Small impacts on the Giant Planet Jupiter

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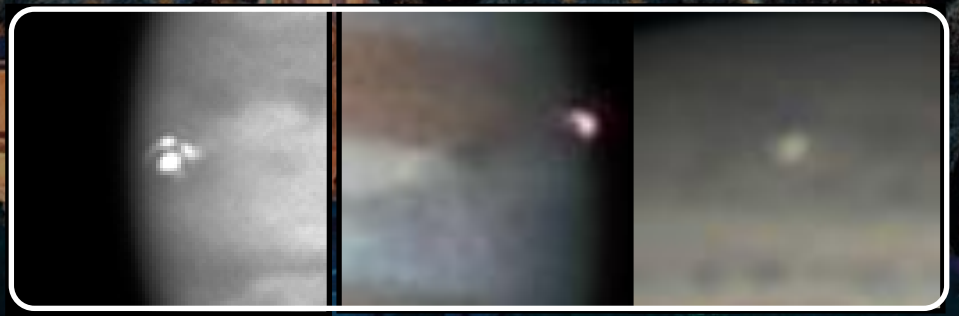
With express thanks to the large community of amateur observers of Jupiter that made this work possible



13th Meeting of the Spanish Astronomical Association, Salamanca, 18 July 2018

Big impacts in Giant Planets

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).

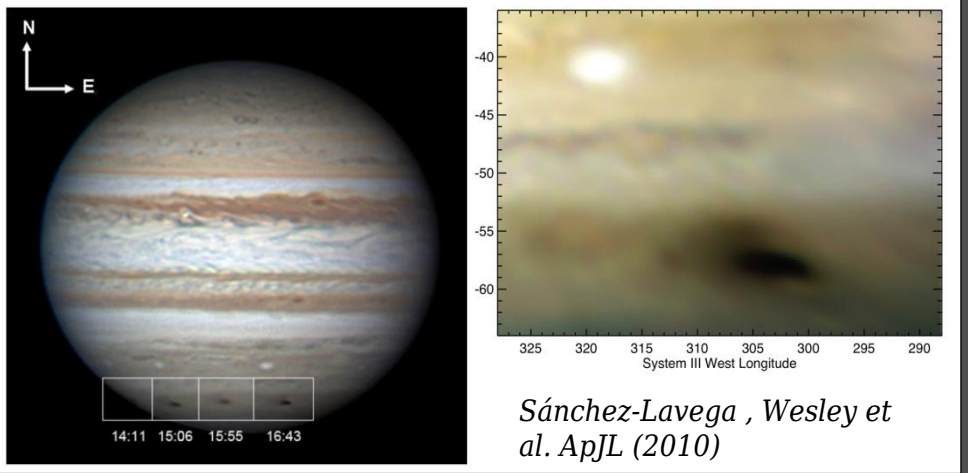
At the time this was coined as "a once in a lifetime event"

Harrington, et al. Jupiter book (2004).

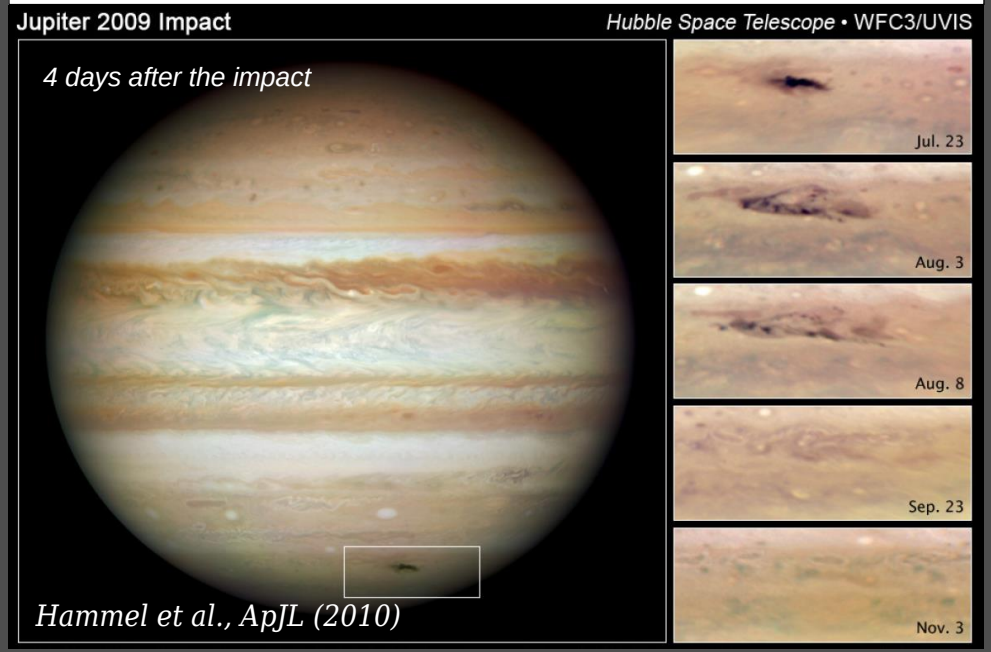
(Background: HST image of the G impact site)

July 19, 2009

Amateur astronomerAnthony Wesley discovers an impact scar in Jupiter



Sánchez-Lavega , Wesley et al. ApJL (2010)

