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DE CATALUNYA
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ROBOTIC EXPLORATION OF THE SOLAR SYSTEM

A3-Image Processing assignment

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May 30, 2021

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1 Problem Definition

"Rediscover" Linda Morabito's discovery of the volcanic plume from the raw data using modern techniques and developing code in *Matlab*.

2 Part A

1. Find and download the original Voyager1 image, in RAW format. You can do this browsing the original NASA data or using the RESSlib library.

In order to find the true raw images, the data folder link has to be used. Once inside, the Io photograph taken by Voyager 1 is coded as $C16481XX > C1648109\_RAW.IMG$. Here can also be found the $GEOMED$ format.

The image library with all available format is Library, while the raw format can be downloaded from RAW.

2. Decode it using the software provided in RESSlib to open and save it in a suitable format to not loose data.

The decoding of the image is possible with the *vicarread5* function which transforms the .img file to a Matlab-readable extension. The code sees if a file is already on the local disk and otherwise downloads it.

3. Prepare a Matlab code that -without loosing detail in the highlights-reveals the plume.

Figure 1: Original photo of Io's plumes.

The image has been processed in six steps. The first enhancement comes increasing the contrast of the image evaluating the maximums and minimums $imgd = (imgd - m)/(M - m)$. The second parameter to change is the local brightening of the image through *imlocalbrighten*. Then *adapthisteq* is applied to adjust the local contrast again. In order to expose the dark areas with out loosing the whites: $img1 = img^x$. After this the overall contrast of the image is adjusted with *imadjust*. Then, to improve details the shapening function is used: *imsharpen*. Finally, the image is saved in uint16. Another aspect to remark is that all the functions are set to cause small changes to avoid burning the image or over-expose details.

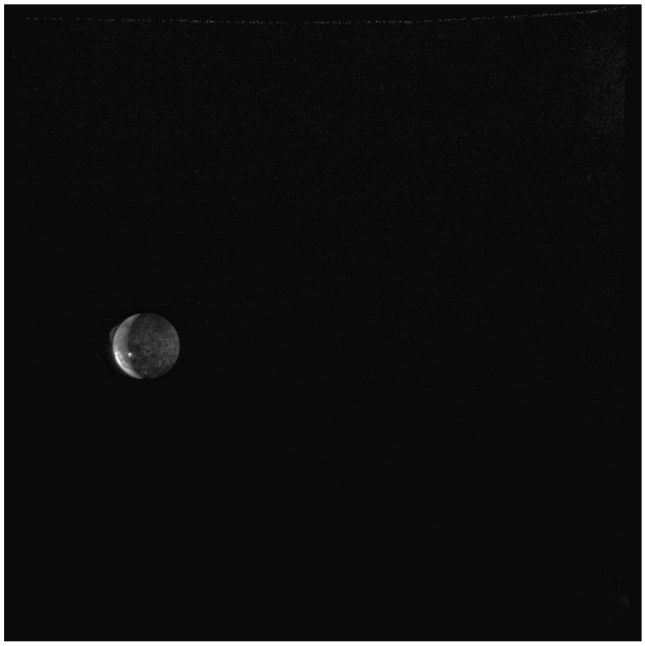

Figure 2: Plume revealed. Source: own

4. Estimate the elevation of the plume.

In order to do estimate the elevation of Io volcanic plume, the figure 3 and points were taking into account. First is known that the diameter of Io is 3643.2 km (2 × radius of 1821.6km) and that the distance in green is equal to $480 - 391 = 89$ pixels. Therefore, the distance in red is equal to $\sqrt{(125-119)^2 + (419-416)^2} = 6.7082$ pixels. In this way the estimated value for the elevation of the plume is given by $\frac{6.7082 \times 3643.2}{89} = 274.5992$ km.
Comparing the estimated value with the real value of 260 km, an error of

$$\frac{|274.5992 - 260|}{|260|} \times 100 = 5.6\%$$

is obtained, which can indicate that the estimation was successful.

