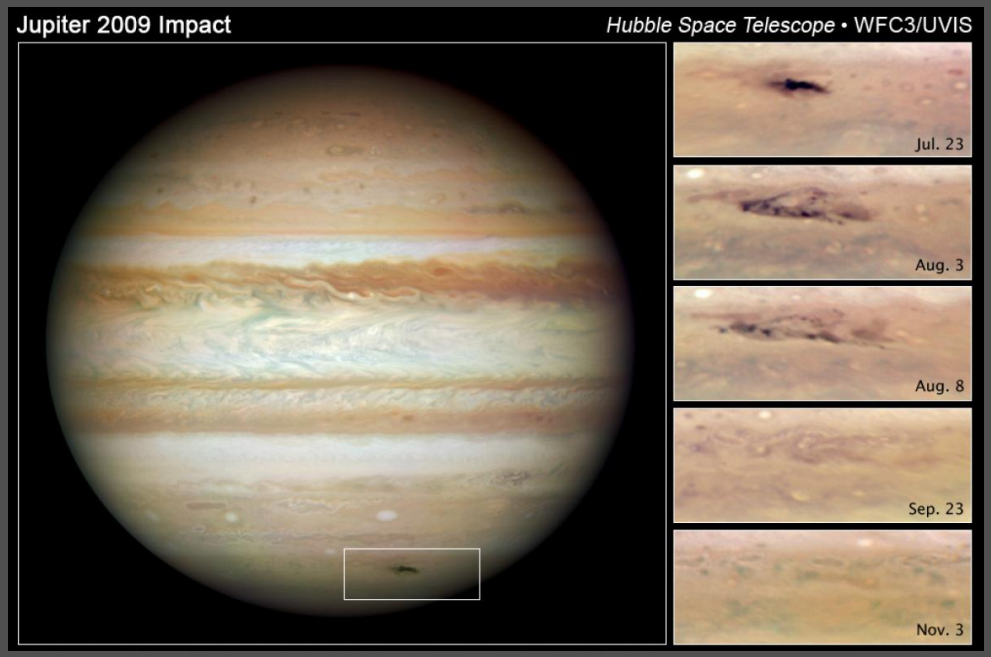
July 19, 2009:

Anthony Wesley discovers an impact scar in Jupiter



Size of the impact object: 0.5-1.0 km

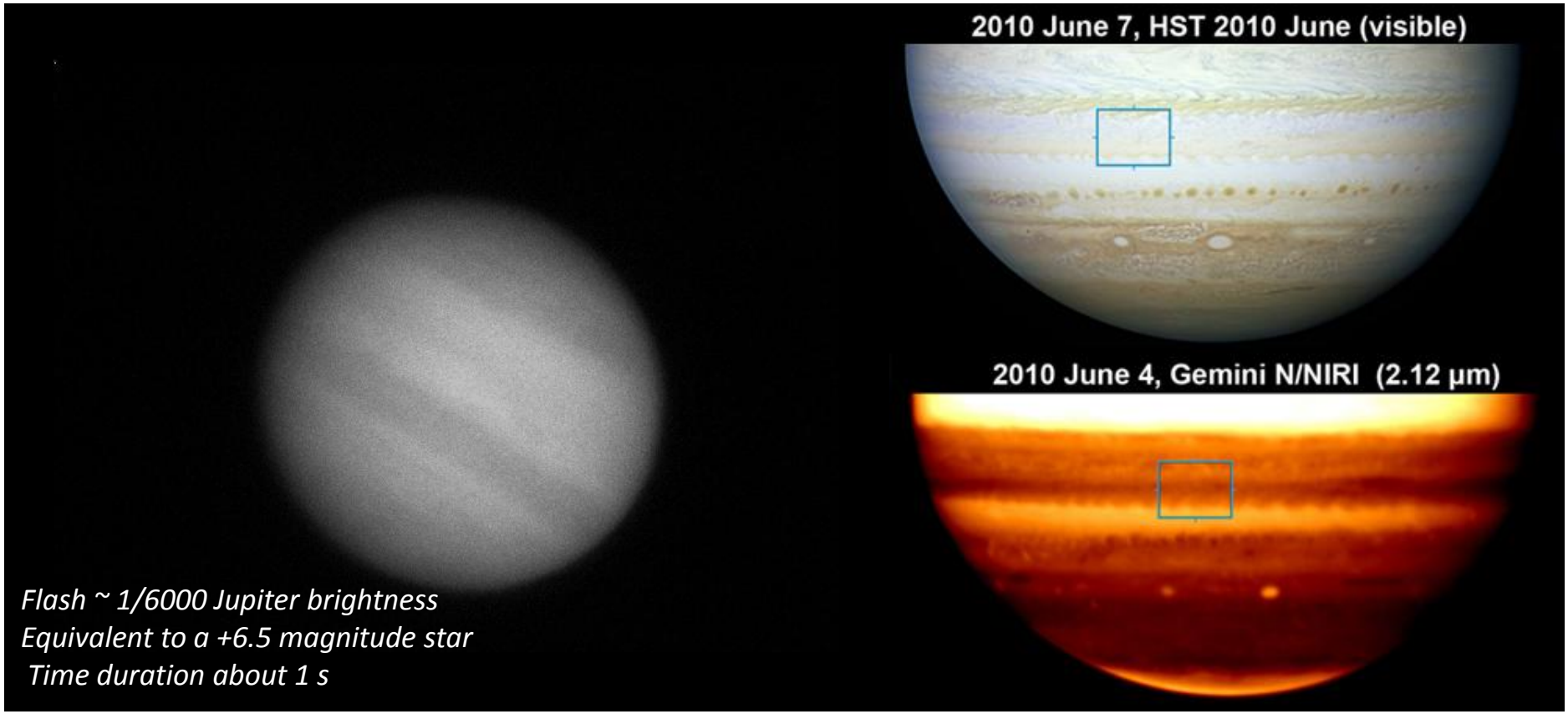
Sánchez-Lavega et al. ApJL (2010)



Hammel et al., ApJL (2010)
Possible asteroidal nature: Orton et al. Icarus (2011)

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 & and a ***red filter****.* ***The second impact in Jupiter found by a single person!***

