EUROPLANET SCIENCE CONGRESS EPSC2022

# Bolide Impacts in Jupiter's Atmosphere in 2020-2021

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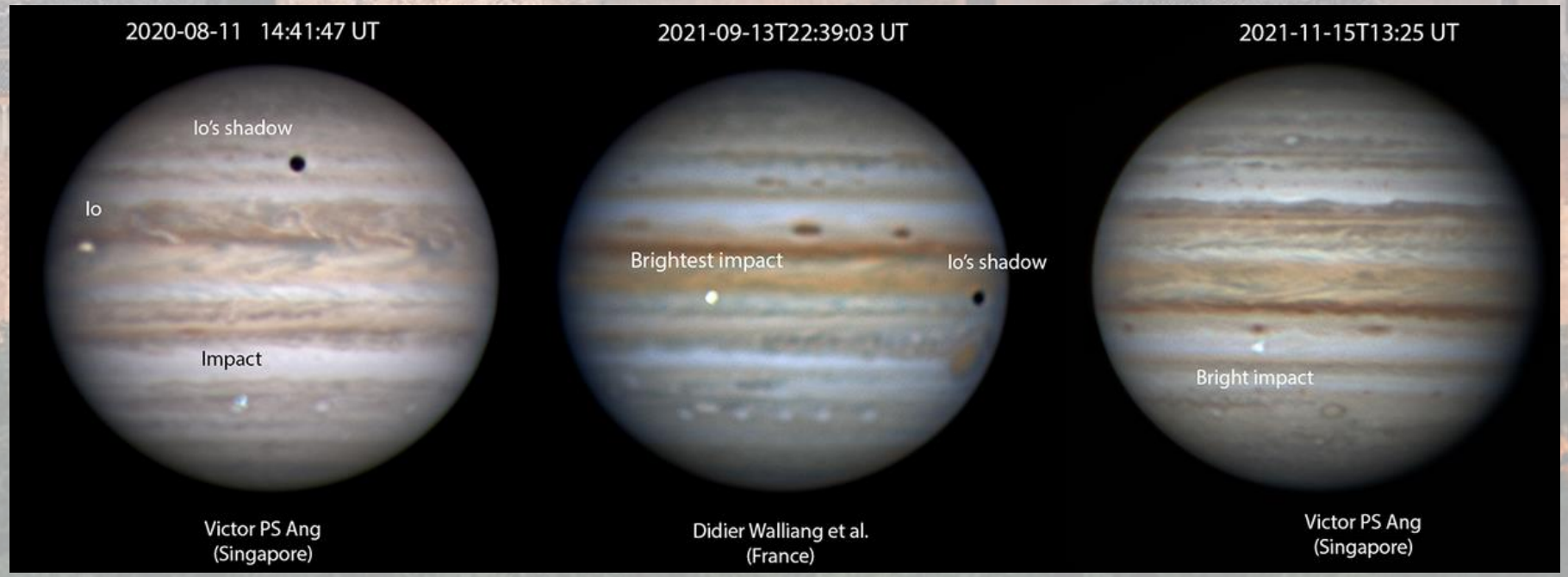


# Background: Two large impacts in Jupiter in 1994 and 2009

## 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).***

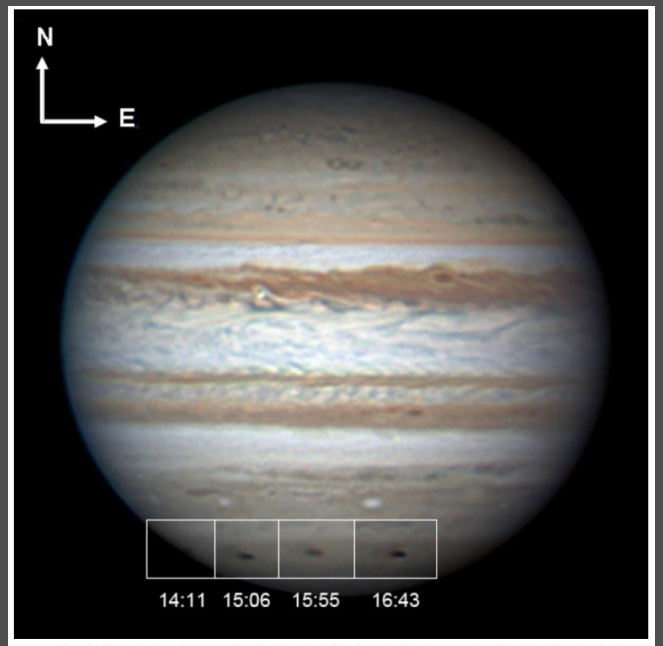
***At the time this was coined as "a once in a lifetime event"***

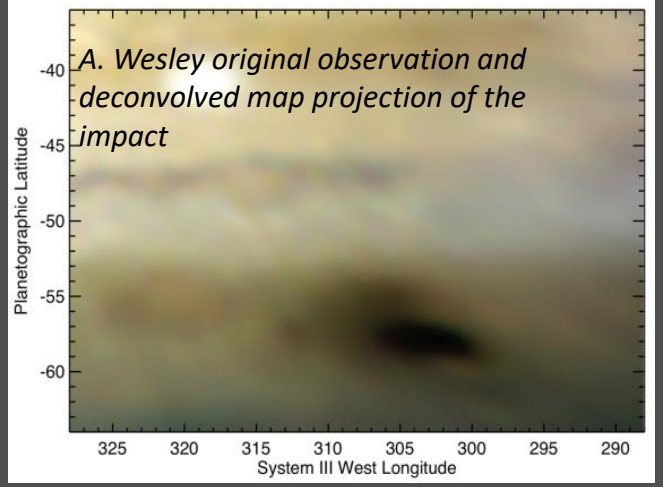
*Harrington, et al. Jupiter book (2004).*

*(Background: HST image of the G impact site)*

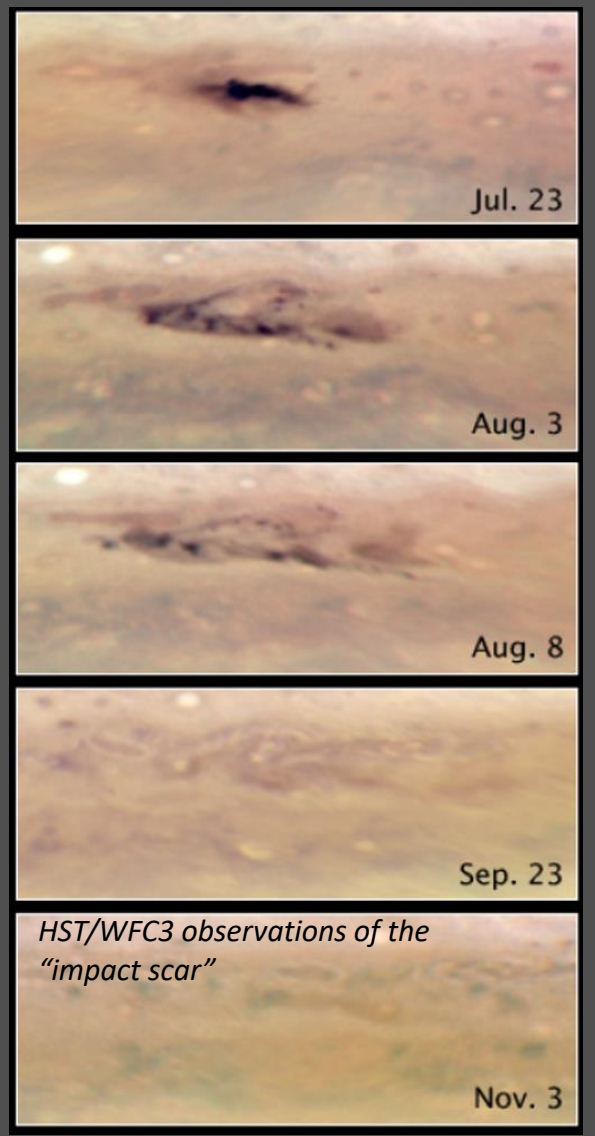
## July 19, 2009: *Anthony Wesley discovers an impact scar in Jupiter*

