Data from the JUNO mission (NASA) to study Kepler's 3rd law in High Schools and at the University

Goals :

- Advertise about the 9-days record, uninterrupted, video showing the wonderful dynamics of the four Jovian satellites around Jupiter (JUNO mission) https://www.youtube.com/watch?v=XpsQimYhNkA
- Provide to the world-wide educational community authentic astronomical data to study the dynamics of Jupiter Satellites, control the validity of Kepler's 3rd Law and estimate the mass of Jupiter with a good precision (~10% error).

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Educational levels : High School, University (Bachelor, Master)

Proposed activities with students :

Depending on the particular knowledege and abilities of students, and assuming that orbits are circular, it is possible with these data :

1) to check the validity of Kepler's 3rd Law ;
2) to determine the power-law expression for Kepler's Law by a linear fit log(T)=f(log(a)). Uncertainties, and a robust measure for Callisto, are needed ;
3) to estimate the mass of Jupiter. We found M_J = (2.1+/- 0.1) x 10^{27} kg. The main source of uncertainty is systematic and not random. It comes from the conversion of pixels to km which is unsure due to the repixellisation between the raw data from the Camera and the NASA video;
4) to observe resonances between the periods of revolution of Jupiter's satellites ;
5) to estimate the inclination of the orbital plane for each satellite.

Other suggestions welcome.

Presentation of the data

The NASA video below presents the dynamics of the 4 main Jupiter satellites as recorded by the JunoCAM Camera during the approching phase of Jupiter by JUNO spacecraft in June 2016. https://www.youtube.com/watch?v=XpsQimYhNkA

1) I have extracted from this video the positions x and y of each satellite at each time step (one frame every 15 minutes). This extraction is not perfect.
2) On this video, one also sees the apparent size of Jupiter increase progressively due to the motion of the spacecraft toward Jupiter over 16 days. Knowing the distance between the spacecraft and Jupiter at each time step à chaque instant (data from JUNO), I have reprojected x and y values at the position of the spacecraft at t = 0, so as to compensate for the motion of the spacecraft.

3) I have choosen to exclude thoses frames after the first long interruption (which happens after 9 days of record), so as to keep a continuous, uninterrupted, data set.

The ZIP contains a few files :

- An Excel, compact, file for students (recommanded) : `juno.xls`
  - 231 lines (1 position per hour)
  - Empty space when satellite not detected, or in Jupiter's shadow
  - apparent distance to Jupiter in millions of km, corrected for JUNO's motion.
- Full data files
  - 873 lines (1 position every 15 min)
  - `NaN` » (Not a Number) when the satellite is not detected
  - Columns relative to JUNOCAM information
  - Two versions for this file
    - raw (`juno_raw.dat`) : distances x and y in pixels, uncorrected for Jupiter's approach.
    - corrected (`juno_rescaled.dat`) : apparent distances to Jupiter in millions of km, corrected for Jupiter's approach.

These files only contain the first 9 days of data. In case you would need the full set (16 jours), the `python` script which allowed the extraction of positions and recalibration of distances is included in the kit.

Tests operated with High School students in the South of France (january 2019)

6 Practical classes (2 hours long each) in three different High Schools near Montpellier (France). Students aged from 15 to 18.

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List of files

- Data files
  - `juno.xls`
  - `juno_rescaled.dat`
  - `juno_raw.dat`
- An enlarged version of the video, for videoprojection : `revolutions_satellites_Jupiter_JUNO_zoom.mp4`
- PowerPoint document, in French : `TP_Juno_v8.ppt`
- The `python` code which extracts the positions x and y of each satellite, converts pixels in distances, and corrects for JUNO's motion : `extract_video_MSSS_v10.py`