Astrometry of the Galilean Moons using Stellar Occultations

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The astrometry of natural satellites can be used to improve their ephemerides.

- ➢ Assist in the preparation of space missions, such as JUICE (ESA) and Europa Clipper (NASA).

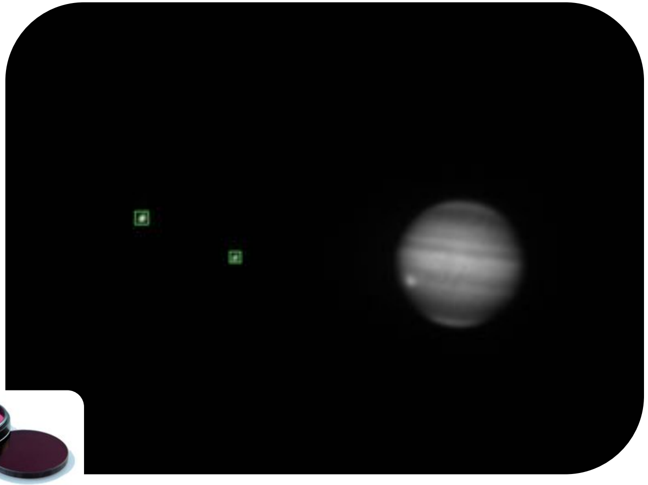
- ➢ Assist in the study of weak forces that affects this system, such as tides. Allowing to constrain the models of these moons interior.

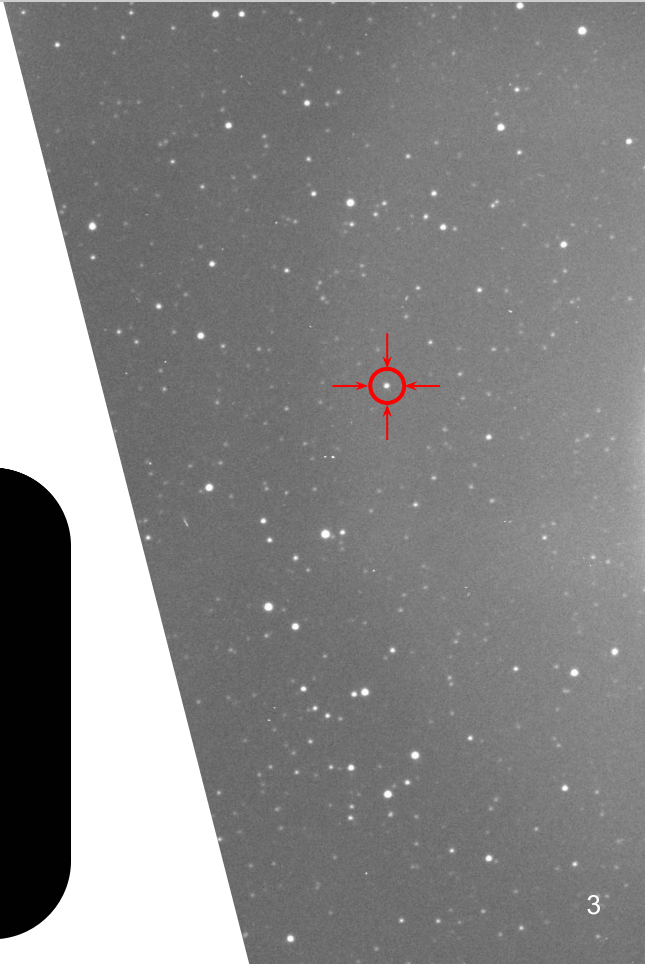
https://www.cosmos.esa.int/web/juice

However, the astrometry of the Galilean moons is not an easy task.