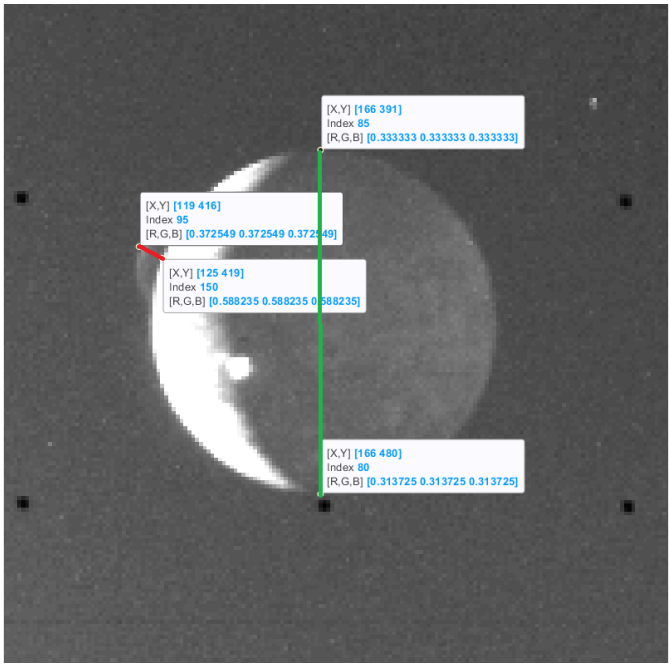

Figure 3: Elevation of the plume estimation

5. Using SPICE, draw the position of Io, Voyager 1 and Jupiter. Identify the direction of the sun and explain the origin of the light that reaches the dark side of Io.

One of the volcanic eruptions seen by Voyager 1 in Io showed that the volcanic cloud is catching the rays of the rising sun. Therefore, the dark hemisphere of Io is made visible by light reflected from Jupiter. This can explain the origin of the light that reaches the dark side of Io.

For generating the figure 4 it was considered the time interval that starts on March 1 1979 and lasts 20 days. Also, the Voyager 1 position is the one from day March 8 1979 when the picture of Io was taken.