*Sánchez-Lavega et al. ApJL, 2009*



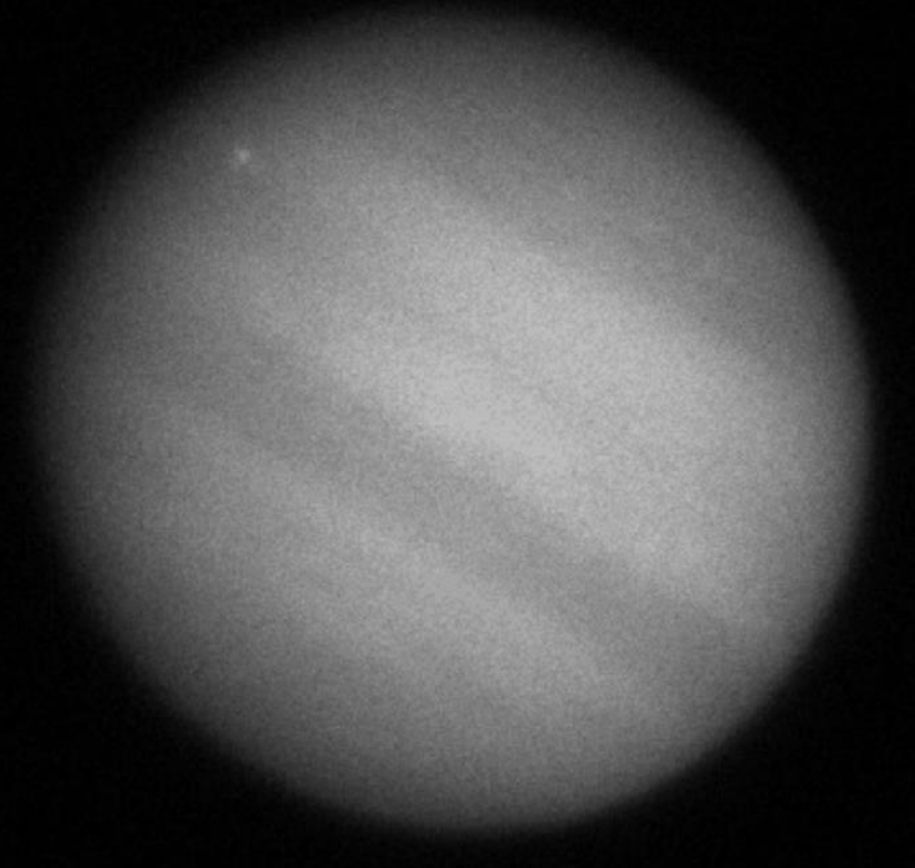

*Hammel et al. ApJL, 2009*



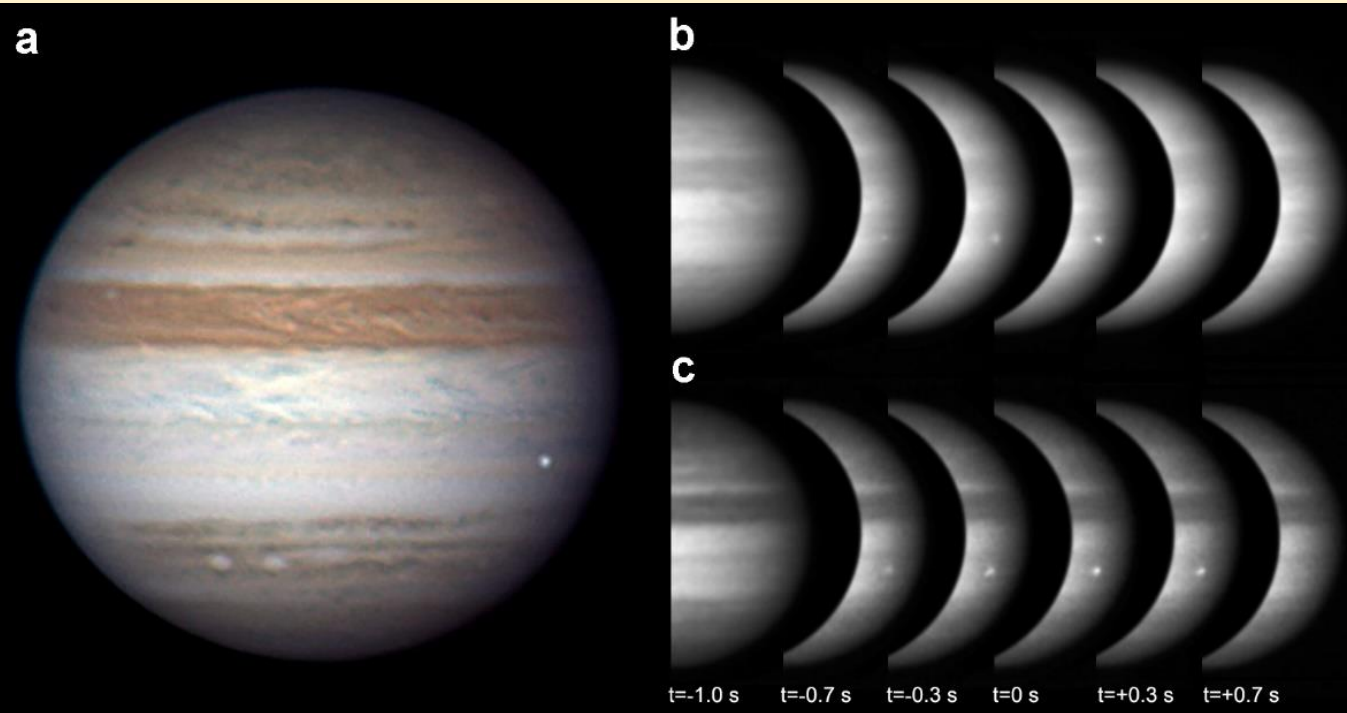

*Possible asteroidal origin, Orton et al. Icarus 2011*

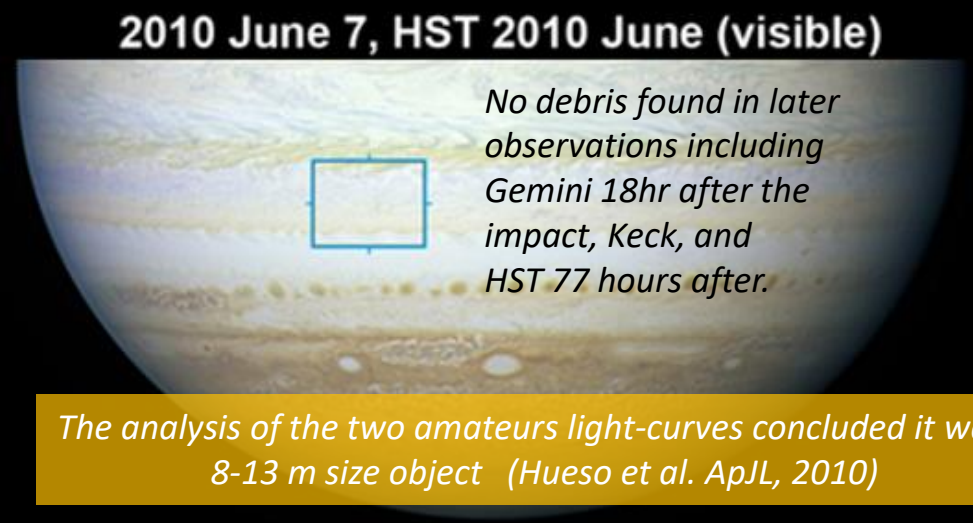
# The first ground-based small impact in Jupiter

*June 3, 2010 at 20:31:20 UT*



*Casual Jupiter observation by A. Wesley (Australia) with a 15'' telescope, a 60fps camera & and a **red filter**. Simultaneous flash recorded in blue by C. Go (Philippines).*

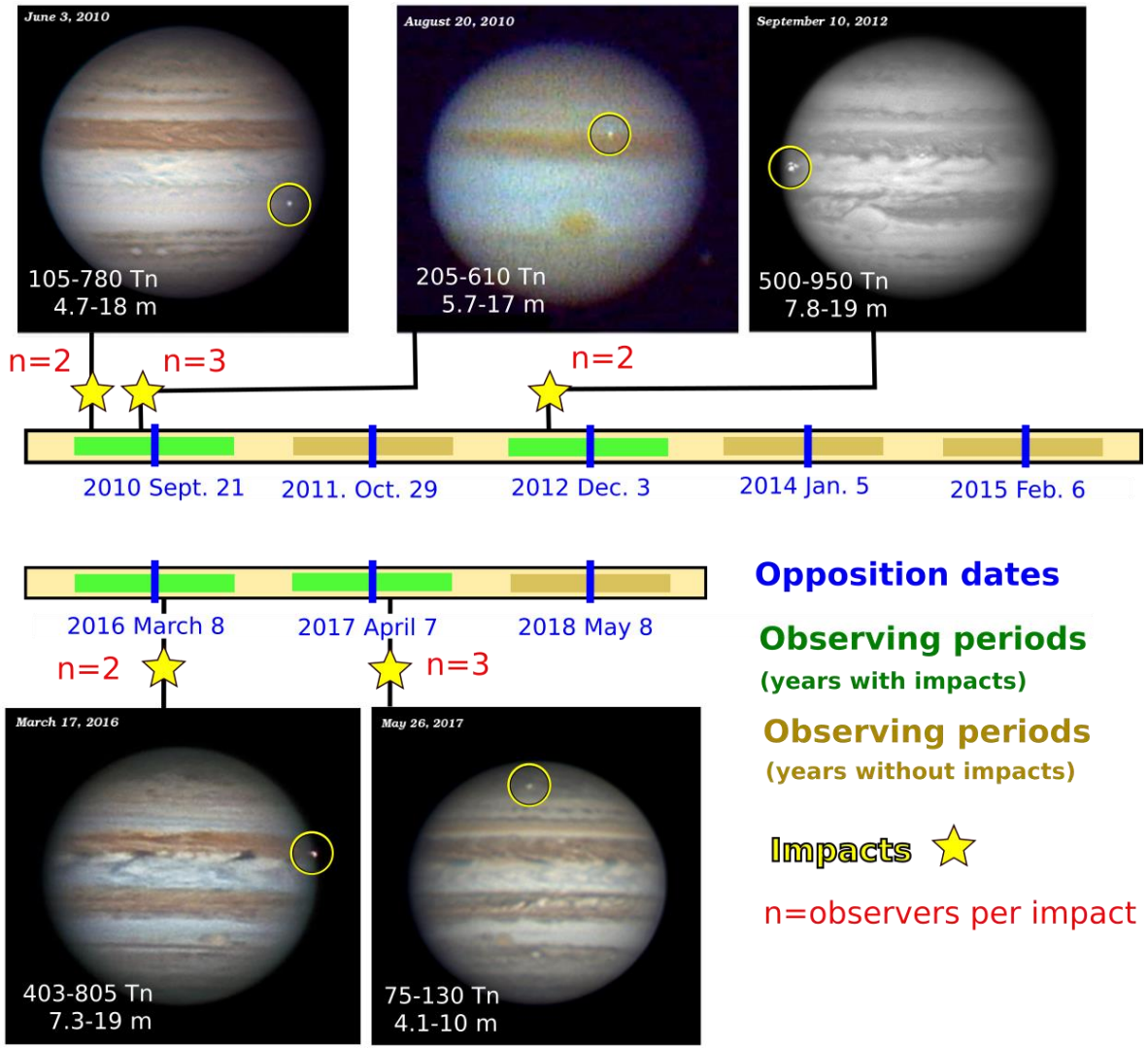



*No debris found in later observations including Gemini 18hr after the impact, Keck, and HST 77 hours after.*

*The analysis of the two amateurs light-curves concluded it was a 8-13 m size object (Hueso et al. ApJL, 2010)*

# An increasing collection of Jupiter flashes




**Opposition dates**

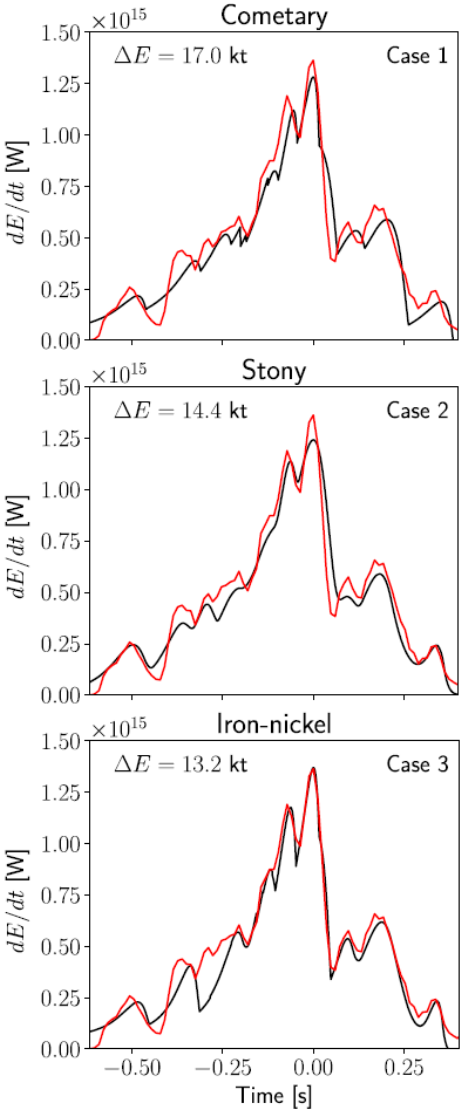
**Observing periods**
**(years with impacts)**