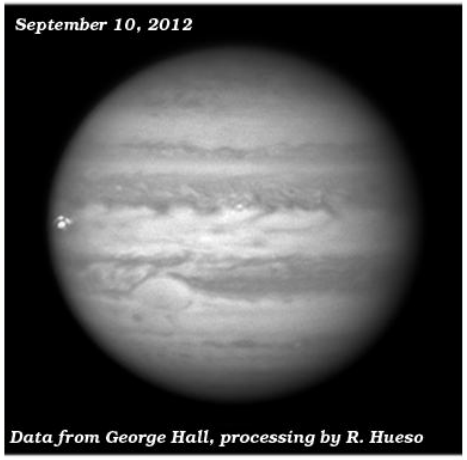


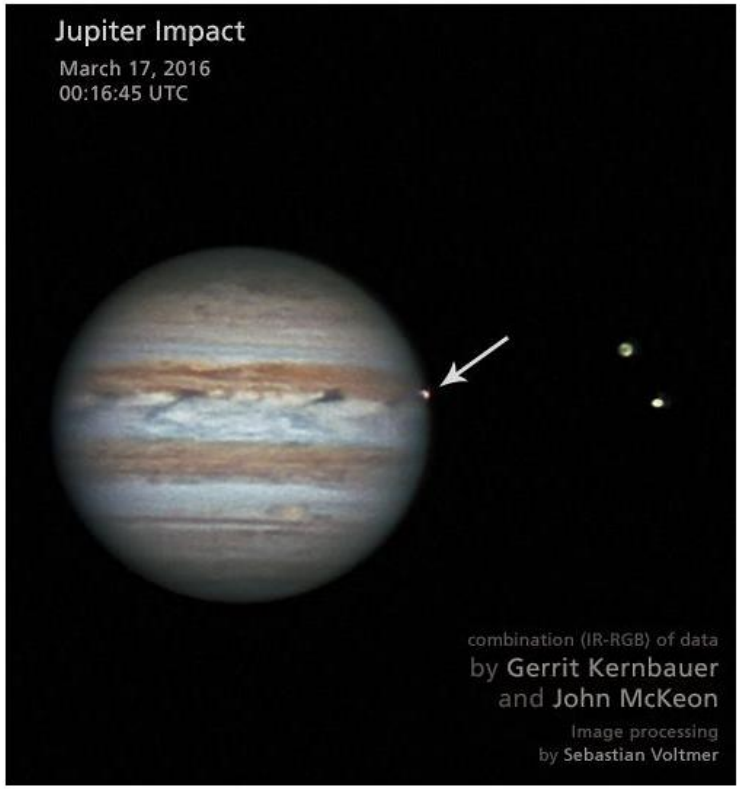
Flash simultaneously observed by an amateur in Phillipines (Christopher Go) using a 11'' telescope, similar camera and a ***blue filter****.*

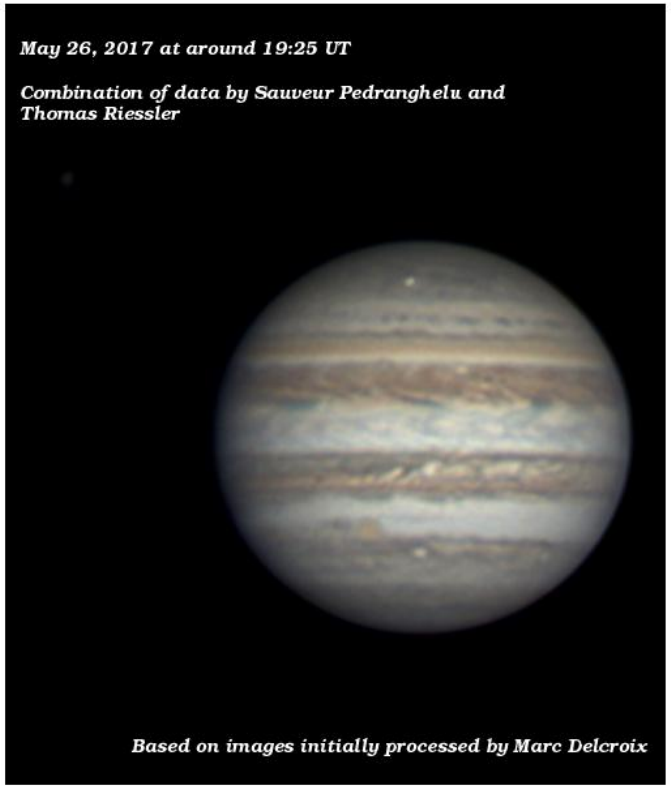
Fast campaign to detect a debris field in the atmosphere (HST, VLT, Gemini, Keck, IRTF, …). No debris found!

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*
Hueso et al. ApJL (2010)