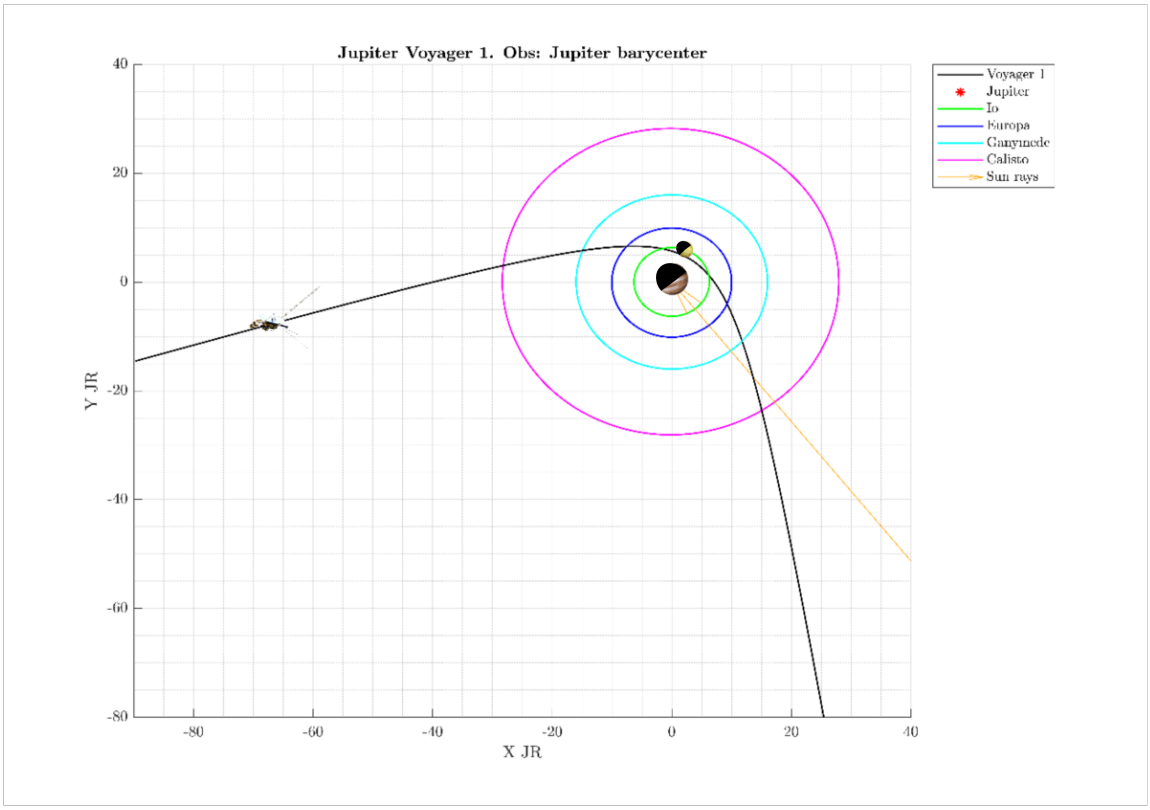

Figure 4: Voyager inside the Jupiter system with SPICE

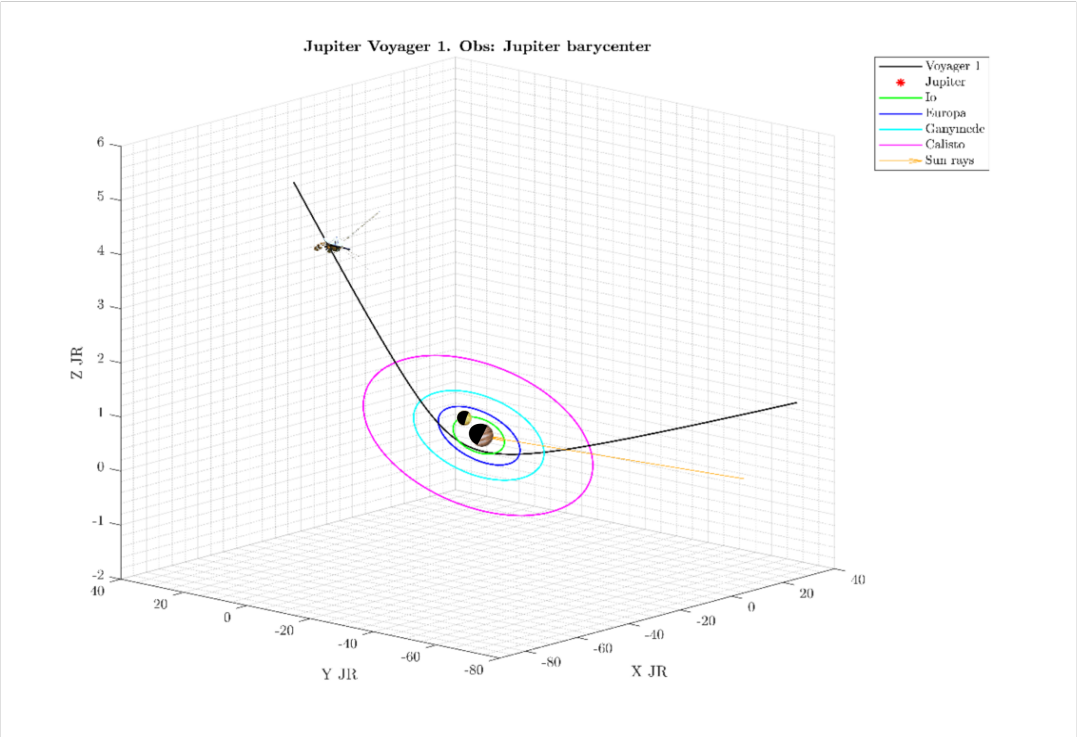

Figure 5: Voyager inside the Jupiter system with SPICE

3 Part B

6. Find stars in the image. Further image-processing to detect stars is applied in the next image. Increasing the contrast and the brightness of the image at the expense of burning Io and reducing its quality.