**Observing periods**
**(years without impacts)**

**Impacts** ★

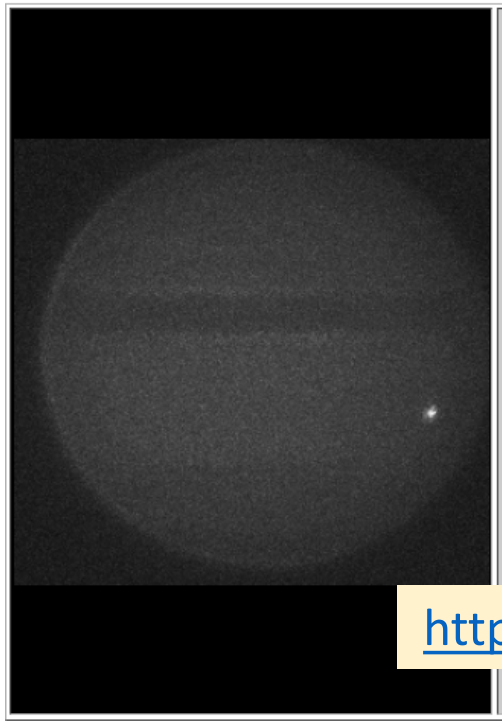
n=observers per impact


*Sankar et al. MNRAS, 2020*
*Detailed simulations to "fit" the observed light curve favoring a non-cometary composition for this event.*




*Hueso et al. A&A, 2013 [Analysis of 3 impacts and impact rate in Jupiter]*
*Hueso et al. A&A, 2018 [Analysis of 5 impacts and improved impact rate]*

# Detecting impacts with software: DeTeCt



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

GEMINI COOPÉRATION ASTRONOMES PRO-AM **2021 price**

**Software download / téléchargement du logiciel** (self updating)
**DeTeCt quick user guide**, Presentation of the project (EPSC2013, BAA workshop)
**NEW!** Presentation du projet, (vidéo) (Journées SF2A, prix Gemini 2021)

email address for distribution list to stay tuned & | Subscribe



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

## Jupiter

estimation of 20,7 impacts per year*
(total includes 38,009 days - 14,7% - of simultaneous observations)
*absolute impact rate on all Jupiter globe - different from the impact rate observable from Earth

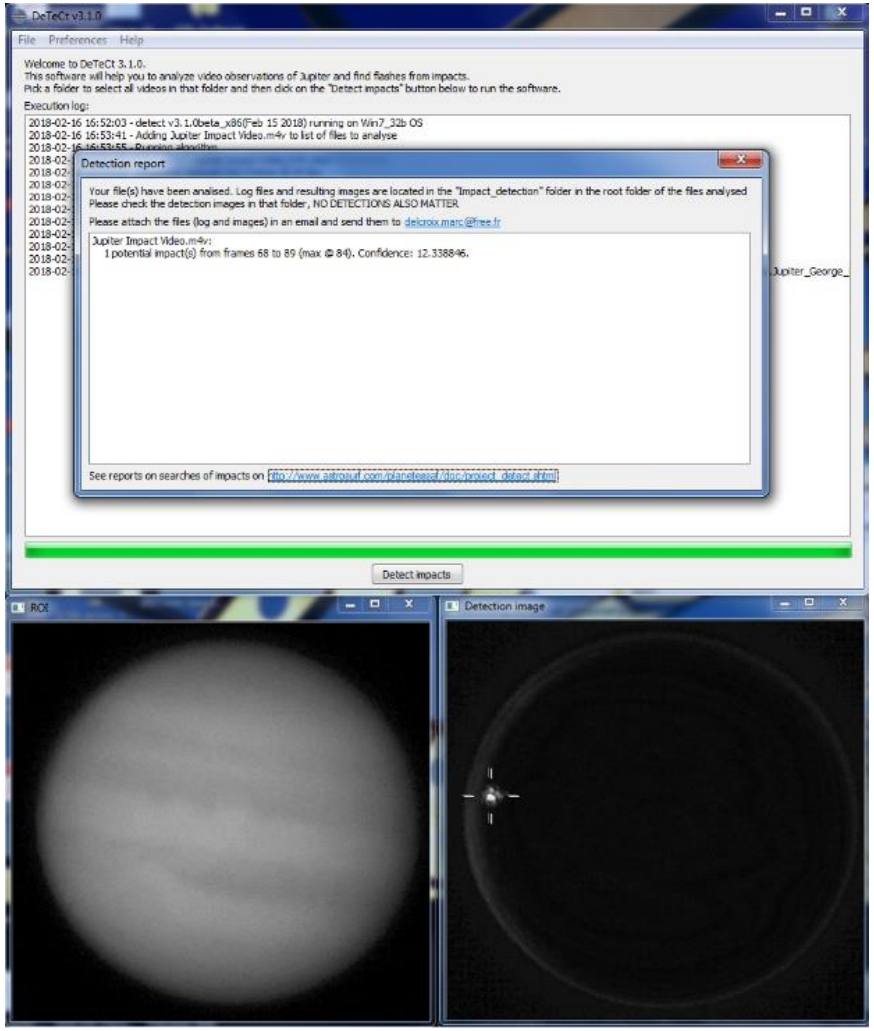
| Observer | Duration | Number of videos | Date range |
|---|---|---|---|
| **Total : 171 observers** | **259.050 days** | **241559 videos** | **2000/08/21 - 2022/09/12** |
| Zac Pujic (Australia) | 26.421 days | 10500 | 2005/02/22 - 2022/07/27 |
| Michel Jacquesson (#7) (France) * | 26.296 days | 11823 | 2014/03/12 - 2022/06/19 |
| Benito Loyola (USA) | 20.921 days | 22457 | 2018/02/17 - 2022/09/07 |
| Paul Rolet (France) | 19.668 days | 17220 | 2012/09/07 - 2022/09/05 |
| Clyde Foster (South Africa) | 12.637 days | 15306 | 2015/01/30 - 2022/05/03 |
| Manos Kardasis (Greece) | 12.191 days | 10815 | 2004/02/29 - 2022/02/19 |
| Jose Luis Pereira (#7) (Brazil) * | 9.977 days | 13858 | 2008/06/29 - 2022/09/10 |
| Sauveur Pedranghelu (#5) (France) * | 8.070 days | 9644 | 2017/05/26 - 2021/09/30 |

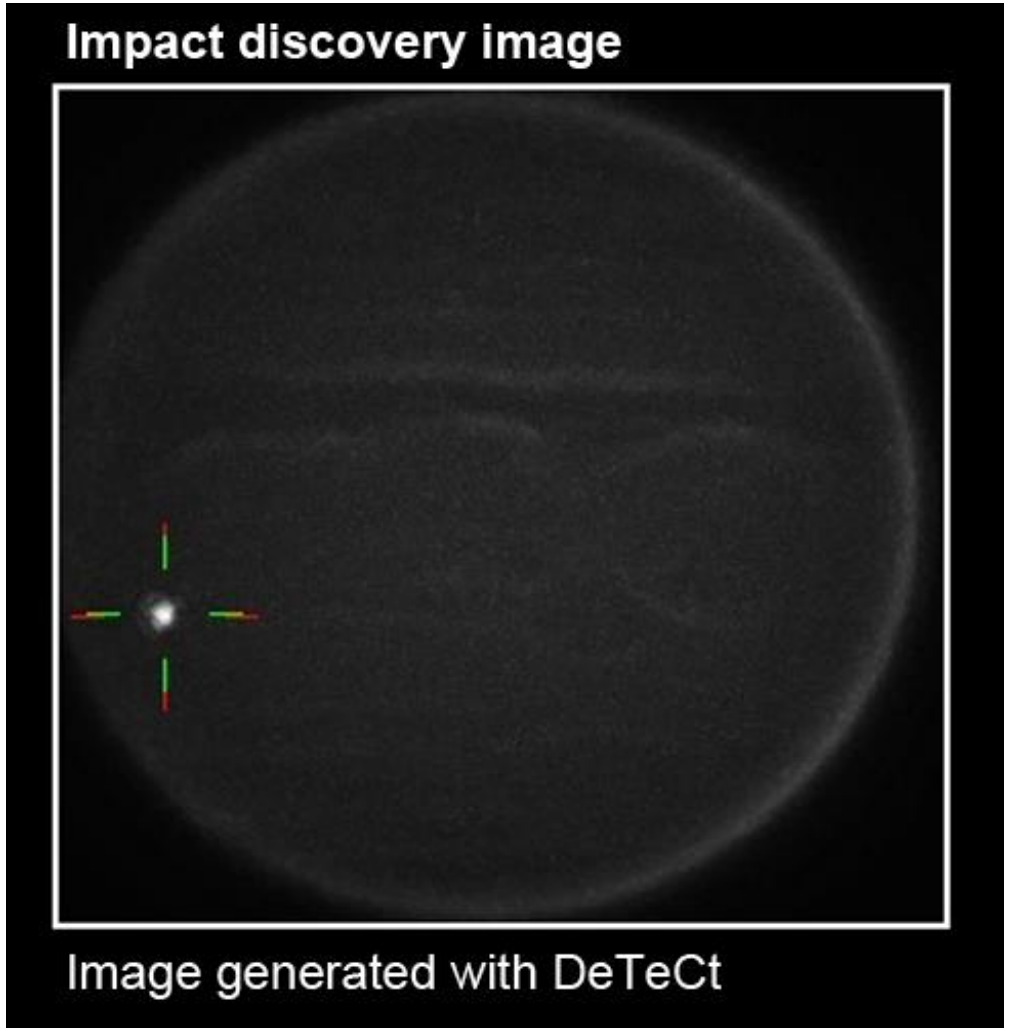
## Saturn

estimation of *less than* 16,2 impacts per year*
(total includes 1,602 days - 3,3% - of simultaneous observations)
*absolute impact rate on all Saturn globe - different from the impact rate observable from Earth

| Observer | Duration | Number of videos | Date range |
|---|---|---|---|
| **Total : 88 observers** | **48.546 days** | **29457 videos** | **2003/11/07 - 2022/09/11** |
| Zac Pujic (Australia) | 7.531 days | 2961 | 2005/02/04 - 2022/07/25 |
| Sauveur Pedranghelu (France) | 5.384 days | 1452 | 2019/06/03 - 2021/09/30 |
| Ethan Chappel (USA) | 4.776 days | 2880 | 2013/07/30 - 2021/12/12 |
| Clyde Foster (South Africa) | 4.517 days | 4305 | 2015/04/06 - 2022/05/25 |
| Marc Delcroix (France) | 3.048 days | 1183 | 2007/01/20 - 2021/08/28 |
| Paul Rolet (France) | 2.834 days | 778 | 2015/05/12 - 2022/08/09 |
| Jose Luis Pereira (Brazil) | 2.091 days | 2060 | 2008/04/27 - 2022/09/09 |
| Andy Casely (Australia) | 1.408 day | 1605 | 2016/08/21 - 2022/08/20 |