… 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 ---

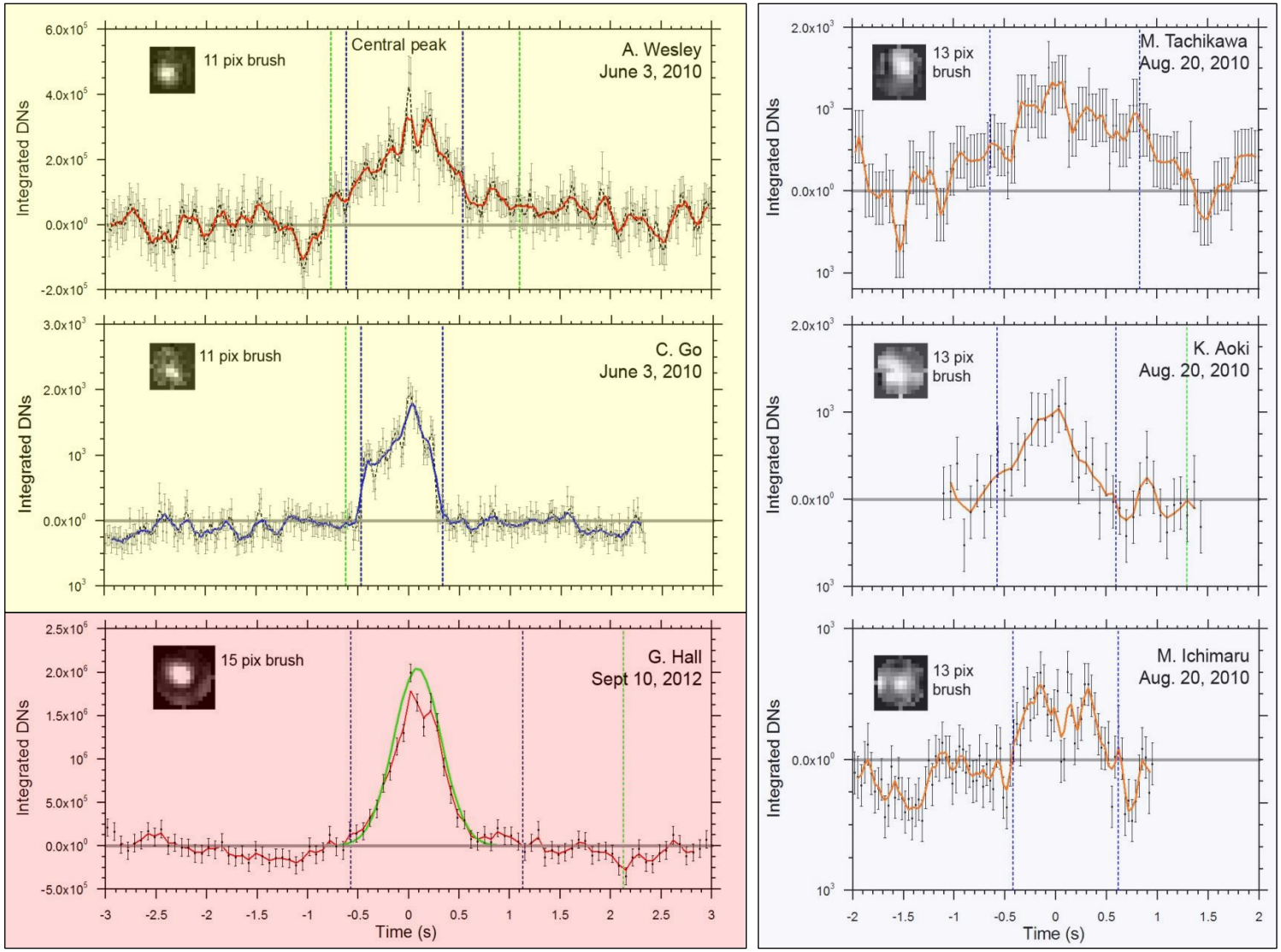
March 17, 2016
Gerrit Kernbauer (Austria)
John McKeon (Ireland).

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



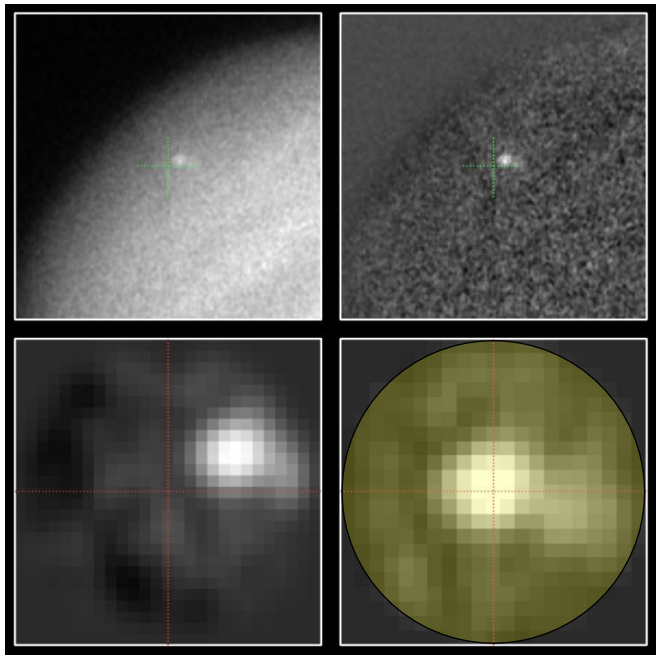
Impacts of objects of sizes: 5-15 m releasing energies of 45-450 kTns

(Chelyabinsk impact-like)

Hueso et al., A&A, 2013

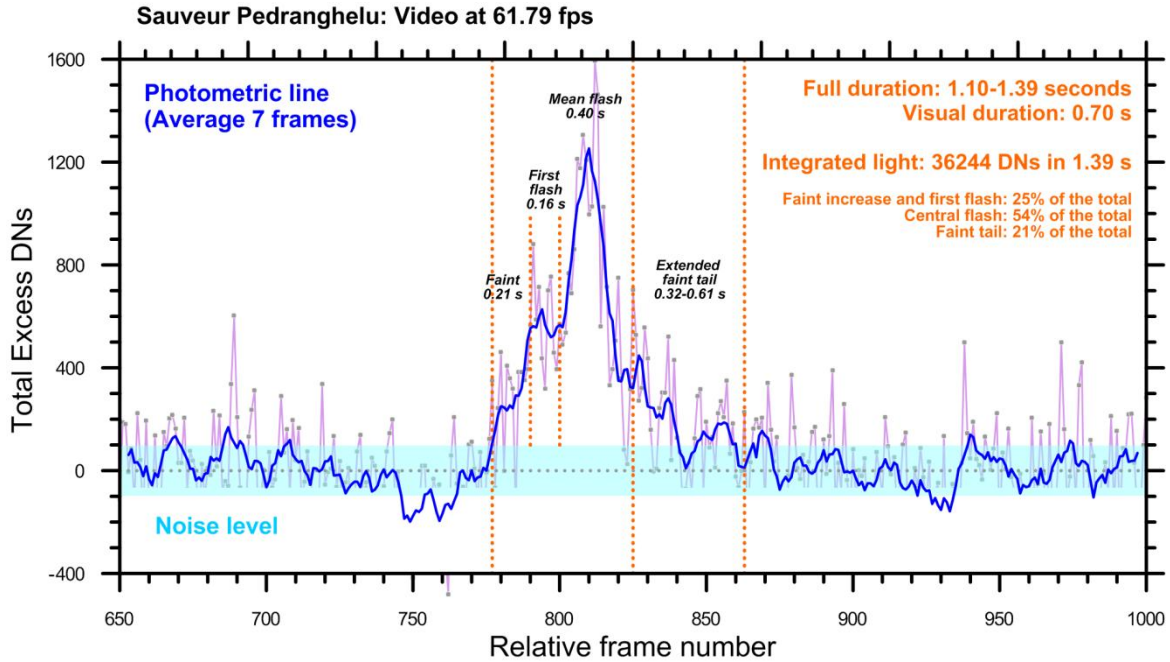
Impact on May 26, 2017@19:25UT - Lightcurves examples