1. Jupiter's brightness in the Field of View (FoV) would quickly saturate the CCD image.

2. An optical filter can prevent saturation, however, a small number of calibration stars usually appear in the images.

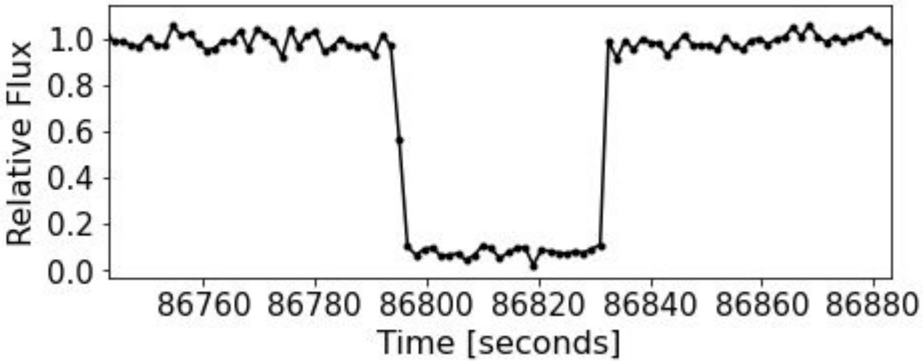


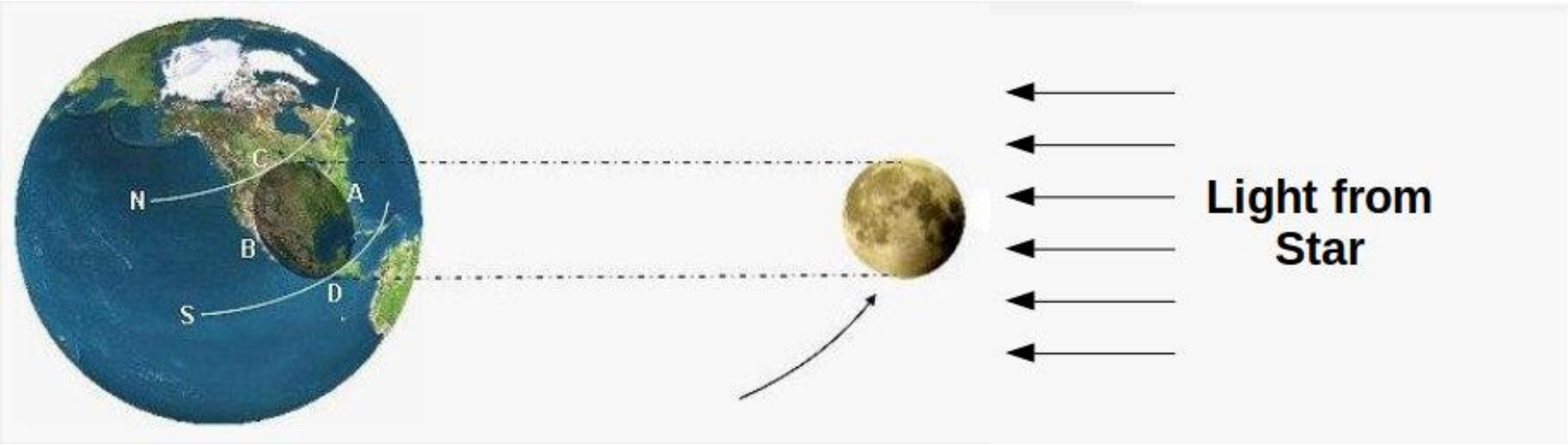


An alternative is the use of other techniques, such as Stellar Occultations.

1. Stellar Occultations occurs when a Solar System Object cross in front of a star for an observer.

2. Each observer will determine the light flux of the star over time and obtain a light curve, if it shows a flux drop than a occultation was detected.





Stellar occultations can be a powerful observational technique.