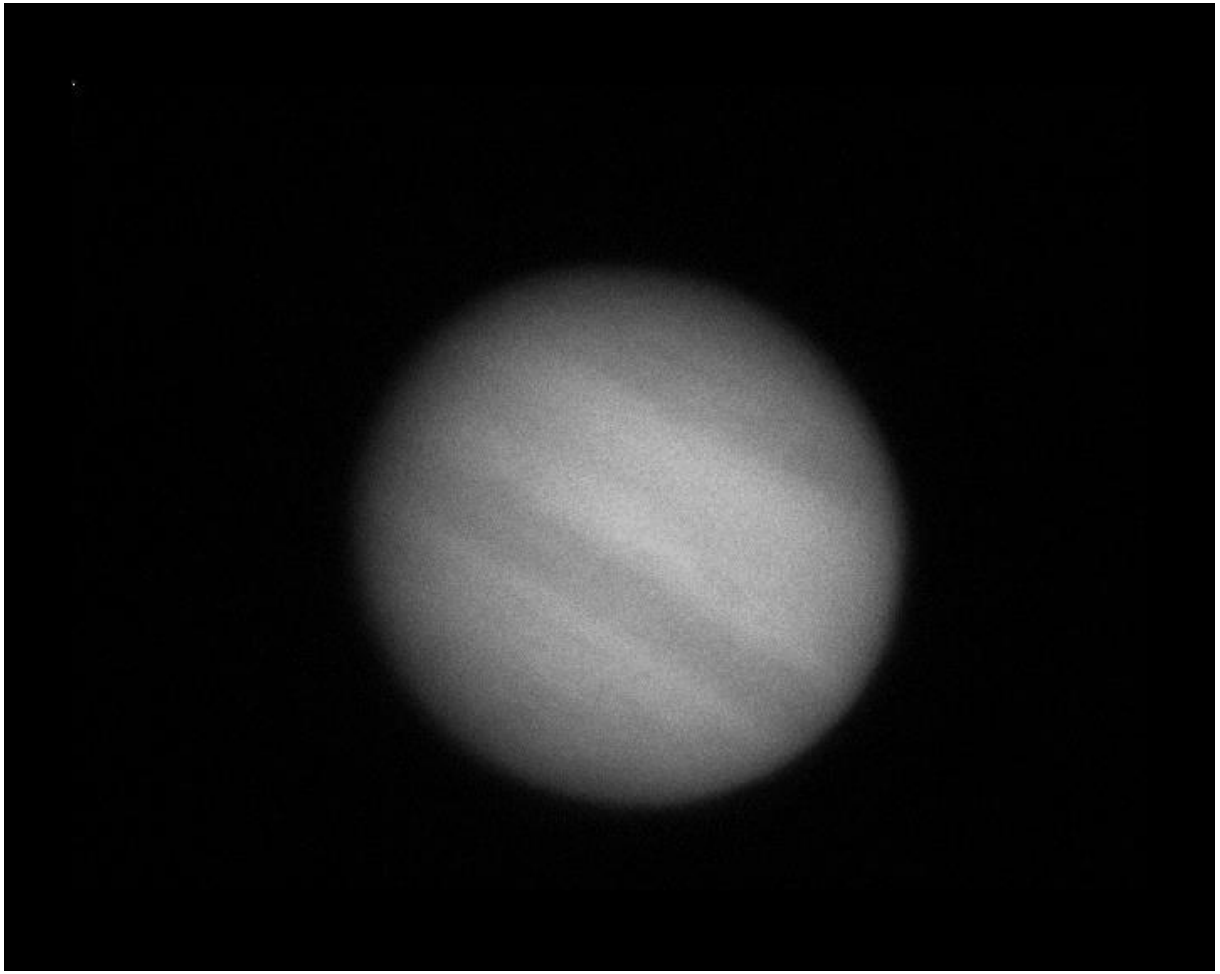


Hammel et al., ApJL (2010)

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 using a 60 fps camera & and a **red filter**.*

The second impact in Jupiter found by a single person!



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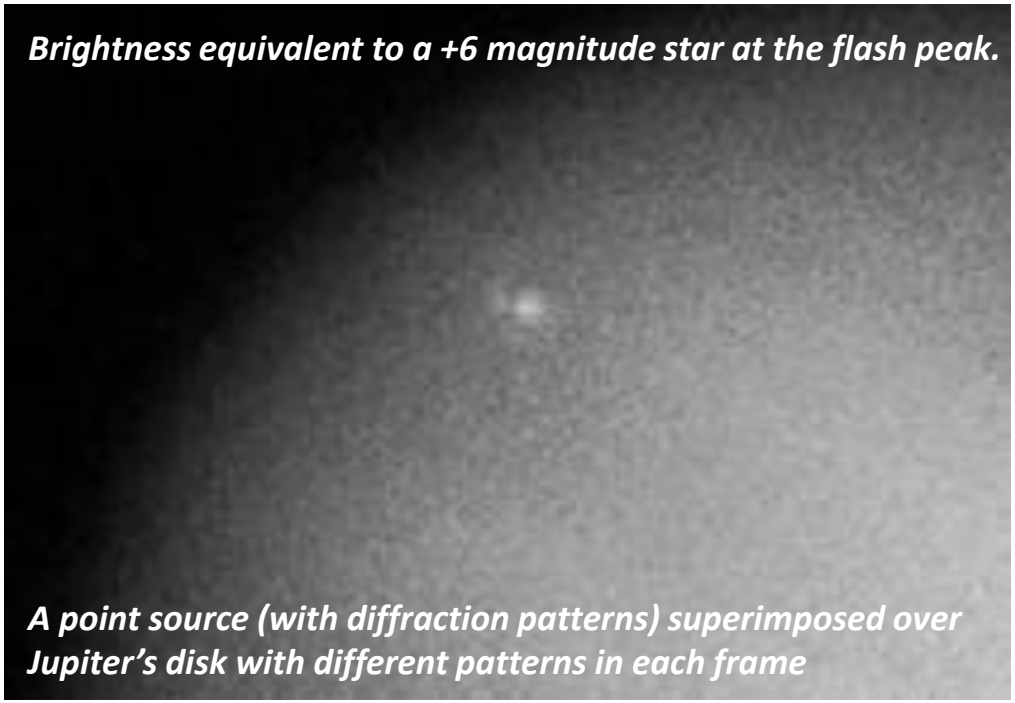
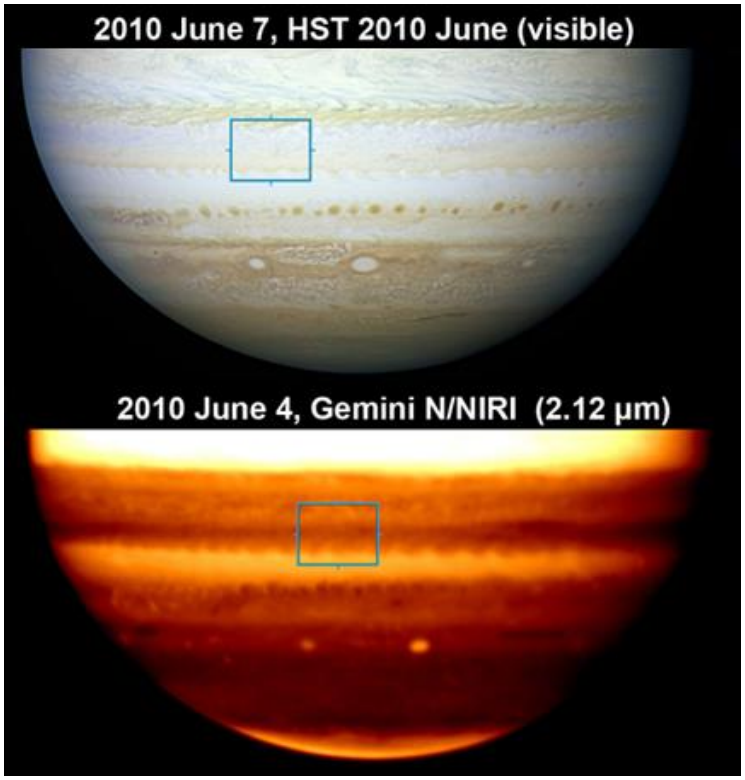


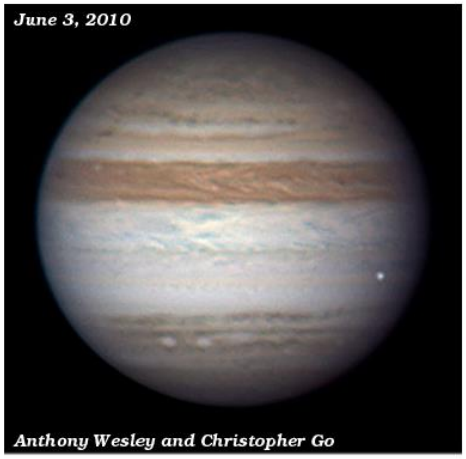
*Flash simultaneously observed by an amateur in Phillipines (Christopher Go) using a 11'' telescope, similar camera and a **blue filter**. Same temporal duration (1 s).*