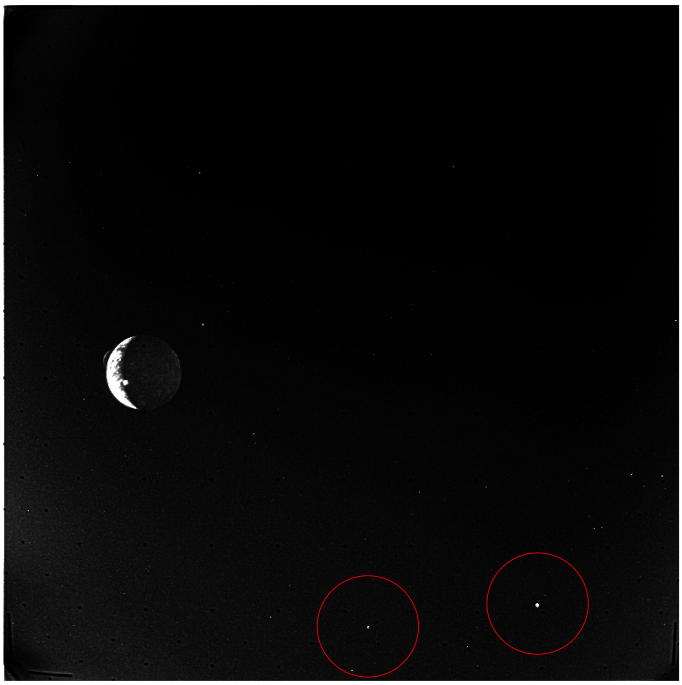

Figure 6: Potential stars

In figure 6 appear two potential stars. Figure 7 shows the actual position of three stars. The two images do not coincide, it might be because the image analysed is flipped. On the other hand, the lower star seen in figure 7 could be the same as the left-bottom in 6 implying that the right-bottom is an error.

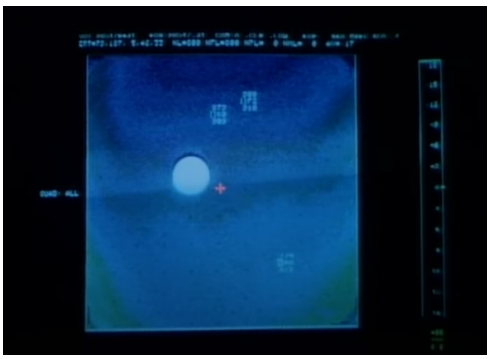

Figure 7: Star detection. Source: Carl Sagan' Cosmos [1]

Figure 8: Imaged reversed.

7. Look for more information about this discovery. For instance, it was reported in Cosmos by Carl Sagan.

This discovery started when Linda Morabito, after seeing the Voyager 1 images taken three days after its closest approach to Jupiter looking back toward Io, received the task of finding the faint stars seen in the background of those images of Io. However, that was a difficult task that required images with extra-long exposure times to make the stars brighter and also to do some image-processing technique called stretching. Afterwards, they were able not only to see the stars but also two other unexpected things: "a bright circular blob along the day/night boundary on Io" and "a fainter umbrella-shaped crescent sticking up a few hundred miles above the edge of Io's climb". At first, they thought that could be a moon passing behind Io, however Linda Mobarito and other Voyager navigation engineers of the team concluded that that was not possible. Thus, the only hypothesis left and that seemed to fit the Io data was that the crescent and bright blob were eruption plumes from active volcanoes on Io. After this amazing discover, other volcanic plumes were discovered and finally all the Io data obtained was making sense. They were able to conclude that Io was a volcanically active world and that its geology changes the same way the weather changes in our planet, since Io is constantly turning itself inside out in order to get rid of all the internal heat that is cause by the combined effects of the satellite resonances and the strong tidal pull of Jupiter.

Figure 9: Linda Morabito pictured after her discovery of Io volcanism, in front of a model of the Voyager spacecraft at NASA's Jet Propulsion Laboratory. Morabito is holding a print of the image that enabled her to make the discovery. Credit: NASA. [2]

The great Carl Sagan also made a reference to this amazing discover in Cosmos. He describes that the volcanic plumes of Io reach so high that they are close to injecting their atoms directly into the space around Jupiter. He also added that probably the volcanoes in Io are the source of the great doughnut-shaped ring of atoms that surrounds Jupiter in the position of Io's orbit and that there is also a probability of that material outgassed from Io contributes to the ring system of Jupiter, after many collisions and condensations. [3]

8. Find other images of volcanic activity in Io, by other spacecraft.

Not only Voyager 1 found images of volcanic activity in Io but also other spacecrafts as Voyager 2, Galileo and Juno.

Four months after the passage of Voyager 1, Voyager 2 flew through Jupiter system and photographed Io. From these photographs, it was possible to see that the surface of Io had changed significantly including the formation of new plumes (10).