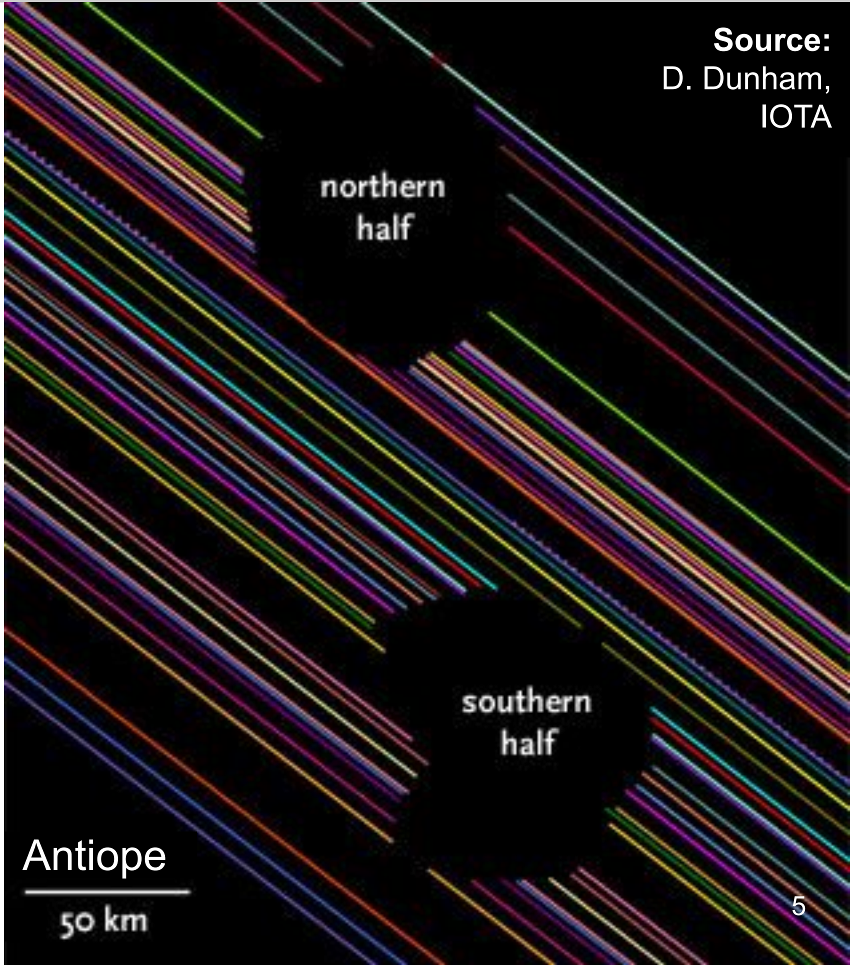
1. Determination of 2D apparent sizes and shapes with km level uncertainties.

2. Probes the vicinity of objects in the search of material (rings, dust shell, etc), or even atmospheres in the nanobar level.

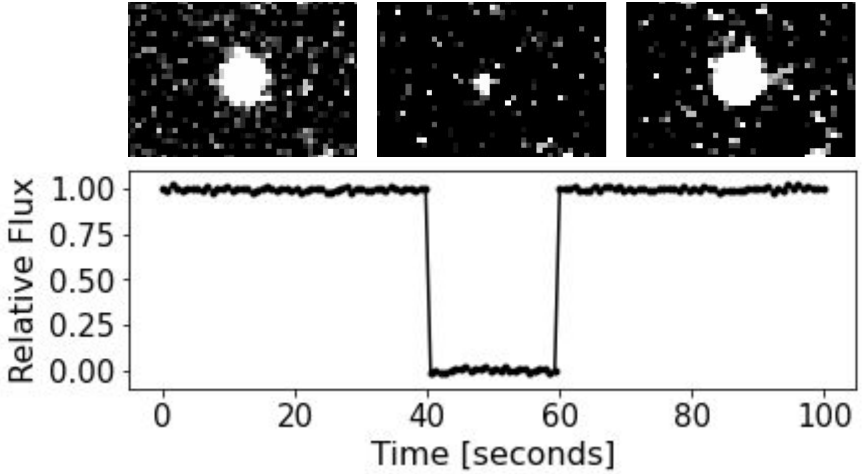
3. Detection of contact binaries and topographic features (craters, chasms, etc)

4. Provides km level astrometric positions, allowing the improvement of the orbits of the occulting body.

Focus of this project



Stellar occultations by bright objects can be very challenging.