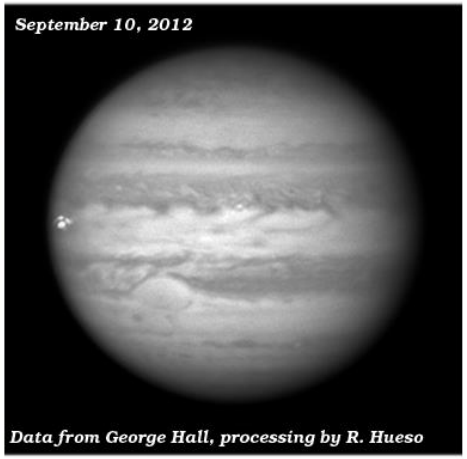


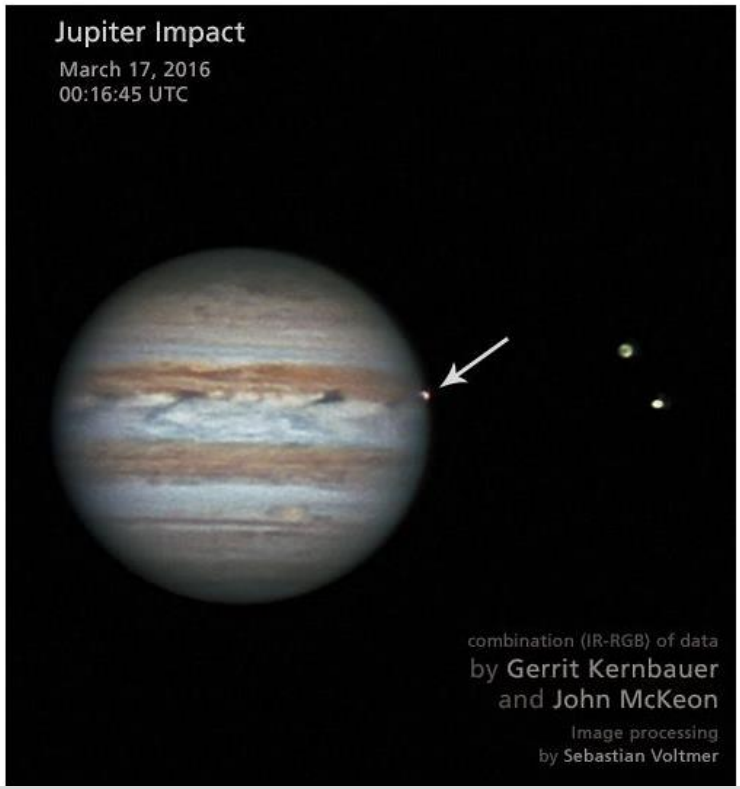
Fast campaign to detect a debris field in Jupiter
*(**HST, VLT, Gemini, Keck, IRTF and more in less than 3 days**)*
→ ***No debris found**!*

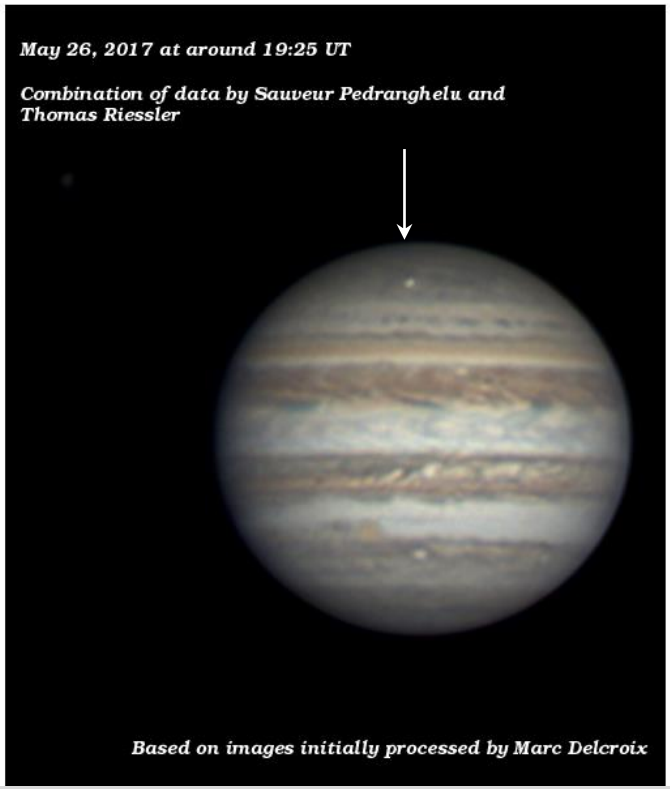
Analysis of the light-curves from Wesley and Go and the lack of observable debris:
*Flash caused by an impact of a **8-13 m object** releasing **1.5-3.0x10^{13} J** of luminous energy*
Hueso, Wesley, Sánchez-Lavega et al. ApJL (2010)

… 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 ---

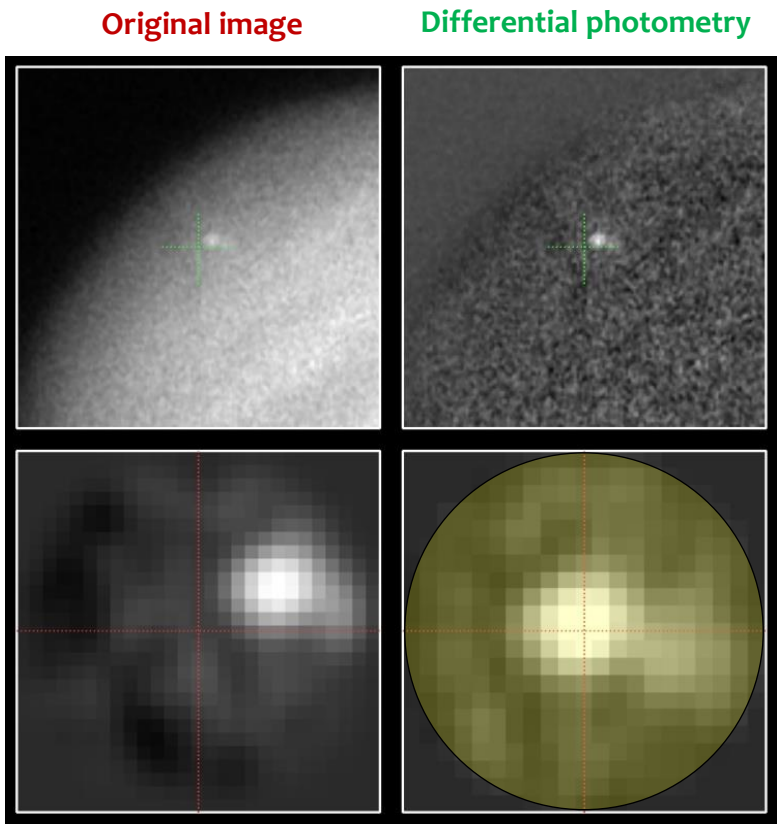
March 17, 2016
Gerrit Kernbauer (Austria)
John McKeon (Ireland).