# Detecting impacts with software: DeTeCt




*Software is based on differential photometry over coregistered images in the video.*

*Difficulties come from the variety of cameras and settings but the latest versios of DeTeCt accommodates the vast majority of cameras used by amateurs.*

***Importance of statistics of negative detections!***
***(a lot of effort is put forward to understand the efficiency of the global survey)***

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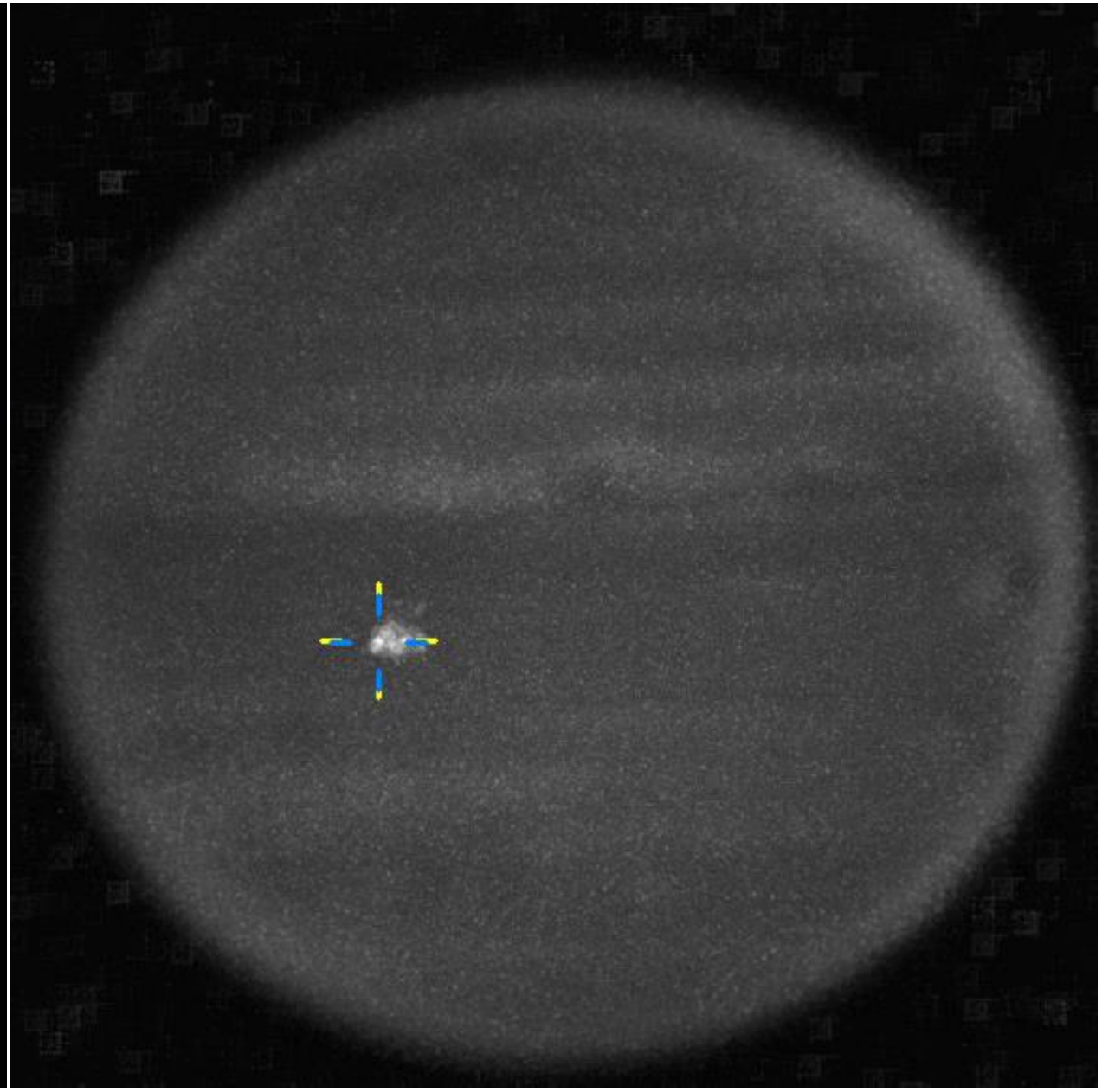
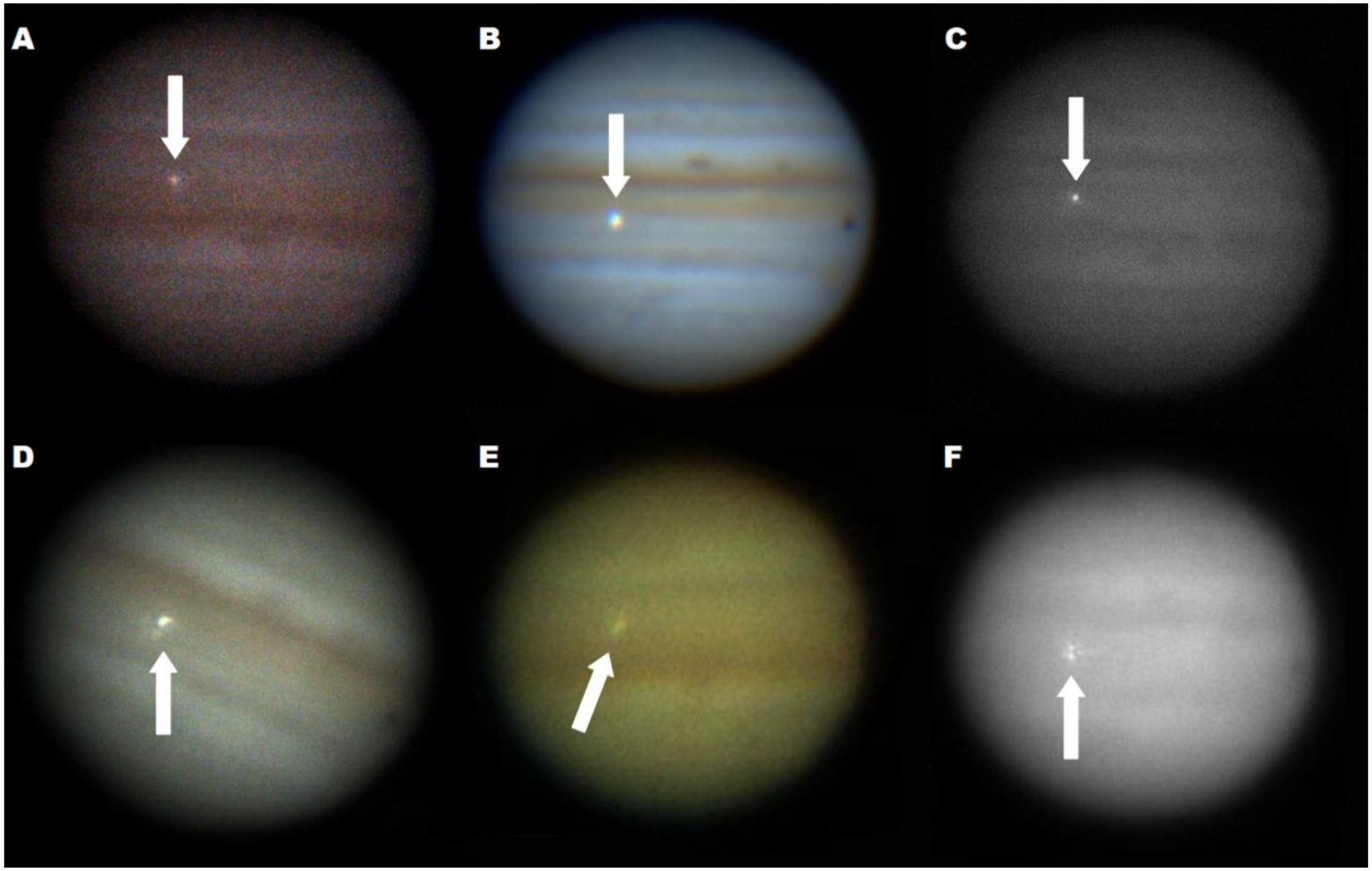
# A new Jupiter impact: Sept. 13th 2021at 22:39:30 UT

Jose Luis Pereira (Brazil)
Alert triggered after analysis with DeTeCt



# The most widely observed small Jovian impact so far!




A: Jose Luis Pereira (Brazil)

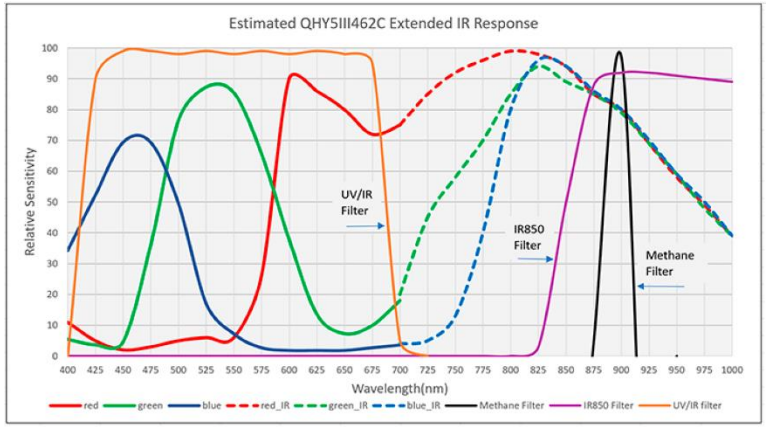
B: Didier Walliang, Thibault Humbert, Stephane Barré, Alexis Desmougin
(France)

C: Harald Paleske (Germany)

D: Jean-Paul Arnould (France)

E: Michel Jacquesson (France)