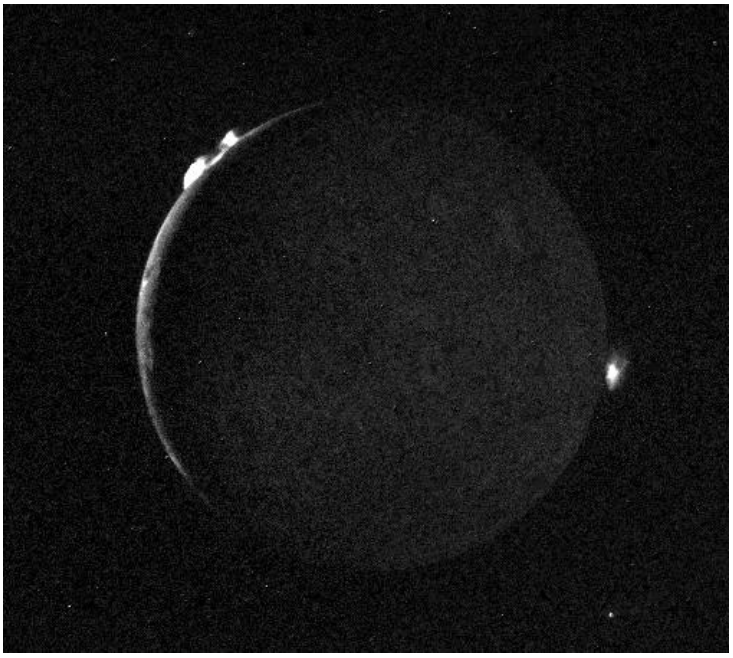

Figure 10: Picture of Io - Crescent with Plumes taken by Voyager 2 took on July 10, 1979. [4]

Galileo spacecraft have also studied Io and they detected even more changes in the moon's "tortured volcanic surface", concluding that Io is not just volcanically active but in fact it is hyperactive, showing the most intense and voluminous volcanic eruptions in the solar system. (11 and 12)

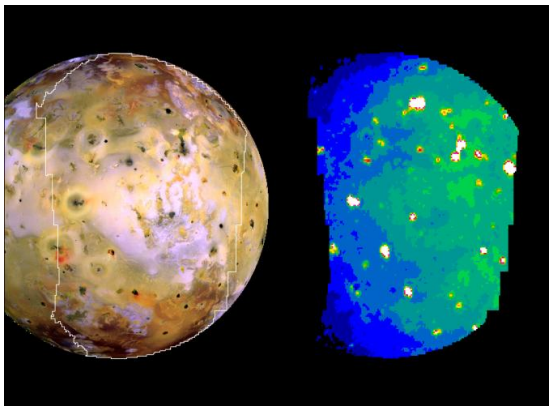

Figure 11: Io in Infrared with Giant Plume's New Hot Spot. [5]

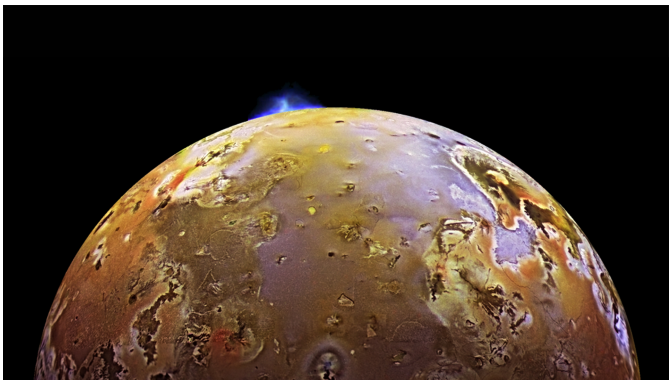

Figure 12: A volcanic eruption on Io seen by the Galileo spacecraft in 1997. [6]

NASA's Juno spacecraft also saw evidence of an eruption in Io, highlighting the hot spots. (13)