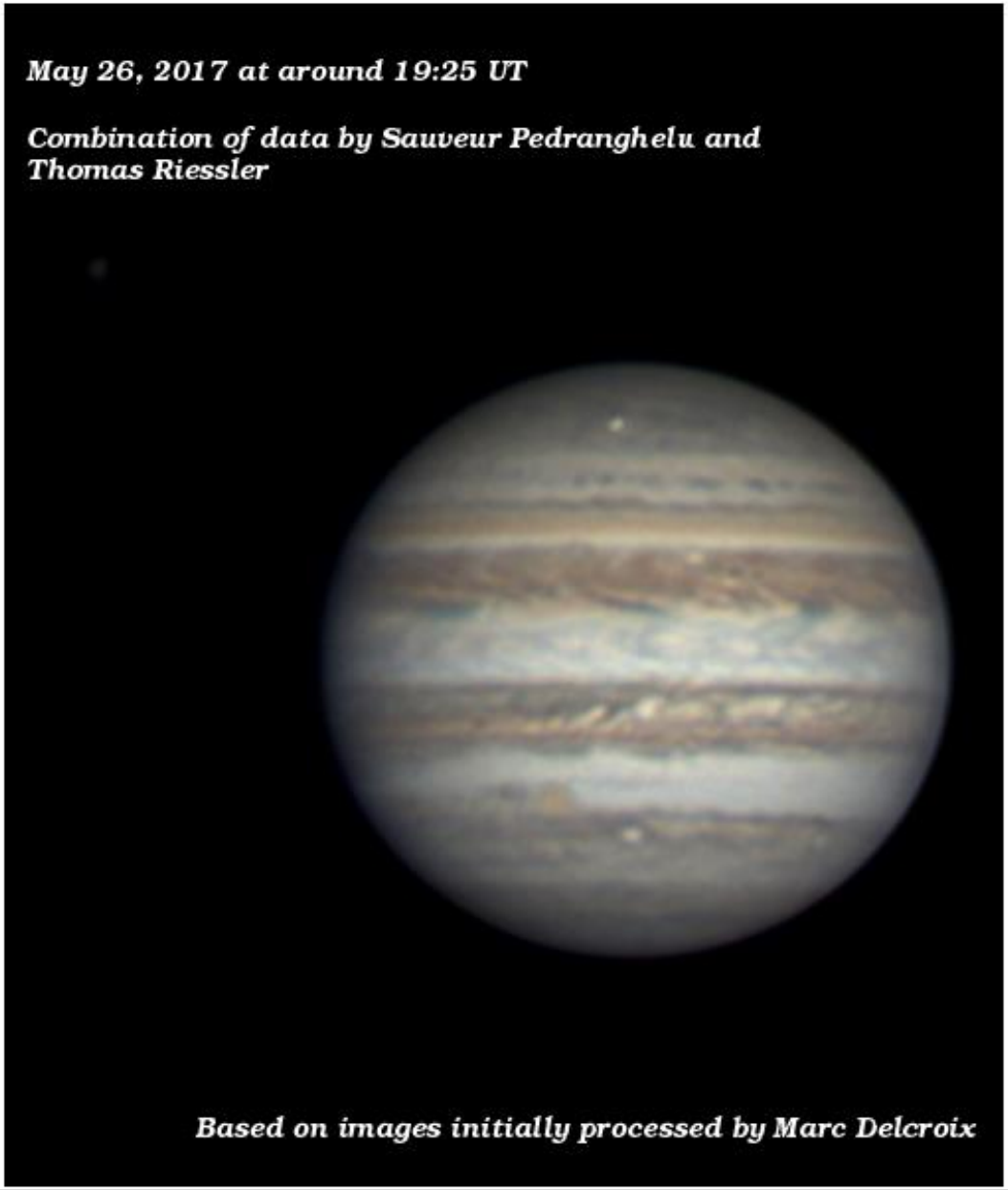
May 26, 2017
Sauveur Pedranghelu (France),
Thomas Riessler (Germany),
Andre Fleckstein (Germany).

2018 –No detections so far

Diversity of telescopes (from 6" to 14"), cameras, speeds, filters, seeing,…

Impacts characterization: Automatic light-curves (dedicated pipeline)