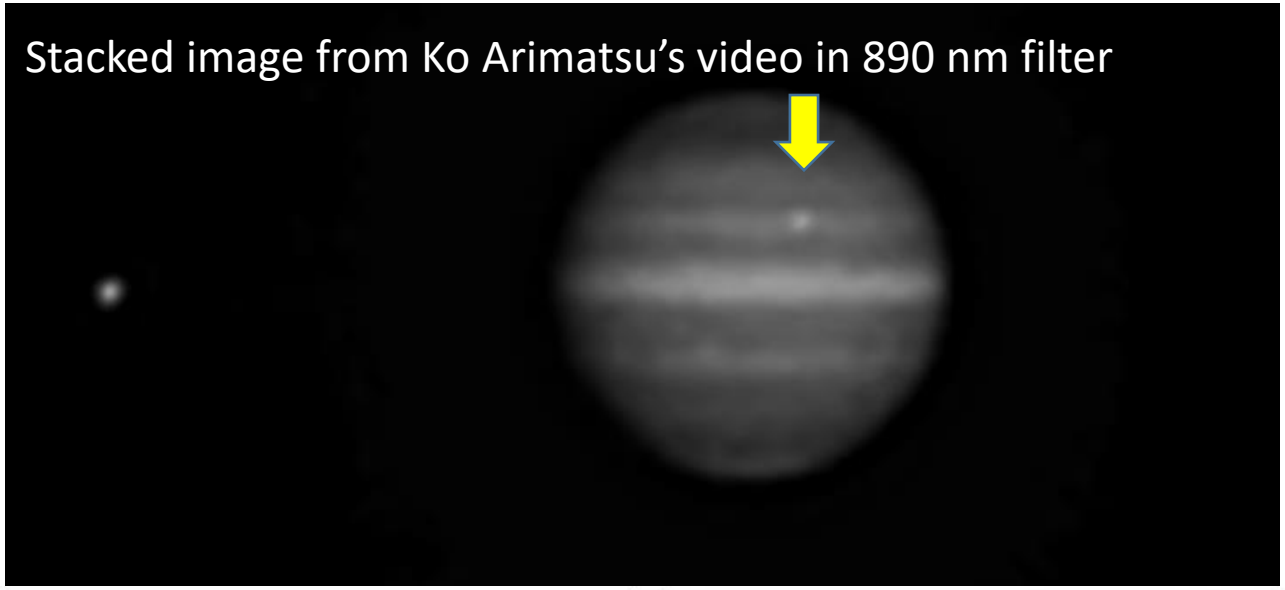
F:Sandu Val Cosmin (Romania)

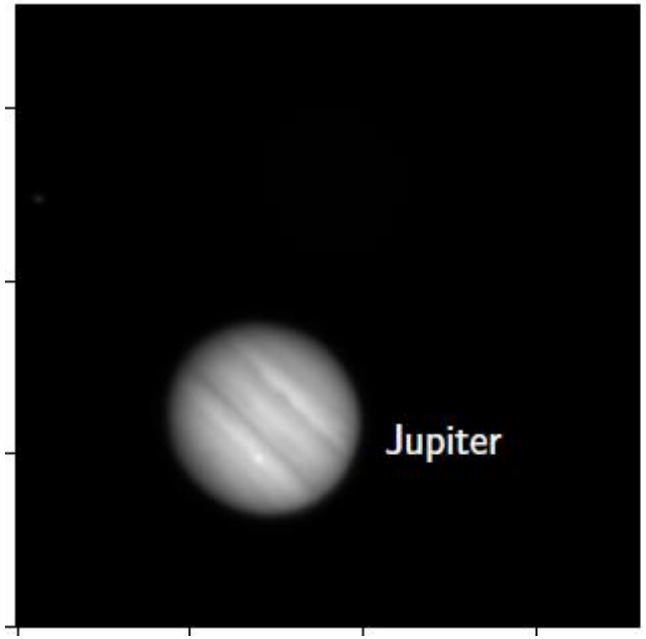


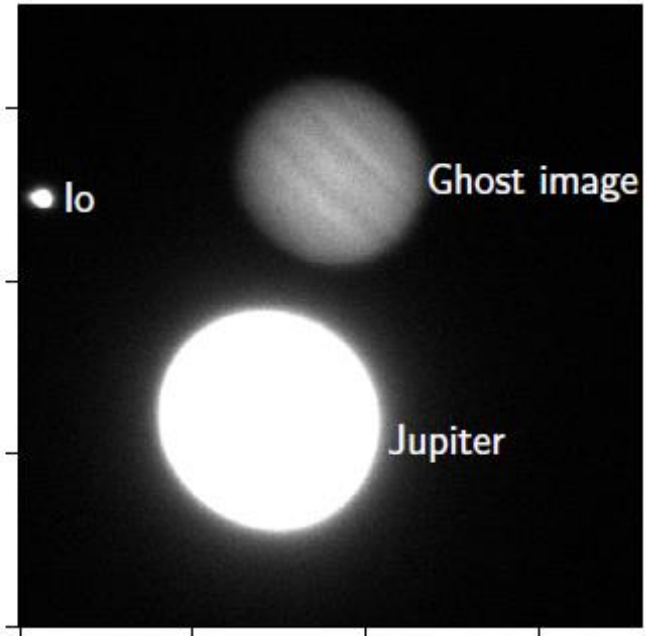

**Variety of observations to calibrate and retrieve light-curves in a consistent manner**

Additional observers that "saw" and reported the flash but did not record it: Jean-Christophe Griveau (limit of detectability). Maciej Libert (on its computer screen; Germany), Simone Galelli (visually; Italy)

# October 15th 2021 at 13:24 UT: First ground-based flash from a professional telescope in multiple wavelengths



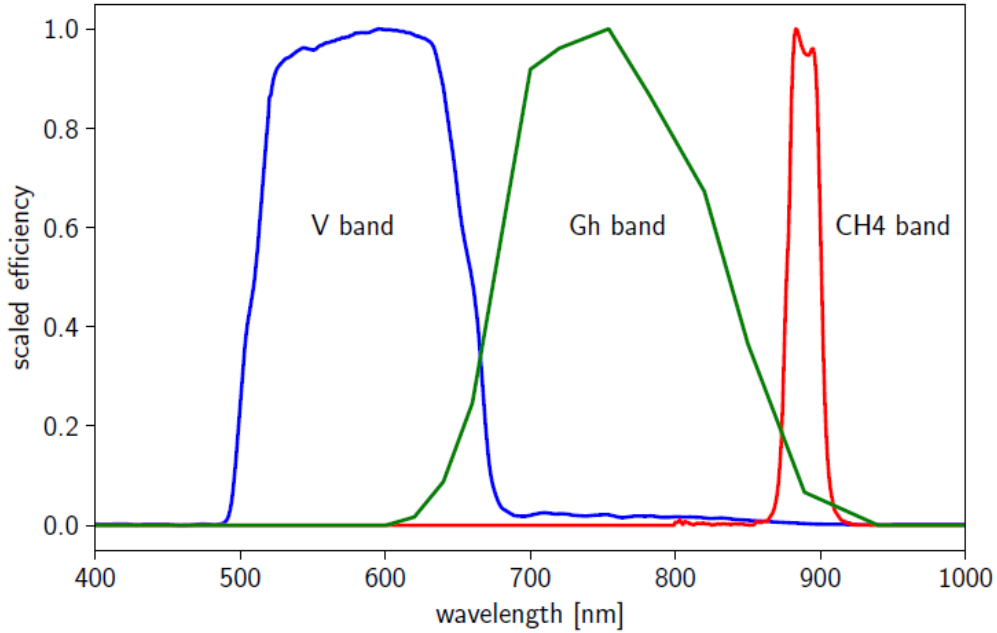




Detection by Ko Arimatsu et al. (Kyoto University, Japan)

PONCOTS System: Telescope + Dichroic + 2 cameras

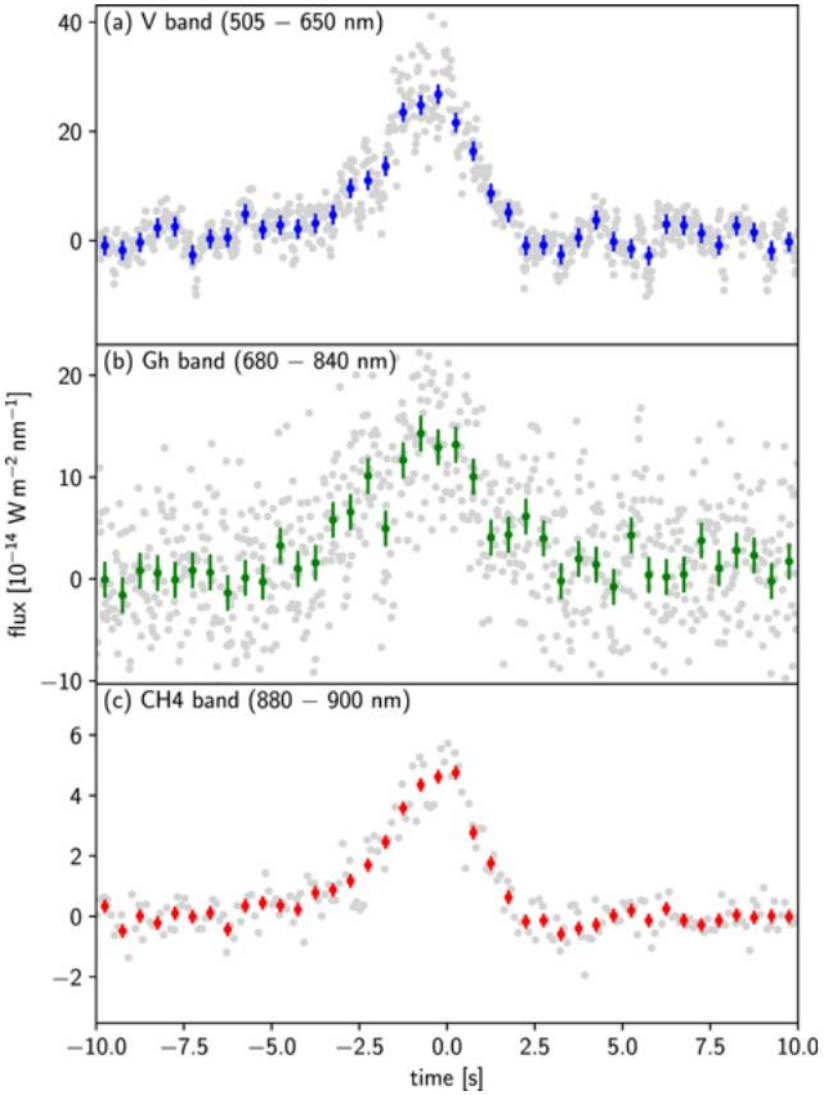
Two videos with three wavelengths thanks to a ghost image. Detailed calibration of the instrument by the PONCOTS team