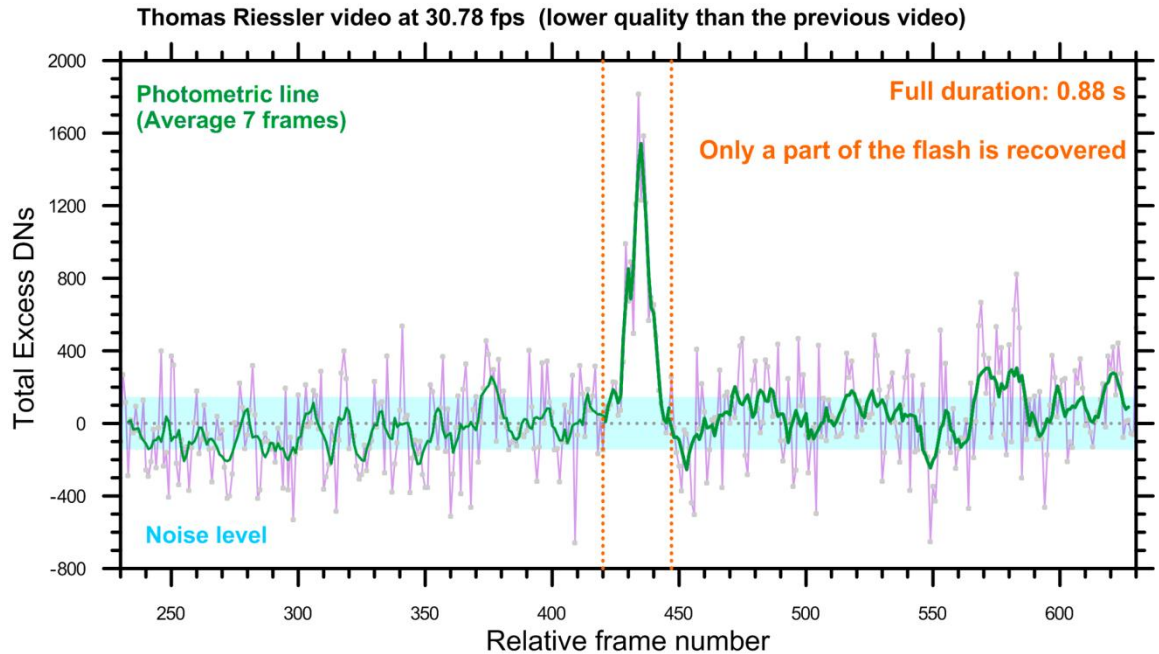
Original image | Differential photometry



"Average" impact location

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





+ Light-curves in RGB channels in both observations

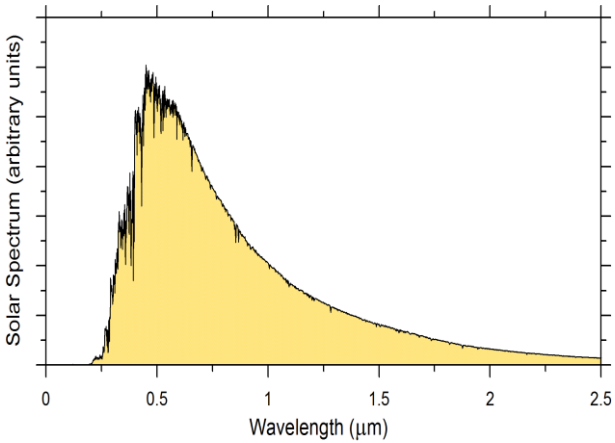
+ Additional light-curve from A. Fleckstein video observations (IR)

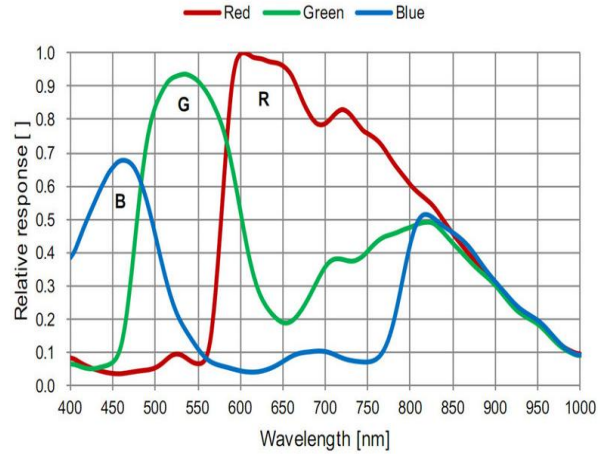
(all with lower quality and detail)

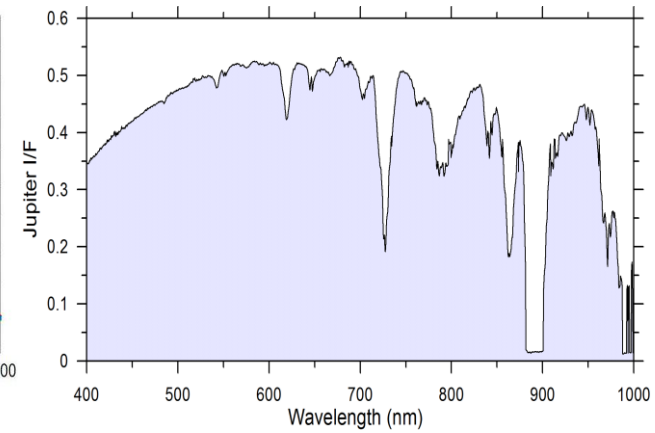
Impact on May 26, 2017@19:25UT - Energy calibration

1) Integrated photometry of Jupiter disk + Solar constant at Jupiter's distance: 45.77 W/m^2

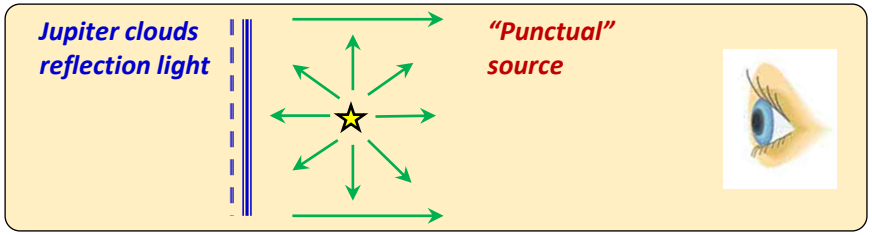
2) Convolution of Solar Spectrum+Camera response+Jupiter spectrum