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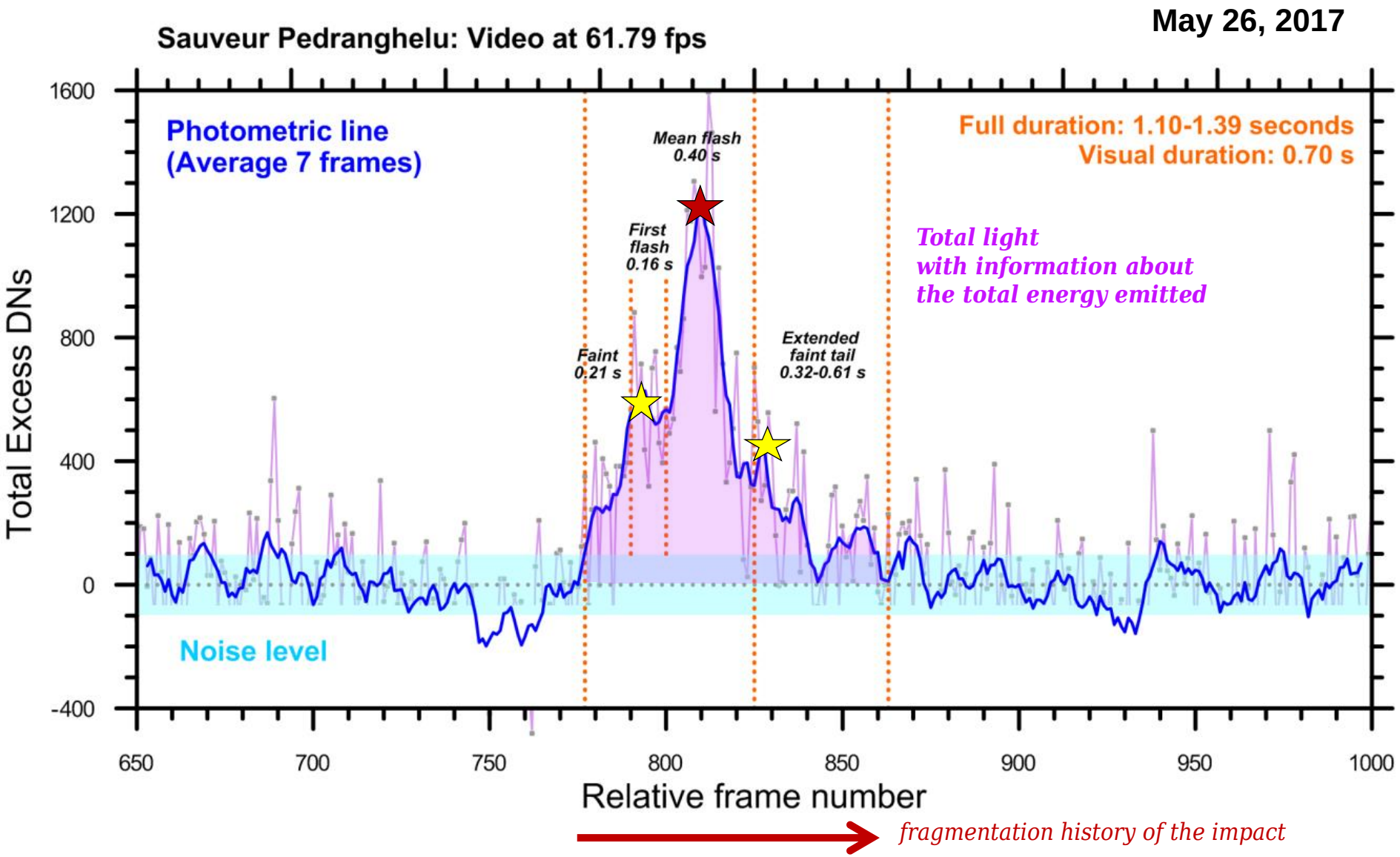
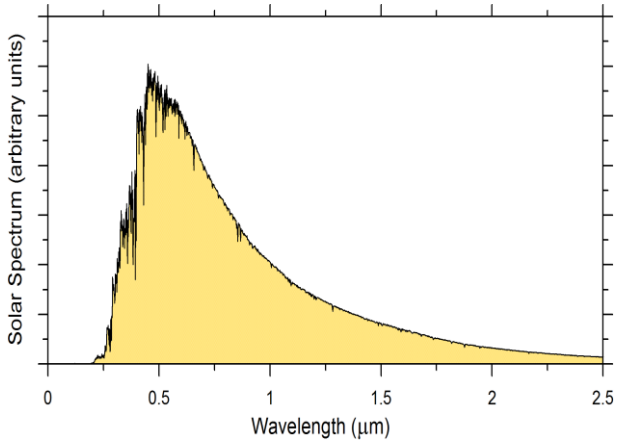
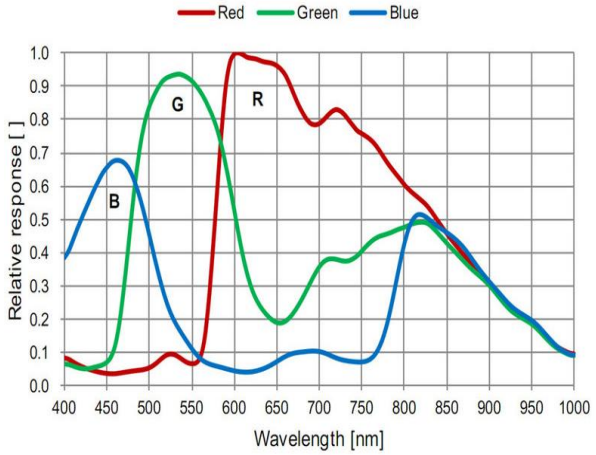


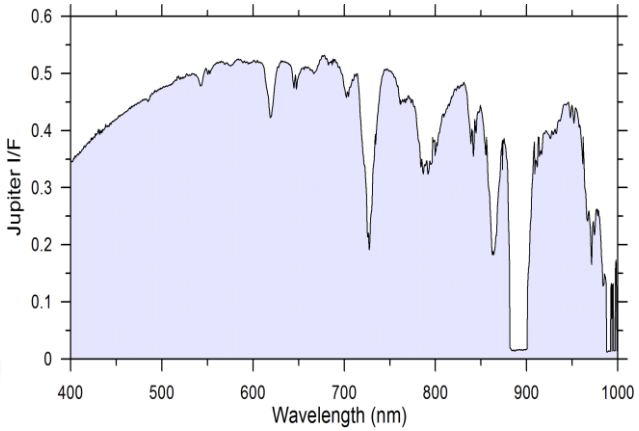
Energy calibration

1) Integrated photometry of Jupiter disk + Solar constant at Jupiter's distance for each date

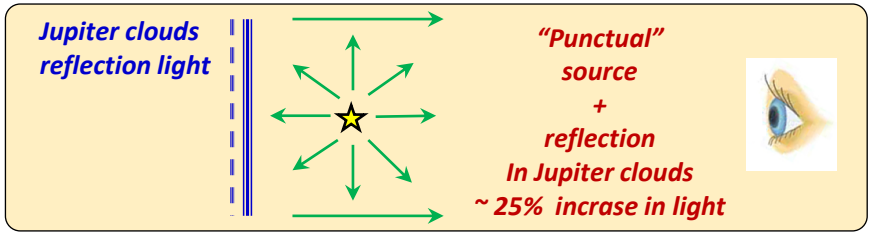
2) Convolution of Solar Spectrum+Camera response+Jupiter spectrum







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

Values from 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)

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

Hueso et al. A&A, 2013

June 3, 2010

Energy $\approx 1.9-14.0\times10^{14}$ *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 $\approx 3.7-11.0\times10^{14}$ *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 $\approx 9.0-17.0\times10^{14}$ *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

Hueso et al. A&A, 2018

March 17, 2016

Energy $\approx 5.6-11.2\times10^{14}$ *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 $\approx 1.3-2.3\times10^{14}$ *J*