*Arimatsu et al., APJL (2022)*

# October 15th 2021 at 13:24 UT: First ground-based flash from a professional telescope in multiple wavelengths

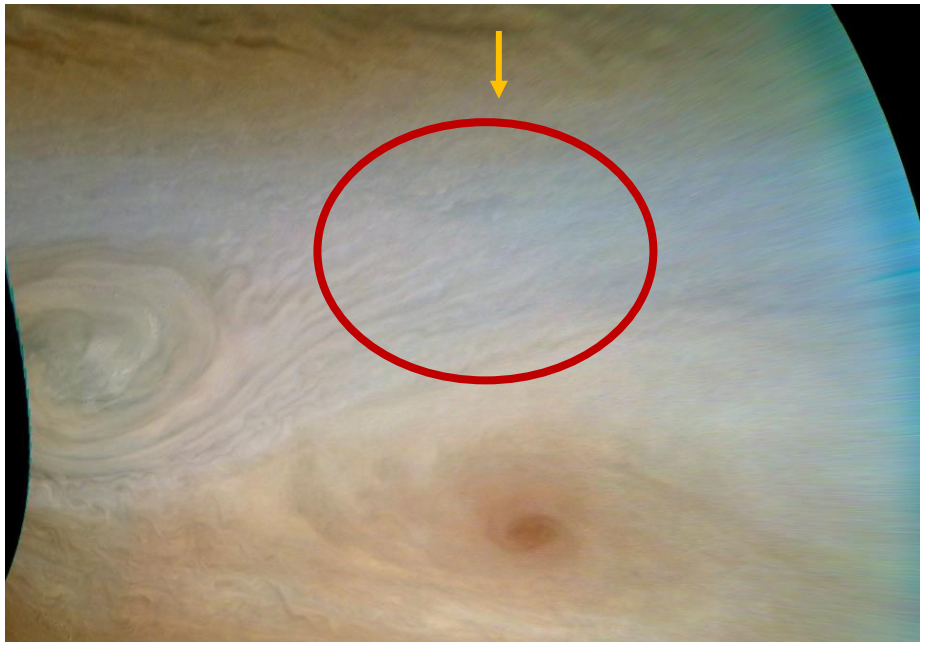
*Arimatsu et al. Detection of an Extremely Large Impact Flash on Jupiter by High-cadence Multiwavelength Observations, APJL (28 June 2022)*




Light-curves in three wavelengths + calibrations of the system with star: **$T_{ef}$=8300 K**

Optical energy – Mass – **Size: 15.2 m (if ρ=2 gcm$^{-3}$) – 35.7 m (if ρ=0.25 gcm$^{-3}$)**

**Impactor 4 times larger than the largest flash impact observed before**

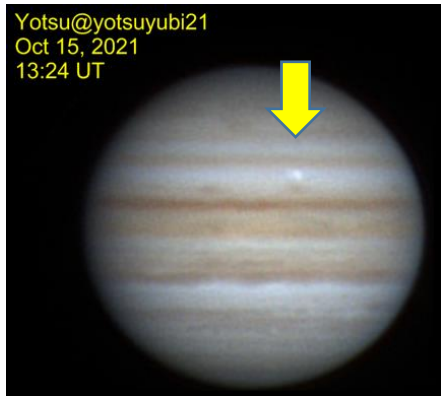


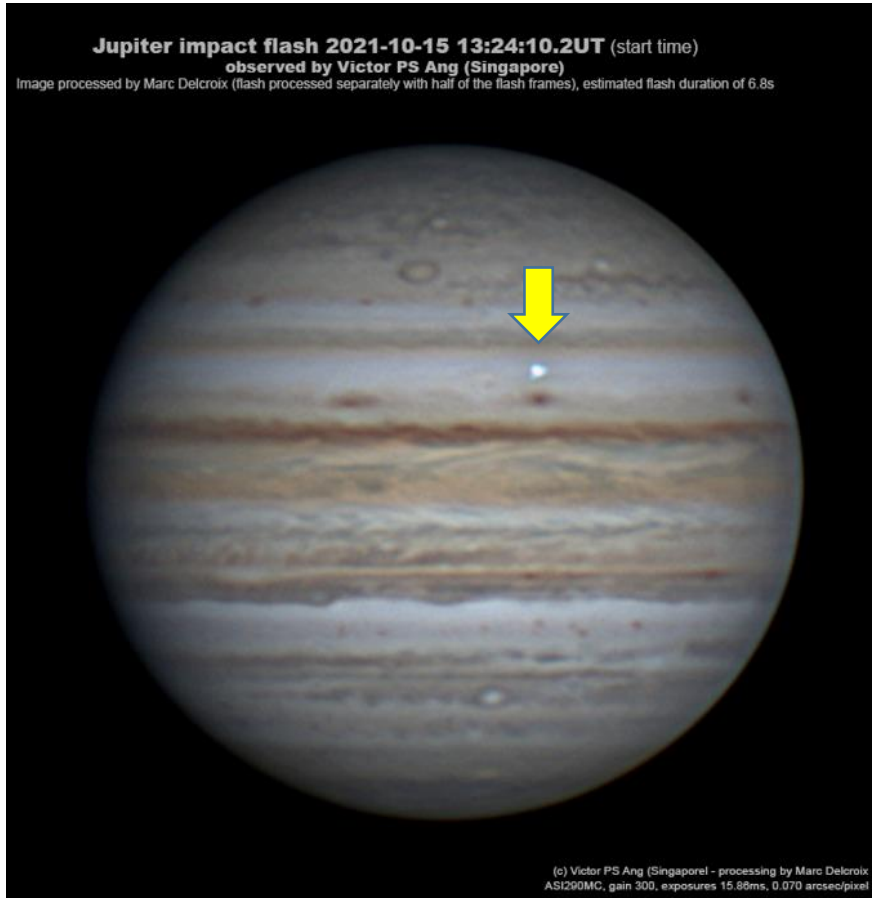
No debris on a Junocam image of the area obtained 28 hr later
(neither in ground-based IRTF images at impact time+20 hours or in amateur images minutes after the impact).

Short survey of the initial observations (one bright flash observed in only 26 hr of accumulated time)

# October 15th 2021 at 13:24 UT: Amateur observations

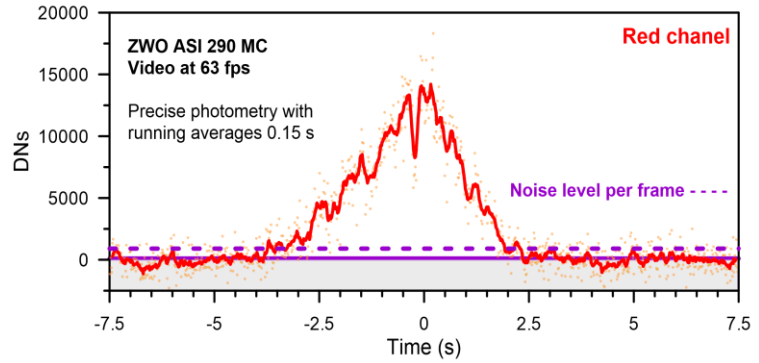
Excellent observation from Victor PS Ang (Singapore) with additional observations from amateurs in Japan

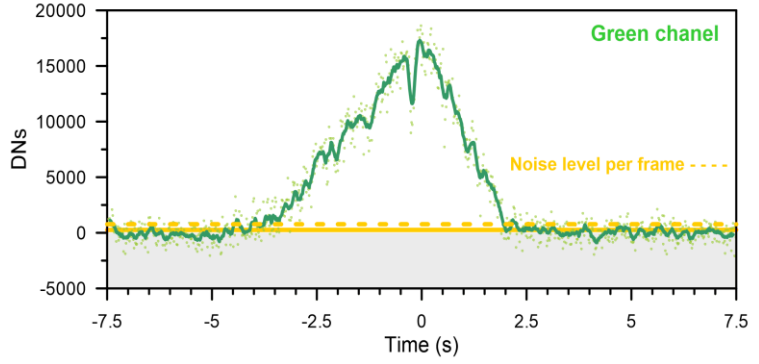


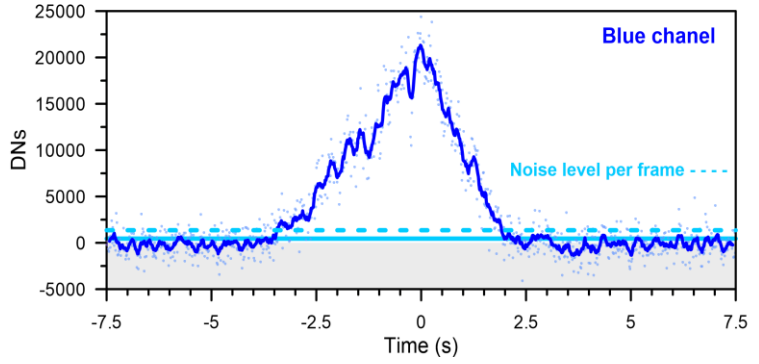




After this detection of the October 15th impact Victor PS Ang run DeTect on past videos and found an additional video on data recorded in Aug. 11th 2020