Fainter Bodies

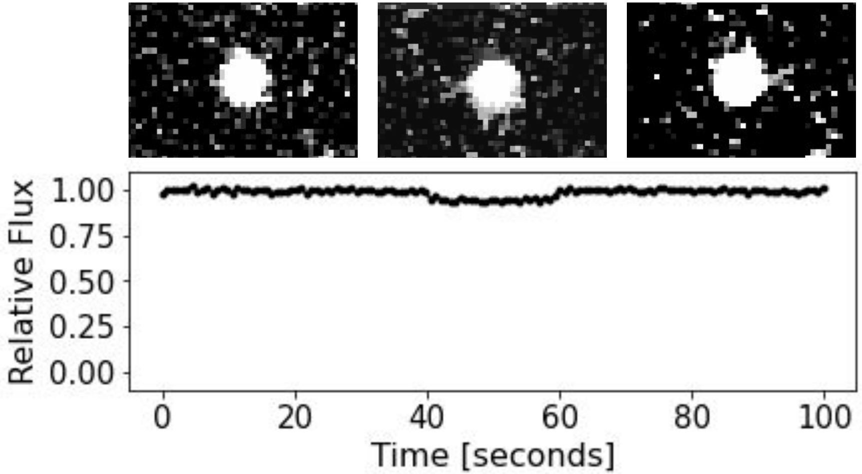
Clear occultation

Magnitude drops that goes to zero.

Brighter Bodies

Very small magnitude drops.

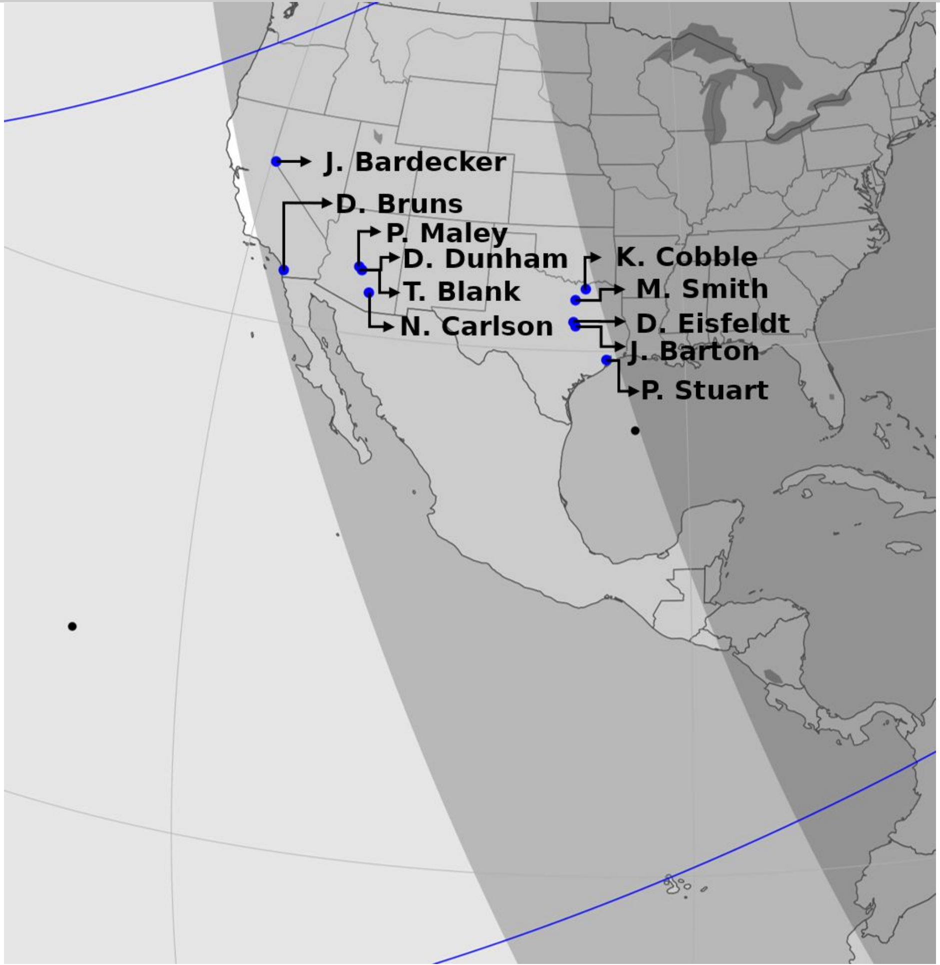
S/N should be the best possible.