$32-55$ ktn

Mass $\approx 75-130$ *Tn*

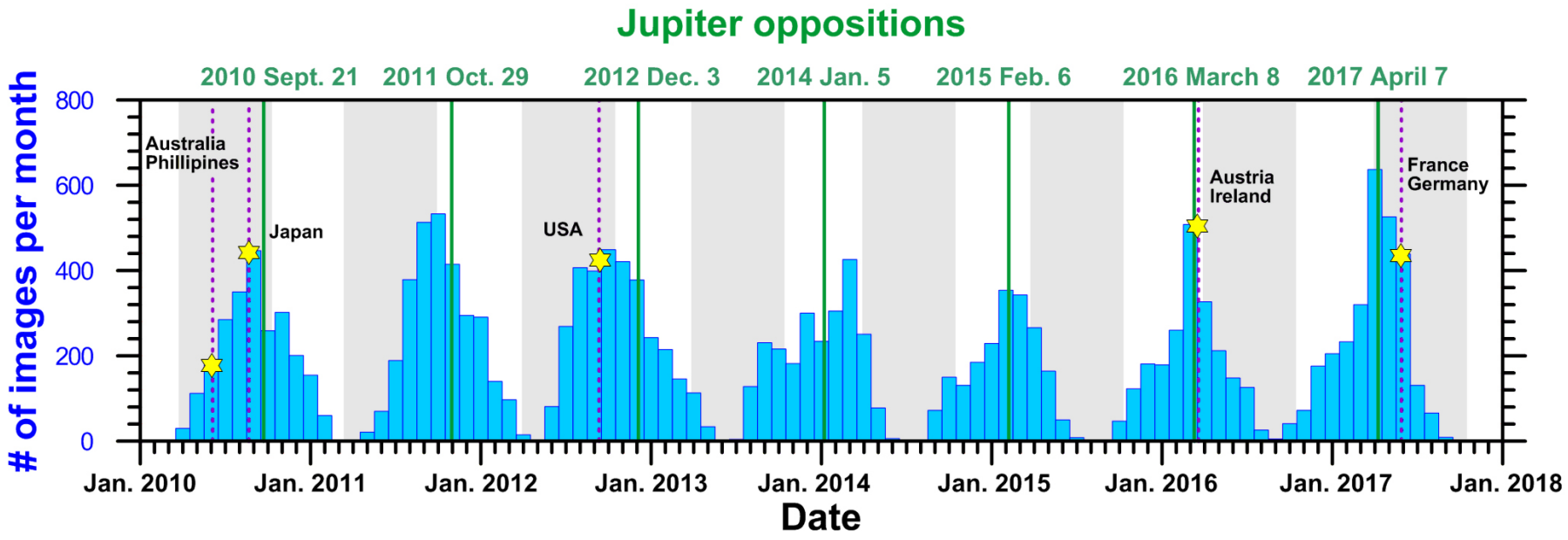
Size (diameter) $D \approx 4.1-5.0$ *m*

$D \approx 6.1-7.4$ *m*

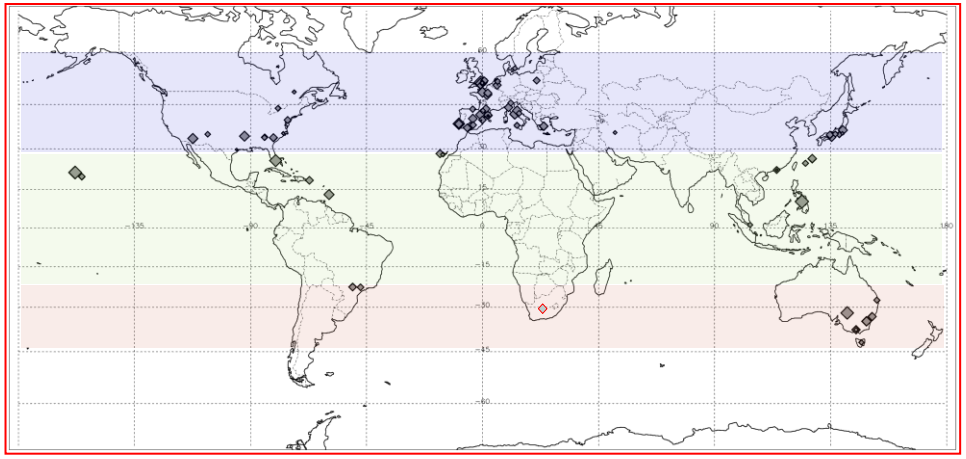
Chelyabinsk-like events [450 ktn] and 5-60 times less energetic than Tunguska (3000-5000 ktn)
1-3x10^{-6} less than the combined SL9 impacts (300.000 kTn)

How representative are these flashes of similar (but undetected) impacts in Jupiter?

Statistical analysis of amateur images contributed to the PVOL2 database http://pvol2.ehu.es (>19,300 images since 2010)



Geographical location of most active Jupiter observers



Good weather (North hemisphere)

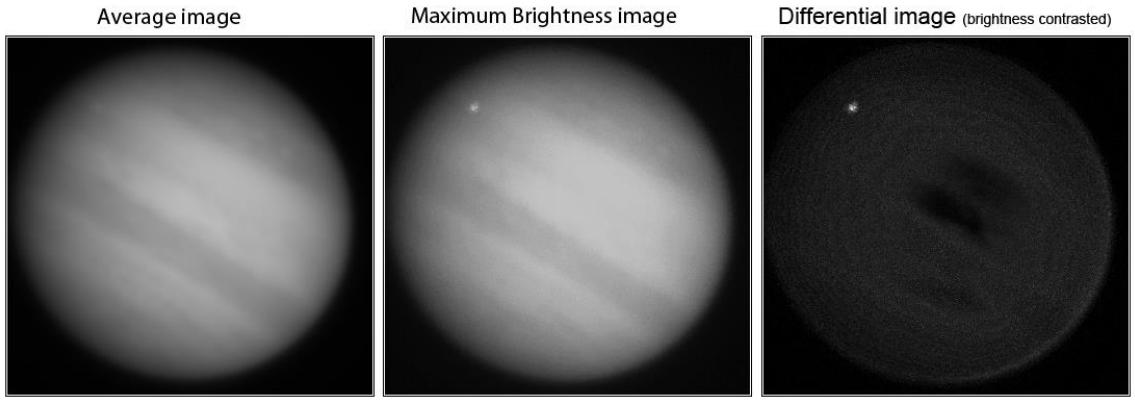
Spring-Summer North hemisphere

Bad weather (North hemisphere)

Autum-Winter North hemisphere

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

Principle: Differential photometry over coregistered images



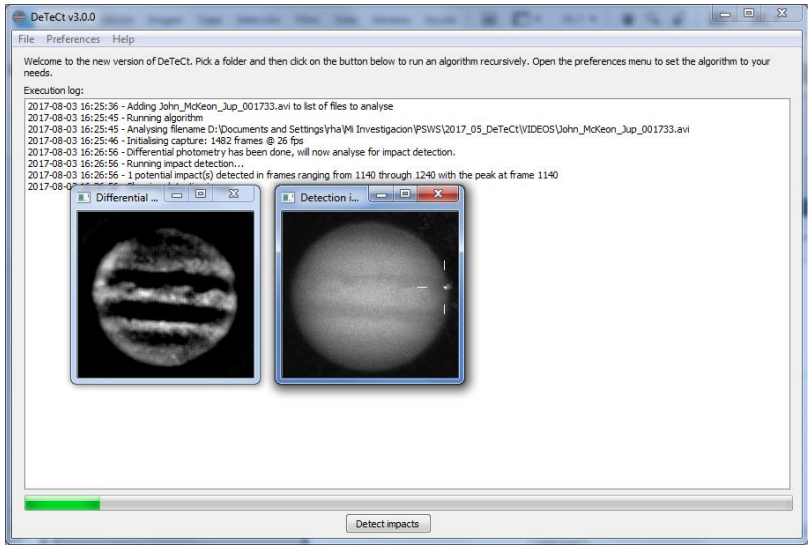
Major difficulty:

-Variety of quality in video observations of the planet.
-Need to analyze tens of thousands of video files equivalent to dozens of Terabytes of data.

Run by individual observers in their own computers! Needs to be easy to use!