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] K → 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: $v \approx 60 km/s$ $\eta \approx 0.16 - 0.22$ (luminous efficiency)

Density: $\rho \approx 2.0 g/cm^3$ Density: $\rho \approx 0.6 g/cm^3$

Impacts reported in Hueso et al. 2013

June 3, 2010

$Energy \approx 1.9 - 14.0 \times 10^{14} J$
$46 - 350$ ktn

$Mass \approx 105 - 780\ Tn$

$Size$ (diameter) $D \approx 4.7 - 9.1\ m$
$D \approx 7.0 - 14\ m$

August 20, 2010

$Energy \approx 3.7 - 11.0 \times 10^{14} J$
$88 - 260$ ktn

$Mass \approx 205 - 610\ Tn$

$Size$ (diameter) $D \approx 5.8 - 8.4\ m$
$D \approx 8.7 - 13\ m$

Sept. 10, 2012 **(most intense)**

$Energy \approx 9.0 - 17.0 \times 10^{14} J$
$215 - 405$ ktn

$Mass \approx 500 - 950\ Tn$

$Size$ (diameter) $D \approx 7.8 - 9.7\ m$
$D \approx 12 - 14\ m$

Latest Jupiter impacts

March 17, 2016

$Energy \approx 5.6 - 11.2 \times 10^{14} J$
$135 - 270$ ktn

$Mass \approx 310 - 620\ Tn$

$Size$ (diameter) $D \approx 6.7 - 8.4\ m$
$D \approx 10.0 - 12.6\ m$

May 26, 2017 ***(smallest impact)***

$Energy \approx 1.3 - 2.3 \times 10^{14} J$
$32 - 55$ ktn

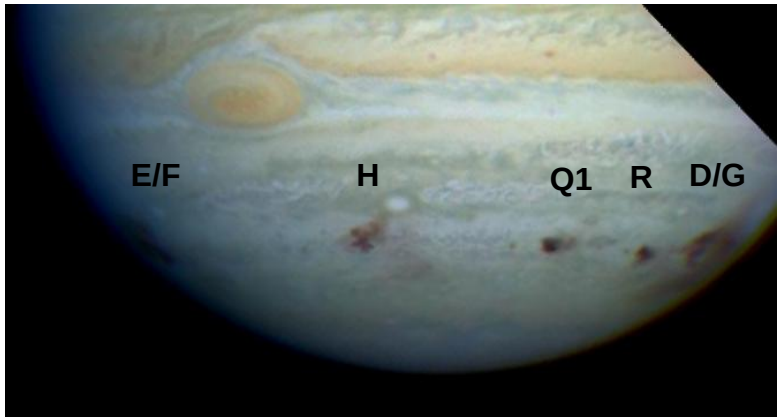
$Mass \approx 75 - 130\ Tn$

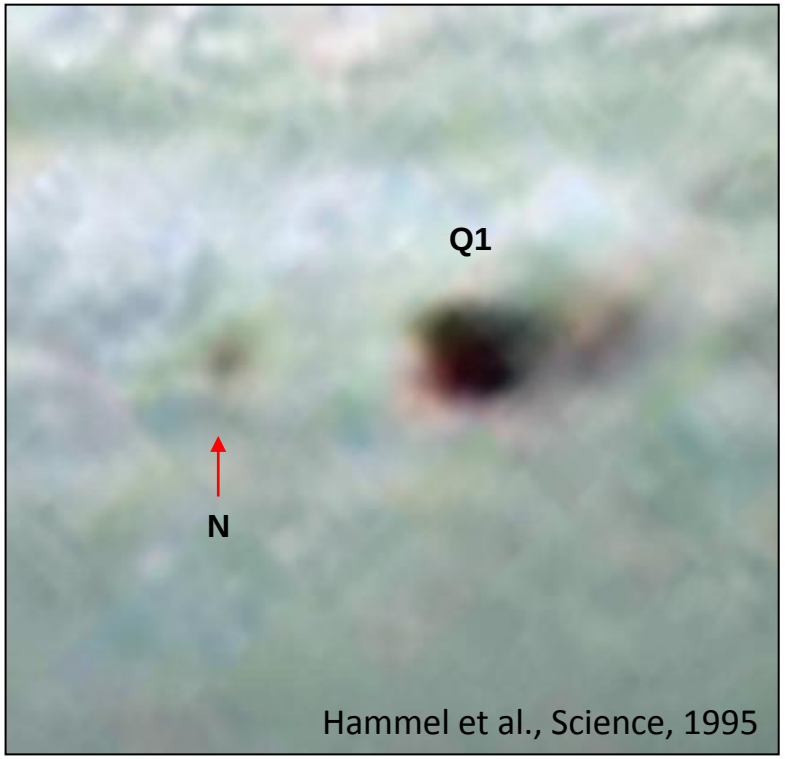
$Size$ (diameter) $D \approx 4.1 - 5.0\ m$
$D \approx 6.1 - 7.4\ m$

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?