## *Light-curves of the October 15th 2021 impact from amateur data*



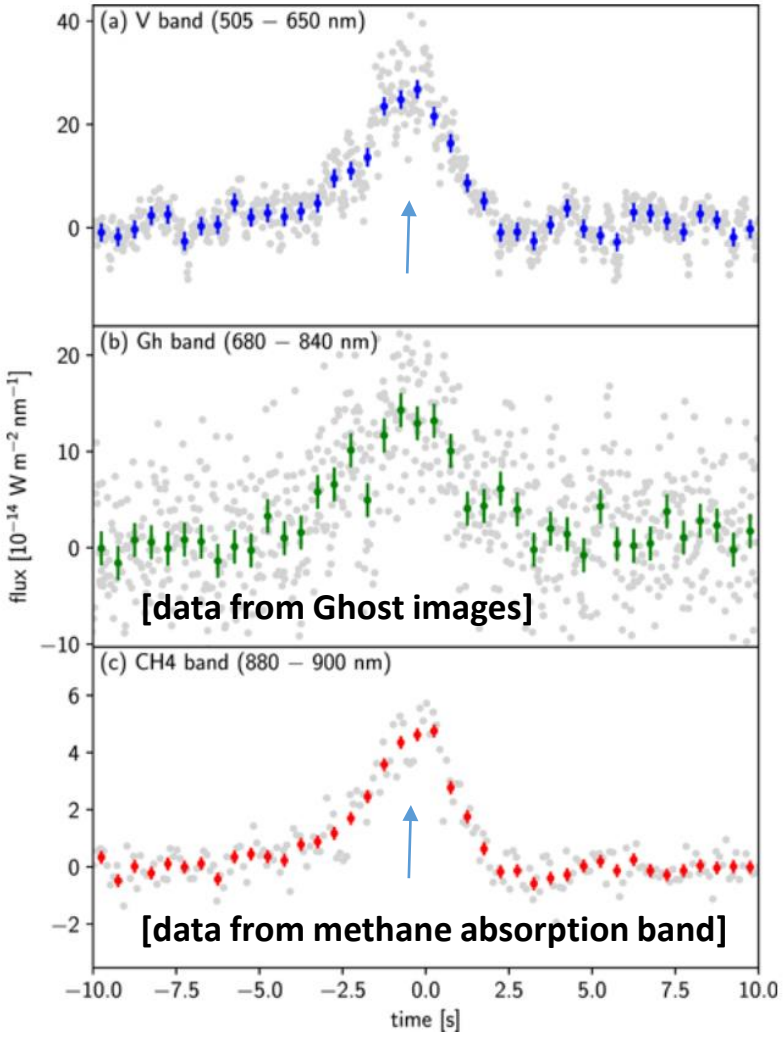



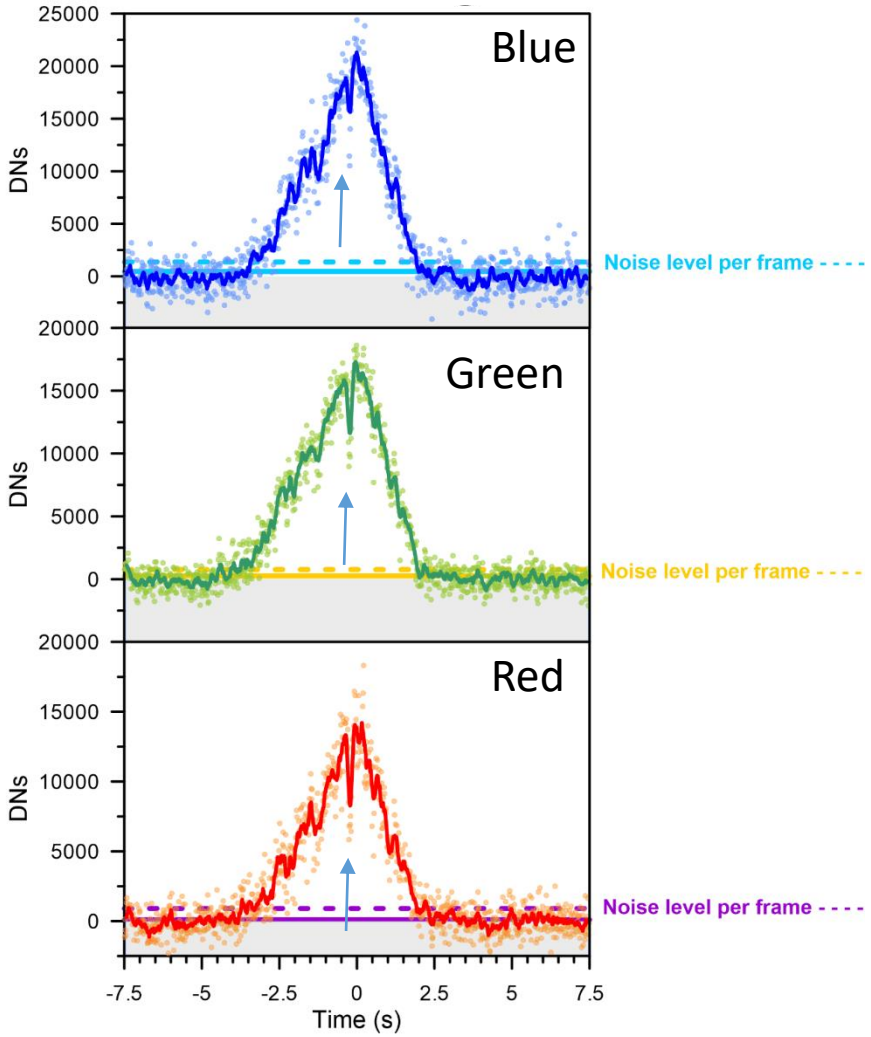
# October 15th 2021 at 13:24 UT: Comparison of both works

## *Light-curves of the October 15th 2021 impact*

Arimatsu et al. (PONCOTS C11'')

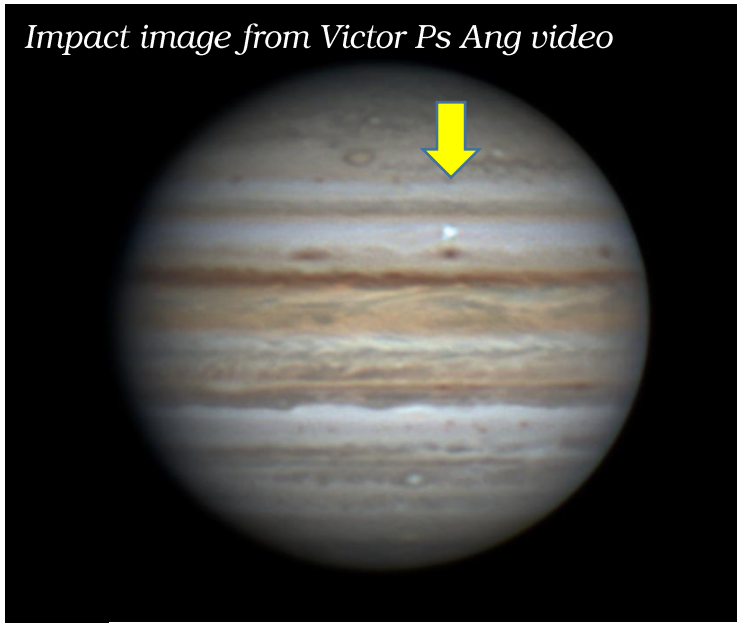


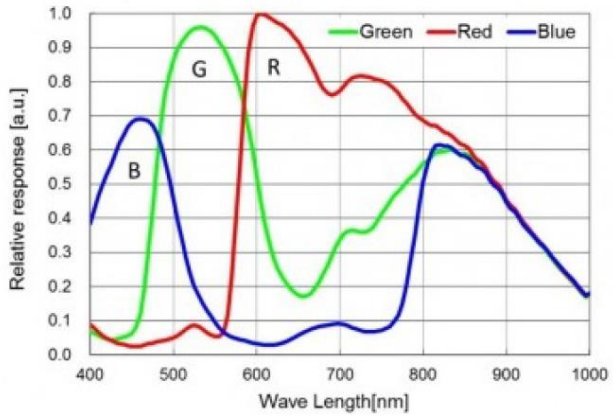

Victor PS Ang (C14'')




Arrows show the central double flash

- **Much better photometry from the amateur data!**
  (much better seeing & more photons)