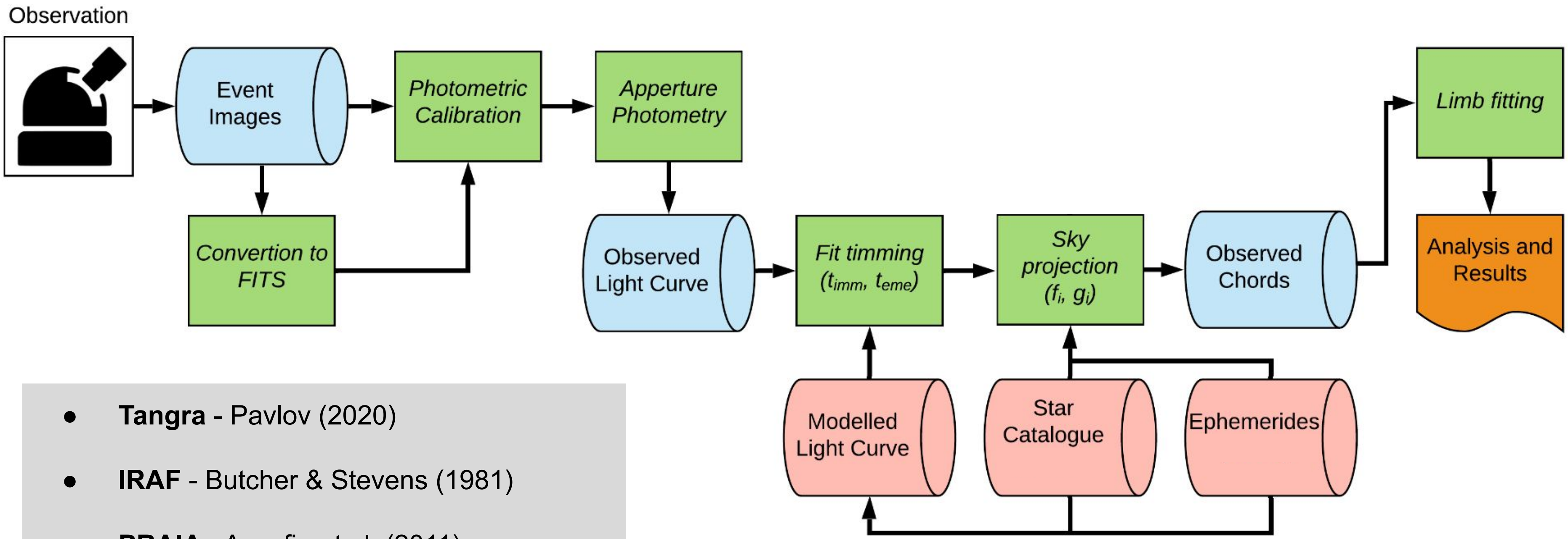
We need to predict such events and organize campaigns to observe them.