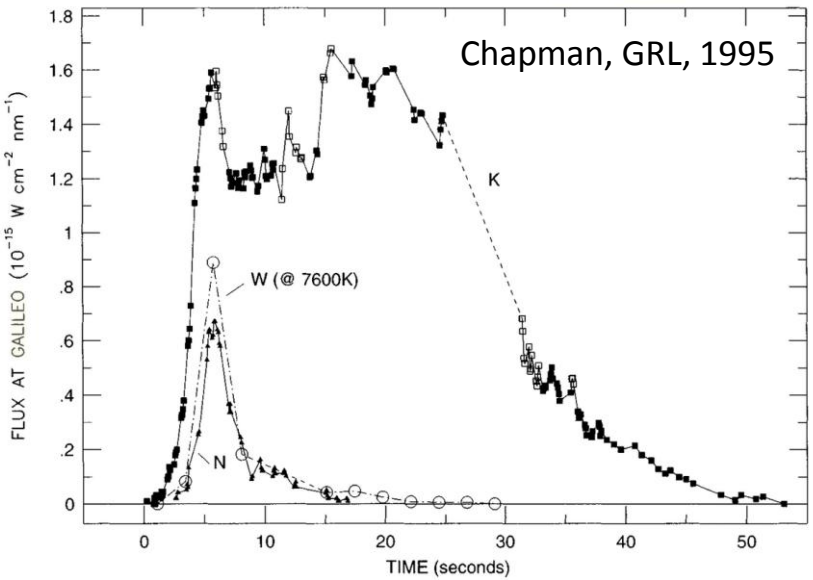
HST observations of SL9 impact debris



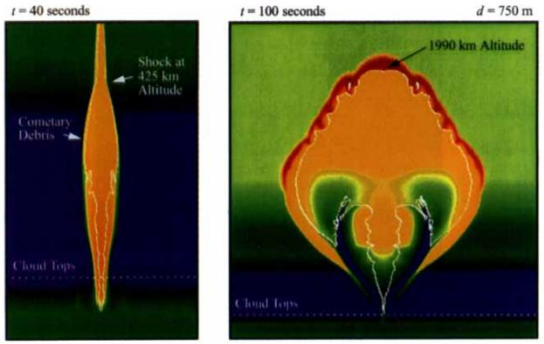


Hammel et al., Science, 1995

Galileo light-curves of SL9 fragment impacts



Extensive numerical simulations



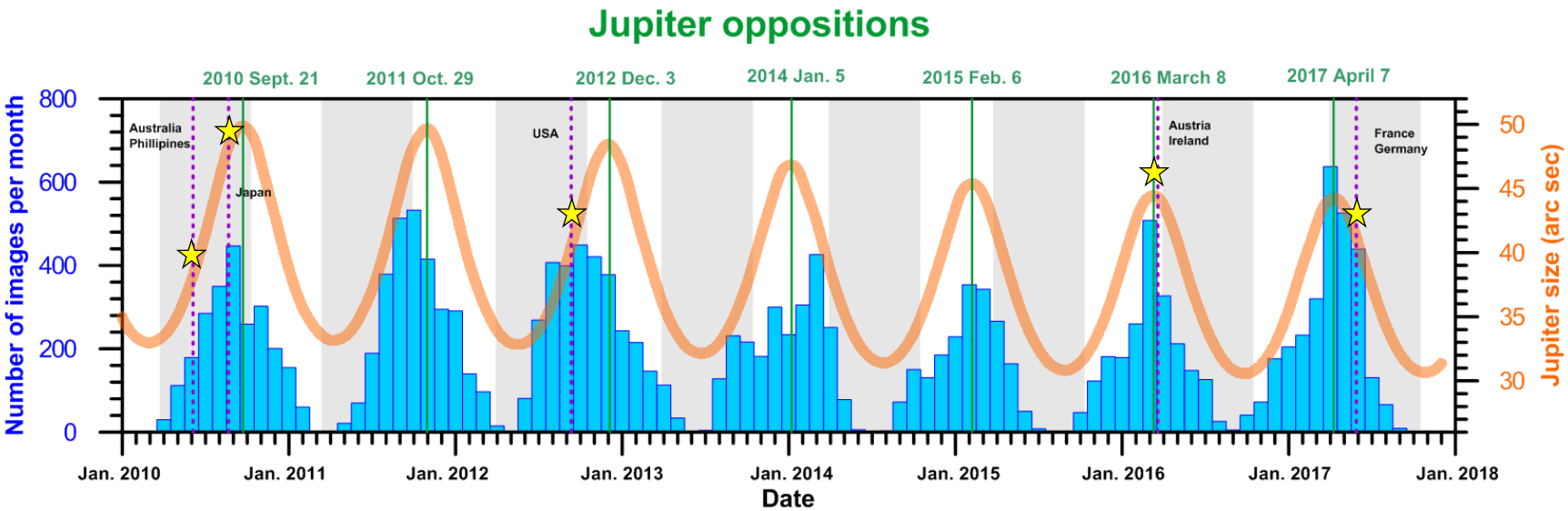
Fragment N had an estimated size of 45 m with a mean density of 0.25 g/cm^3

Crawford, Annals of the NY Academy of Science, 1997

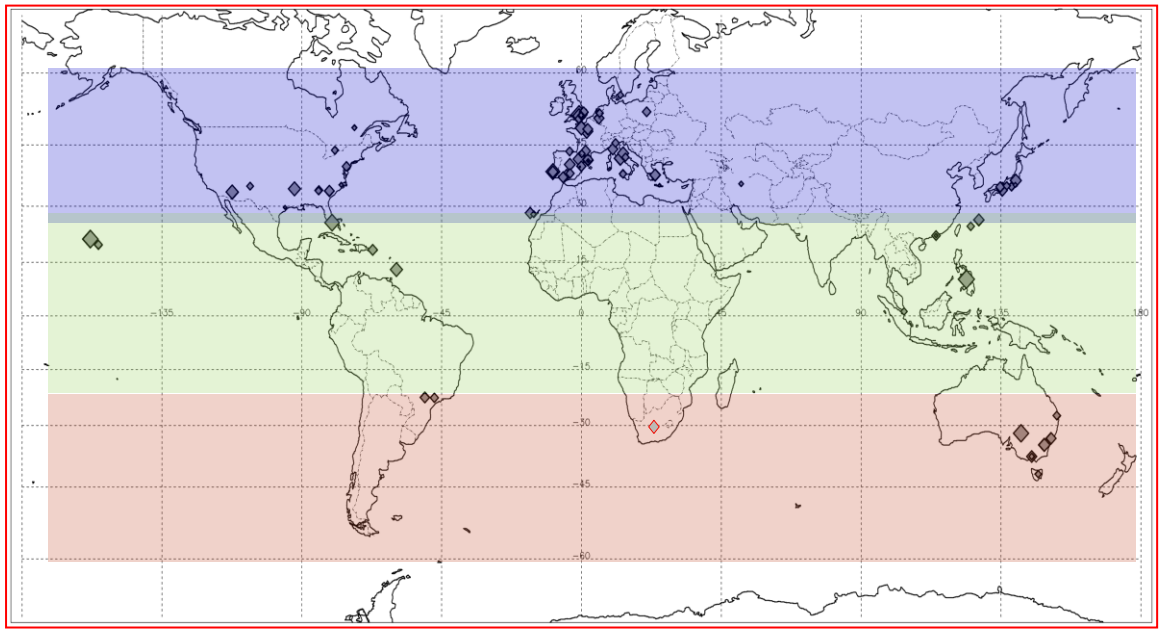
SL-9 fragment N: 14 times more massive than the largest possible mass for the flash detected in September 2012 or 180 times more massive than the smallest flash detected in May 2017.