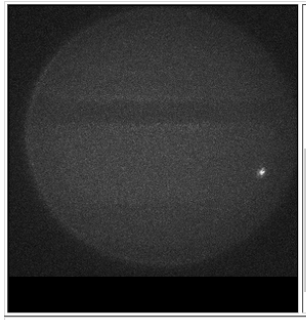
DeTeCt3.0: UPV/EHU (Funded by Europlanet-2020 RI) + Marc Delcroix

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



Statistical analysis of "non-detection" log files run by Marc Delcroix

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



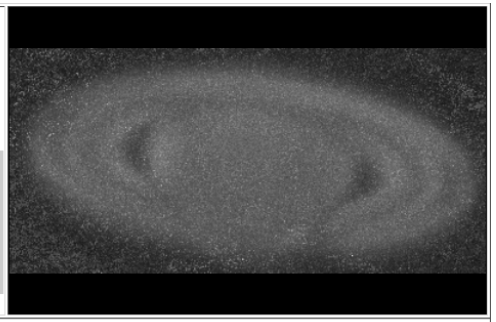
Impact flashes detection with DeTeCt software project/
Projet de détection de flash d'impacts avec le logiciel DeTeCt
by/*par* Marc Delcroix

Presentation of the project (EPSC2013, BAA workshop)

17/03/2018: NEW SOFTWARE VERSION 2.0.6 / *NOUVELLE VERSION 2.0.6 DU LOGICIEL*

Software download and tutorial for participating to the project
Téléchargement du logiciel et tutoriel pour participer au projet

NEW 26/03/2017 : Join the impact_detection Yahoo group for exchanges and support !



Jupiter

estimation of 3,9 impacts per year (0,3 per month)
total excludes 4,813 days of simultaneous observations

Observer	Duration	Number of videos	Date range
Total : 79 observers	**92.503 days**	**80603 videos**	**2004/02/29 - 2018/07/06**
Zac Pujic (Australia)	15.557 days	6372	2005/02/22 - 2018/06/05
Paul Rolet (France)	11.438 days	9271	2012/09/07 - 2018/07/05
Michel Jacquesson (France)	9.152 days	6620	2014/03/12 - 2017/01/23
Manos Kardasis (Greece)	6.993 days	5668	2004/02/29 - 2017/09/12
Thomas Ashcraft (USA)	4.969 days	5886	2013/10/09 - 2016/11/30
Benito Loyola (USA)	4.769 days	1775	2018/02/17 - 2018/07/06
Bernd Gaehrken (Germany)	4.095 days	5673	2016/03/06 - 2018/06/24
Alan Coffelt (USA)	3.593 days	2605	2013/10/04 - 2018/05/14
Marc Delcroix (France)	2.810 days	2184	2006/04/13 - 2018/06/26
Xavier Dupont (France)	2.062 days	1867	2012/08/16 - 2015/04/25
Grant Blair (USA)	1.988 day	1874	2013/08/20 - 2016/04/21
Hampton University Sayanagi Group (USA)	1.912 day	1396	2018/03/23 - 2018/06/19
Agapios Elia (Cyprus)	1.734 day	1922	2013/11/09 - 2018/06/12
Trevor Barry (Australia)	1.612 day	2421	2009/07/06 - 2012/12/30
Christophe Pellier (France)	1.530 day	739	2012/02/20 - 2015/02/12
David Domine (France)	1.450 day	907	2016/02/25 - 2017/04/10
Pascal Bayle (France)	1.390 day	1697	2012/11/30 - 2015/05/10
Torsten Mellenthin (Germany)	1.218 day	1416	2016/01/28 - 2017/06/24
Lammertus de Vries (Spain)	1.171 day	635	2009/08/03 - 2015/05/08
Stephane Gonzales (France)	1.131 day	1243	2013/12/20 - 2018/06/03
Jocelyn Serot (France)	1.121 day	845	2014/01/10 - 2018/06/12
Arnaud Claisse (France)	0.941 day	842	2014/01/19 - 2016/05/03
Matic Smrekar (Slovenia)	0.932 day	1631	2009/07/29 - 2016/06/10
Jean-Luc Dauvergne (France)	0.930 day	586	2016/05/04 - 2018/07/03
Pic du Midi (Delcroix/Dauvergne) (France)	0.840 day	1636	2010/09/29 - 2017/06/11
Paul Jones (USA)	0.819 day	723	2011/08/29 - 2015/04/05

Saturn

estimation of less than 31,6 impacts per year (2,6 per month)
no simultaneous observations

Observer	Duration	Number of videos	Date range
Total : 17 observers	**11.558 days**	**5107 videos**	**2005/02/04 - 2018/07/06**
Zac Pujic (Australia)	5.155 days	2103	2005/02/04 - 2018/04/21
Marc Delcroix (France)	2.112 days	913	2007/01/20 - 2018/06/26
Paul Rolet (France)	1.059 day	279	2015/05/12 - 2017/08/16
Manos Kardasis (Greece)	0.791 day	398	2008/03/10 - 2017/03/25
Grant Blair (USA)	0.445 day	255	2014/03/14 - 2016/04/24
Oleg Zaharciuc (Moldova)	0.443 day	213	2016/05/22 - 2018/07/06
Pic du Midi (Delcroix/Dauvergne) (France)	0.297 day	338	2012/08/06 - 2017/06/12
Arnaud Claisse (France)	0.260 day	62	2015/05/21 - 2016/05/04
Societe Astronomique de Touraine (France)	0.223 day	92	2014/03/14 - 2016/07/16
Stephane Gonzales (France)	0.195 day	89	2015/05/23 - 2017/06/05
David Domine (France)	0.171 day	35	2016/04/23 - 2017/04/08
Alan Coffelt (USA)	0.150 day	56	2015/05/03 - 2017/04/26
Matic Smrekar (Slovenia)	0.089 day	85	2011/06/27 - 2016/06/06
Charles Galdies (Malta)	0.077 day	81	2014/06/08 - 2015/07/17
Blake Estes (USA)	0.055 day	79	2016/05/08 - 2016/05/13
Adrien Marezac (France)	0.022 day	18	2017/06/11 - 2017/06/11
Torsten Mellenthin (Germany)	0.006 day	11	2017/04/01 - 2017/06/23

- ***80,600 videos equivalent to 92.5 days of observations by 79 observers***

Estimation of the number of comparable Jupiter impacts per year

Hueso et al. A&A, 2018

Higher than [3.9] from the DeTeCt analysis of non-detections (most videos are of poor quality)

[0] per year

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

[50] per year

Absolute minimum [0.67]

(5-6 impacts in 8-9 yrs counting the 2009 impact)

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

[5 -15]

[22-44]