1. Predict the events;
2. Request time (for large telescopes);
3. Mobilize the amateur community;
4. Deployment of Stations
5. Gather all the Data and Reports

Example of the Occultation by Ganymede (21/12/2020)

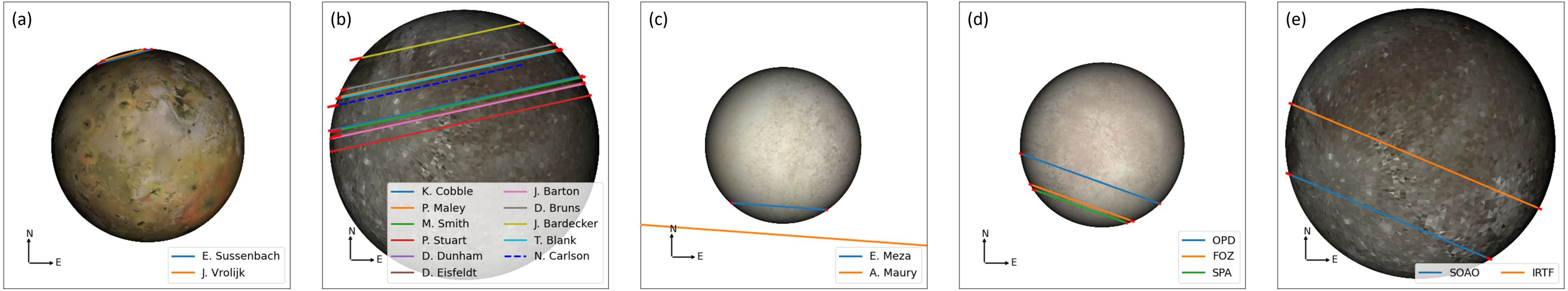


The analysis pipeline goes from the images to the resulting position.



- **Tangra** - Pavlov (2020)
- **IRAF** - Butcher & Stevens (1981)
- **PRAIA** - Assafin et al. (2011)
- **SORA** - Gomes-Júnior et al. (submitted) (http://sora.readthedocs.io)

We obtained astrometrical positions with uncertainties in the milliarcsecond level.



Event	Sat.	Date and time	RA	DEC	ΔRA	ΔDEC
a	501	2021-04-02 10:24	21 43 04.37583 (1.1 mas)	-14 23 58.1536 (0.7 mas)	+5.3	-2.9
b	503	2020-12-21 00:49	20 09 33.56022 (0.9 mas)	-20 35 38.0137 (1.7 mas)	-3.9	-0.1
c	502	2019-06-04 02:26	17 16 59.89400 (1.1 mas)	-22 28 06.5375 (1.1 mas)	-3.7	-3.1
d	502	2017-03-31 06:44	13 12 15.54781 (1.9 mas)	-05 56 48.6987 (1.6 mas)	-0.2	-0.3
e	503	2016-04-13 11:57	11 03 41.32089 (4.1 mas)	+07 34 55.6614 (4.7 mas)	-2.2	+7.6

- **The offsets were calculated considering the ephemerides `DE440.bsp` and `jup365.bsp`.**

Stellar occultations is one of the best techniques to determine positions.

- Classic CCD Astrometry → 100 mas (Kiseleva et al., 2008)
- Photographic Plates → 65 mas (Robert et al., 2012)
- Precision Premium → 30 mas (Peng et al., 2012)
- Stacking of images → 30 mas (Lainey et al., 2017)
- Mutual Phenomena → 20 mas (Saquet et al., 2017)
- Mutual Phenomena → 11 mas (Morgado et al., 2019c)
- Mutual Approximation → 11 mas (Morgado et al., 2019a)
- Mutual Approximation → 7 mas (Morgado et al., 2016)
- Radar Astrometry → 2 mas (Brozovic et al., 2020)
- Stellar Occultation → 2 mas (Morgado et al., in prep)
- Stellar Occultation → 1 mas (Morgado et al., 2019b)