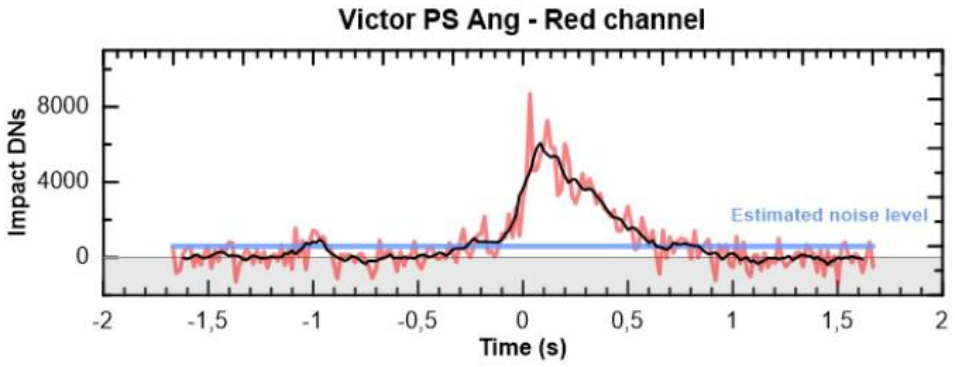


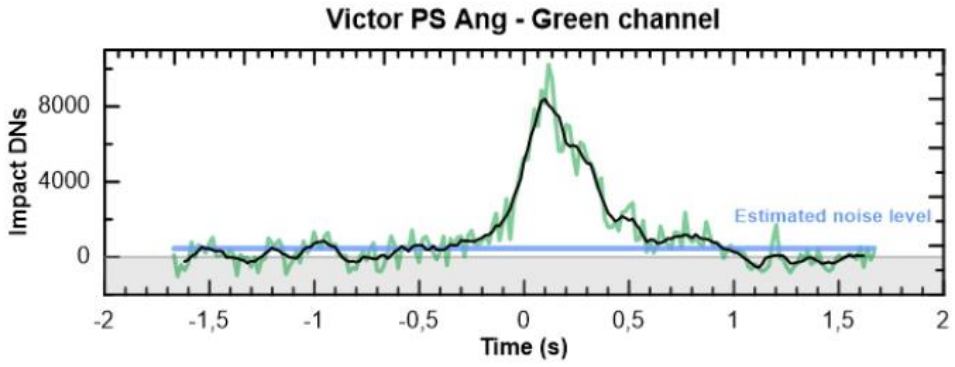



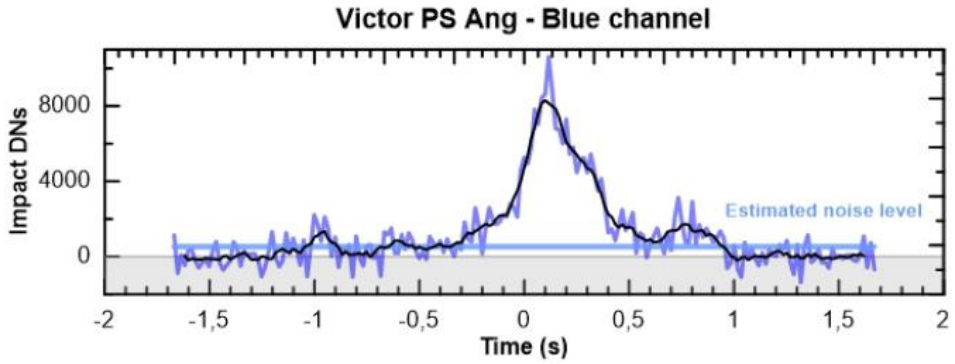

- But amateur data is less suitable to constrain brightness temperature

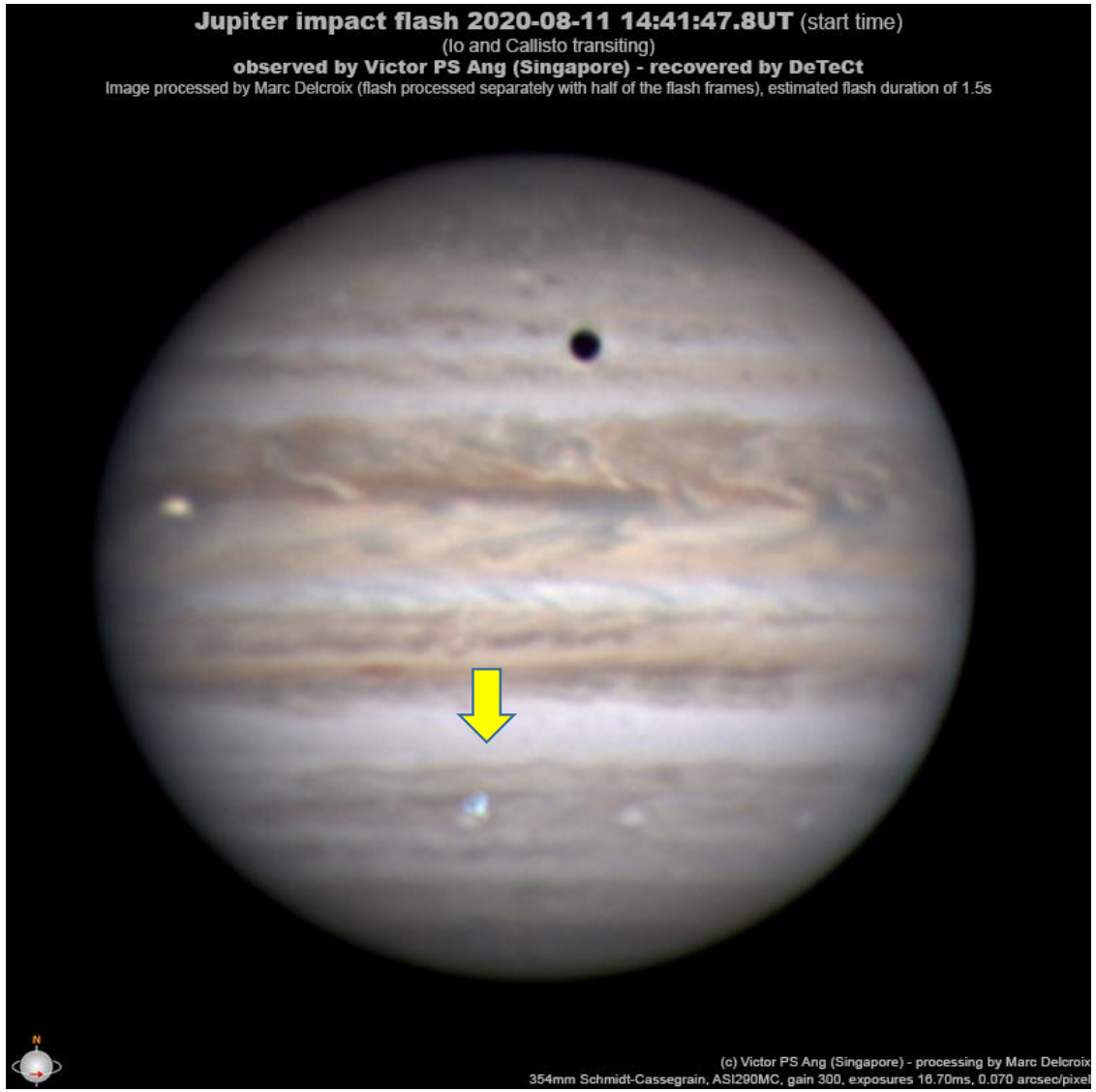
# August 11th 2020 at 13:24 UT: A "new" "old" impact recovered with DeTeCt

***Light-curves*** Victor PS Ang (C14'')



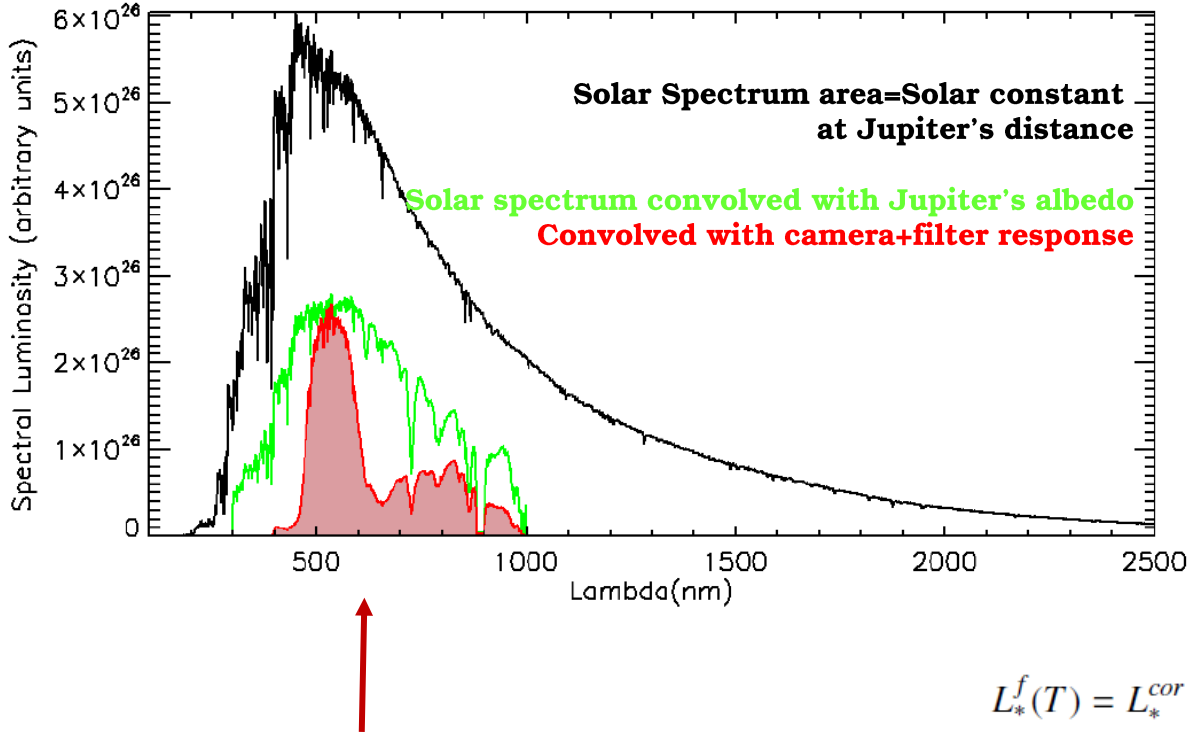



# **Energy calibration:** *Jupiter integrated flux, solar spectrum, Jupiter albedo, system response, flash brightness temperatures*

We follow Hueso et al. (2010, 2013, 2018):
Photometry in each filter is compared with Jupiter brightness and the 1DN equivalent to Watts is obtained from the solar constant at Jupiter' distance, its albedo and system response




Energy detected for Jupiters total DNs

Solar constant at Jupiter's distance

Jupiter's albedo

$$L_* = \left(S_J \cdot \pi R_{eq} R_p\right) \cdot \left(\frac{\int_0^\infty F_\odot(\lambda) \cdot I/F(\lambda) \cdot C(\lambda)\mathrm{d}\lambda}{\int_0^\infty F_\odot(\lambda)\mathrm{d}\lambda}\right) \cdot \left(\frac{I_*}{I_J}\right) \cdot \Delta t$$

Energy corresponding to Jupiter's flux

Solar spectrum

System response

$$L_*^f(T) = L_*^{cor}\left(\frac{\int_0^\infty F_{BB}(T,\lambda)\mathrm{d}\lambda}{\int_0^\infty F_{BB}(T,\lambda) \cdot C(\lambda)\mathrm{d}\lambda}\right),$$

Relative efficiency of the system to capture radiation with a given black-body temperature

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

Efficiency of conversion from kinetic energy into luminous energy (Brown et al., 2002)

# Preliminary Results

| Date (yyy-mm-dd) | Kinetic energy (ktn) | Mass ($10^3$kg=ton) | Diameter (m) $\rho = 2{,}0$ g/cm$^{-3}$ | Diameter (m) $\rho = 0{,}6$ g/cm$^{-3}$ | Diameter (m) $\rho = 0{,}25$ g/cm$^{-3}$ |
|---|---|---|---|---|---|
| 2010-06-03 | 46-350 | 107-780 | 4.7-9.1 | 7.0-14 | 9.3-18 |
| 2010-08-20 | 88-260 | 205-610 | 5.8-8.4 | 8.7-13 | 12-17 |
| 2012-09-10 | 215-405 | 500-950 | 7.8-9.7 | 12-14 | 15-19 |
| 2016-03-17 | 175-350 | 403-805 | 7.3-9.2 | 10.9-13.7 | 14-19 |
| 2017-05-26 | 32-55 | 75-130 | 4.1-5.0 | 6.1-7.4 | 8.3-10 |
| 2020-08-11 | 57-99 | 132-230 | 4.9-6.2 | 7.3-9.3 | 9.8-12.4 |
| 2021-09-13 | 440-512 | 1024-1190 | 8.6-10.5 | 14.8-15.6 | 19.9-20.9 |
| 2021-10-15 | 625-1088 | 1455-2531 | 10.9-13.8 | 16.2-20.7 | 21.7-27.7 |

Hueso et al A&A 2018

This work

From single video of Victor PS Ang ***Brightness T: 7000-10000 K***

From the best videos removing those with saturated frames ***Brightness T: 6000-8500 K***

From single video of Victor PS Ang ***Brightness T: 7000-10000 K***

**Arimatsu: 1600 -2600 kTn (Brightness Temp: 8300 K)**

**Discrepancy with our analysis of this impact by a factor 2.4**

# Conclusions

- ***The two impacts in September 2021 and October 2021 are clearly the largest flashes observed in Jupiter [1.5-2.5 larger than any previous flash]***
  *Together they do not significantly change the impact rate expected in Jupiter calculated in Hueso et al. (2018) from 5 impacts from 2010-2018 (10-65 impacts per year of objects from 5-20 m) but only 4-25 observable per year in a perfect survey (one side of the planet is not visible, polar regions not visible and 9months of observations)*

- ***There is a discrepancy in the mass and energy of the larges impact occurred in October 2021.***
  *Aritmatsu et al. give a mass-energy 2.4 times larger than our analysis. While it is difficult to reconciliate such a large object with the lack of debris from Junocam images and the short survey of the PONCOTS search, we expect to analyze the original methane-band video to better constrain this interesting event.*

- ***Future impacts:***
  *We continue adding more amateur astronomer collaborators and researchers to improve the* ***efficiency to detect these events****. Impact rates in Jupiter are* ***compatible with new larger impacts leaving debris in the upper atmosphere every decade*** *and* ***very small impact flashes*** *should be detectable in missions like Juno [**Giles et al., GRL, 2021:** **Detection of a Bolide in Jupiter's Atmosphere With Juno UVS**]*
  *and JUICE and Europa Clipper in the future.*