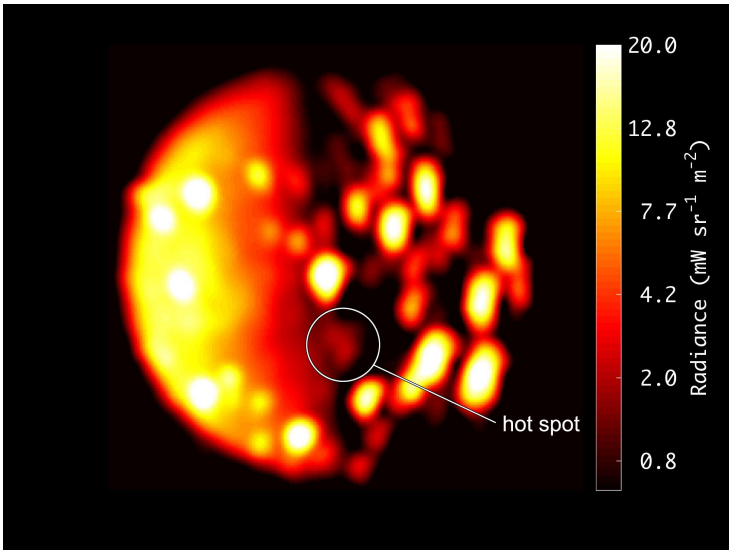

Figure 13: Highlights the location of the new heat source close to the south pole of Io. The image was generated from data collected on Dec. 16, 2017, by the Jovian Infrared Auroral Mapper (JIRAM) instrument aboard NASA's Juno mission. [7]

En route to the icy worlds inhabiting the outer regions of our solar system, NASA's New Horizons spacecraft went past Jupiter, catching once more the evidence of volcanic plumes in Io. (14).

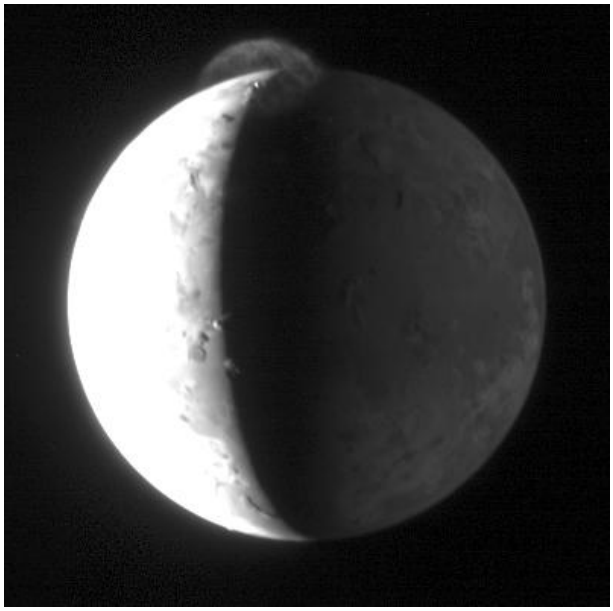

Figure 14: Image snapped by the spacecraft's high-resolution telescopic camera in March 2007 show a 200-mile-high plume spewing from Tvashtar volcano in Io's northern hemisphere.[8]

References

[1] Carl Sagan. *Carl Sagan's Cosmos: Episode 6-Travellers' Tales*. URL: https://www.youtube.com/watch?v=EbljFJERflA&ab_channel=TomKNJ.

[2] Iain Todd. *Volcanoes on Io: an interview with Voyager scientist Linda Morabito*. URL: https://www.skyatnightmagazine.com/space-missions/volcano-jupiter-moon-io-interview-voyager-linda-morabito/.

[3] Carl Sagan. *Cosmos*. Vol. 1. Edicions Universitat Barcelona, 2006.

[4] NASA/JPL. *PIA02254: Io - Crescent with Plumes*. URL: https://photojournal.jpl.nasa.gov/catalog/PIA02254.

[5] NASA/JPL/University of Arizona. *PIA03534: Io in Infrared with Giant Plume's New Hot Spot*. URL: https://photojournal.jpl.nasa.gov/catalog/PIA03534.

[6] Paul Scott Anderson. *New Juno images of Io's fiery volcanoes*. URL: https://earthsky.org/space/juno-spacecraft-io-volcanoes-from-a-distance.

[7] NASA/JPL-Caltech/SwRI/ASI/INAF/JIRAM. *PIA22601: Location of Io's New Hotspot*. URL: https://photojournal.jpl.nasa.gov/catalog/PIA22601.

[8] NASA/Johns Hopkins University Applied Physics Laboratory/Southwest Research Institute. *PIA09360: A "Plumefall" on Io*. URL: https://photojournal.jpl.nasa.gov/catalog/PIA09360.