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 **(17643 images since 2010)**



Geographical location of observers



Good weather (North hemisphere)

Spring-Summer North hemisphere

Bad weather (North hemisphere)

Autum-Winter North hemisphere

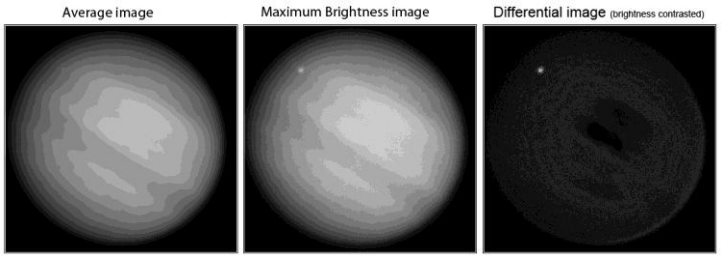
# Images from Low latitudes:	21%
# Images from North latitudes:	**65%**
# Images from South latitudes:	16%

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

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

http://www.astrosurf.com/planetessaf/doc/project_detect.shtml

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

Jupiter

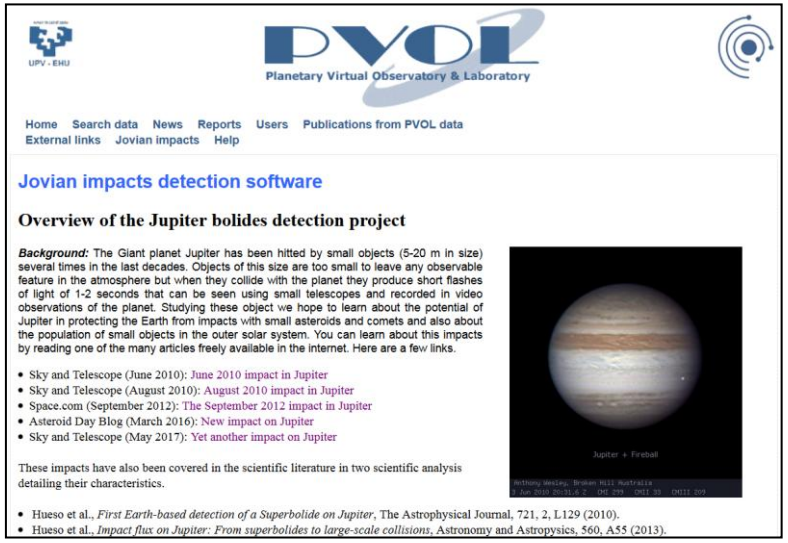
estimation of 4,4 impacts per year (0,4 per month)

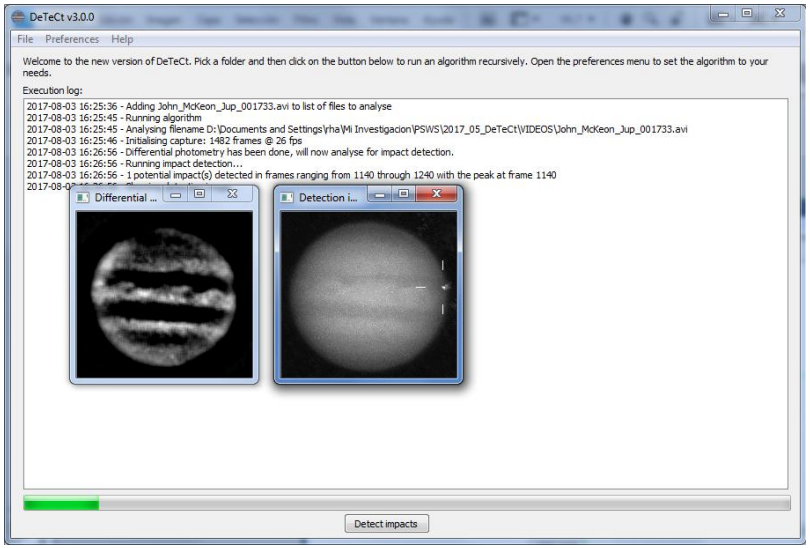
Observer	Duration	Number of videos	Date range
Total : 71 observers	83.636 days	71196 videos	2004/02/29 - 2017/07/16

But most of the observations are under bad conditions and the software does not find the impacts in the worst observations.