If you don't believe that

Anthony Wesley won the impact lottery two times

→ 2 impacts in 8 years

in an accumulated observing time of about 400 hrs

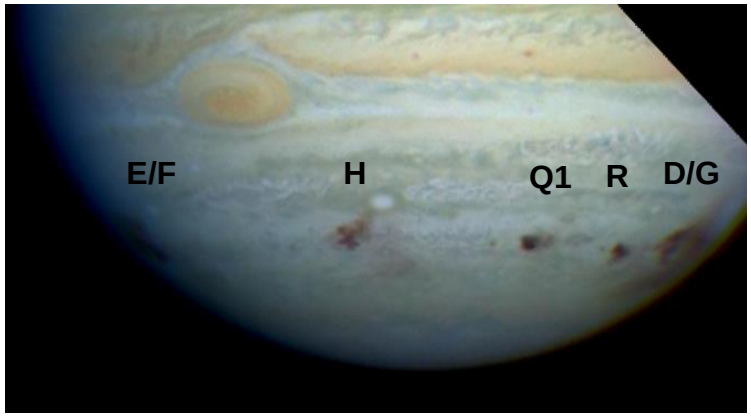
We only observe 9/12 months and 1/3 of the planet

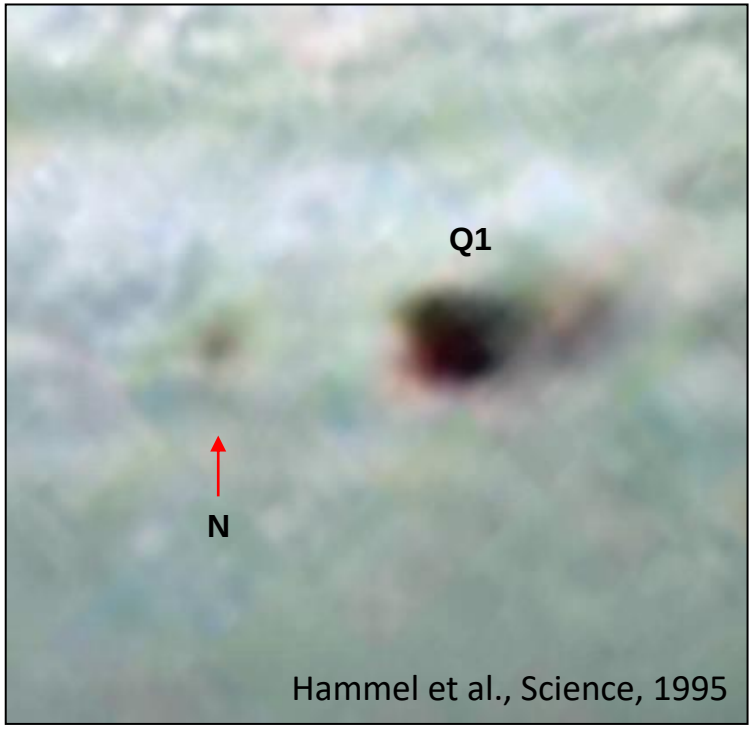
Global estimate: [4-25]

10-65 "total flux" of 5-20-m size impacts per year

No consequences on the chemistry of Jupiter's upper atmosphere

HST observations of SL9 impact debris





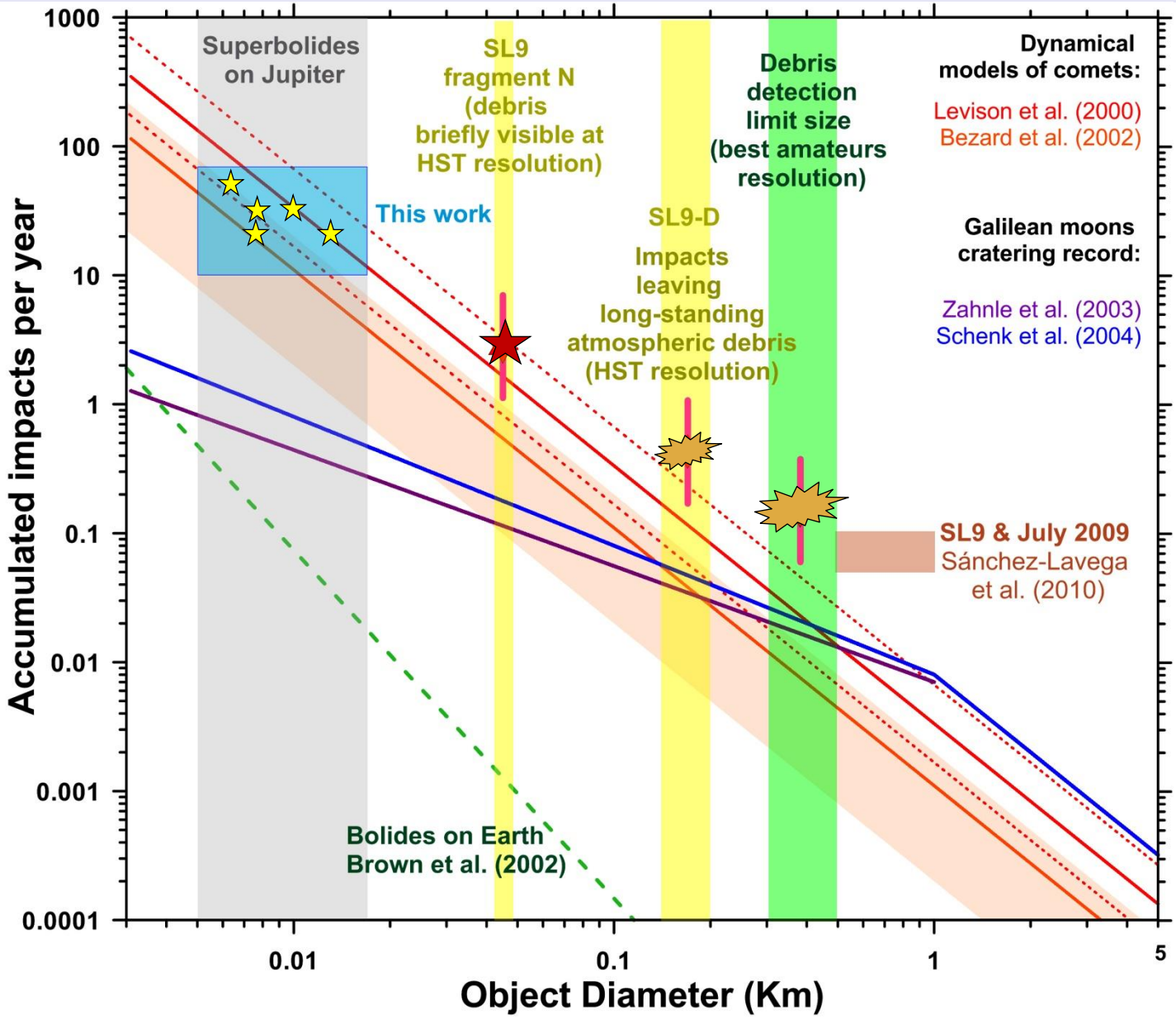
SL-9 fragment N: 45 m in diameter

14 times more massive than the impact flash detected in **September 2012.**

180 times more massive than the smallest impact flash **in May 2017**.

How often should we expect to find such an impact leaving an observable debris field in 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* ***2-12*** *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 6-30 years*** *for about one week for "regular" amateur observers.*