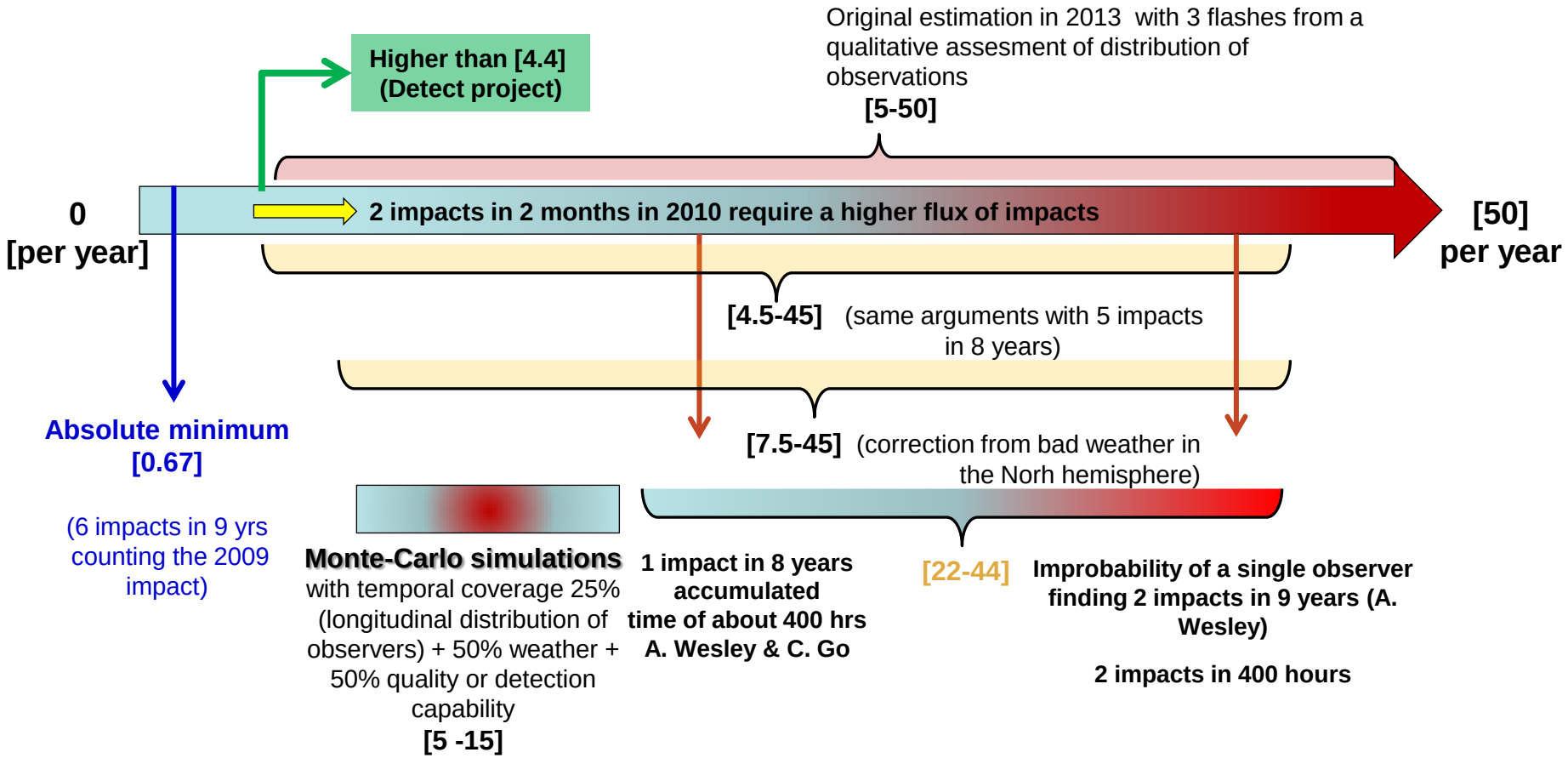
DeTeCt3.0: UPV/EHU + Marc Delcroix (Funded by Europlanet-2020 RI

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





Estimation of the number of comparable Jupiter impacts per year



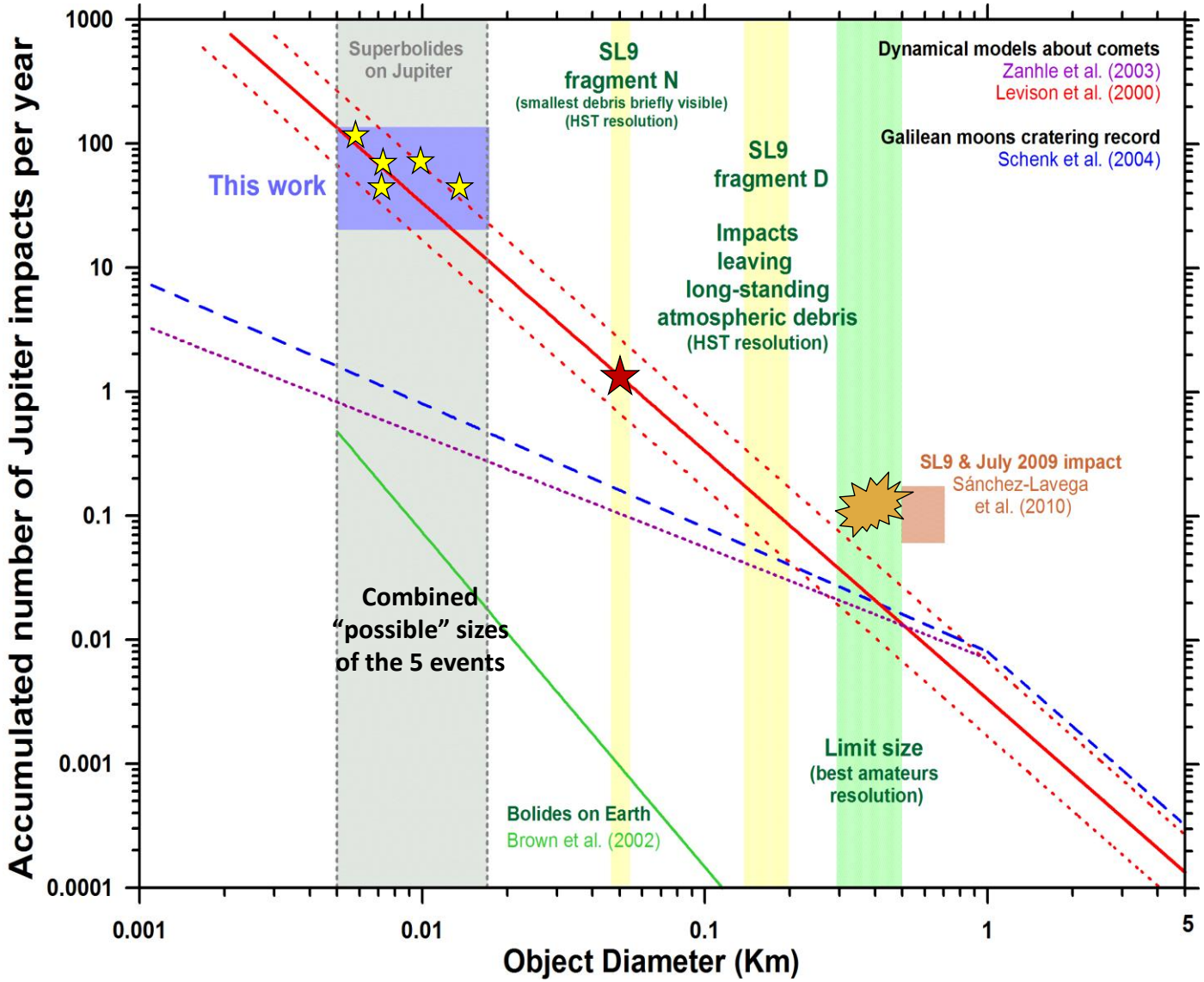
Global estimate:
[5-30]

→

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

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

Updated Flux of impacts in Jupiter & Conclusions



10 m size objects ★ *should be detected yearly in the next Jupiter oppositions.*

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 occulr 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.