DIN - DEPARTMENT OF INDUSTRIAL ENGINEERING

PhD Course in Mechanics and Advanced Engineering Sciences (DIMSAI)

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DEVELOPMENT OF METHODS FOR THE "GLOBAL" EPHEMERIS ESTIMATION OF THE GAS GIANTS SATELLITE SYSTEMS:

THE SATELLITE SYSTEMS OF THE GAS GIANTS

1. The Satellite systems

The satellite systems of Saturn and Jupiter are complex dynamical systems, with several interactions happening between the moons, rings and the central body, such as orbital resonances, tidal interaction or librations.

During this last year, both Cassini and Juno spacecrafts had been used to carry out gravity measurements of Saturn and Jupiter, respectively. Both were inserted into similar, almost polar, highly eccentricity orbits with low pericenter altitudes. During pericenter passages, tracking the motion of the spacecrafts from the DSN enabled the retrieval of the gravity field of both gas giants at an unprecedented level of accuracy. The gravity determination will provide constraints on the interiors structures of both gas giants and also on the satellite system dynamics, the satellite ephemeris.

The main aim of this project is to improve the ephemeris of the gas giant satellite systems using an improved gravity field of the central body, estimated using tracking data of deep space proves. To accomplish our objective we will use data of three different Deep space missions, Cassini, Juno and Galileo.

2. Jupiter Gravity Field

The The 11th of July of 2017, Juno completed the 7th perijove. Only 2 of these first seven orbits were devoted to gravity field determination, PJ03 and PJ06.

In both perijoves, X and Ka bands were available providing a strong suppression of the dispersive plasma noise, mainly caused by the Solar corona and the Io plasma torus. Using a multiarc approach was possible to estimate the spherical harmonics of the gravity field, the pole, and the k_{22} love number.

With the Juno gravity analyses a first evidence of the hemispherical gravity field asymmetries, mainly related to the atmospheric dynamics, has been discovered.

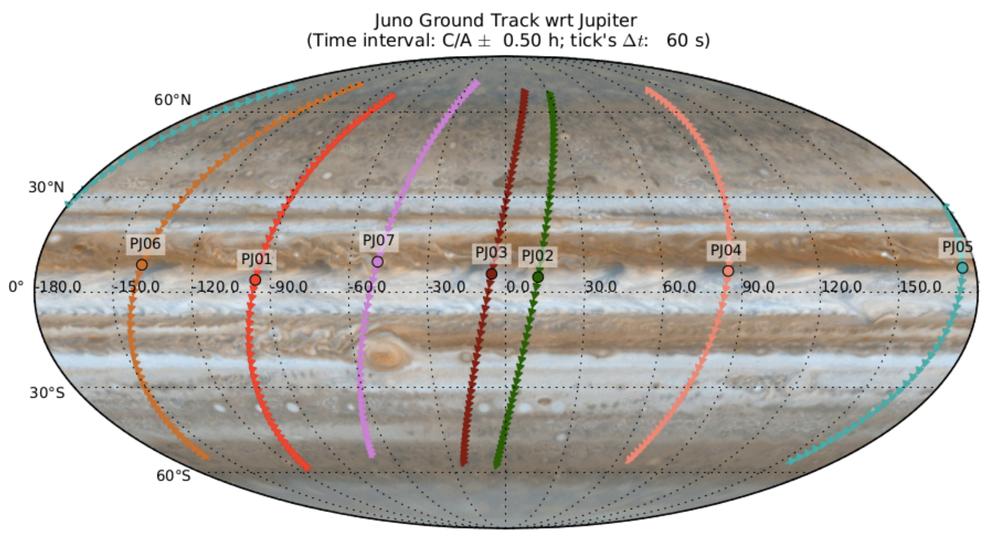

Figure 1: Juno ground track with Jupiter.

	Value x10^{+06}	3-σ x10^{+06}
J_2	14696.568	0.006
J_3	-0.0419	0.009
J_4	-586.601	0.003
J_5	-0.071	0.006
J_6	34.203	0.009
J_7	0.113	0.017
J_8	-2.422	0.024
J_9	-0.137	0.044
J_{10}	0.167	0.072

Table 1: Estimated gravity field coefficients (unnormalized).

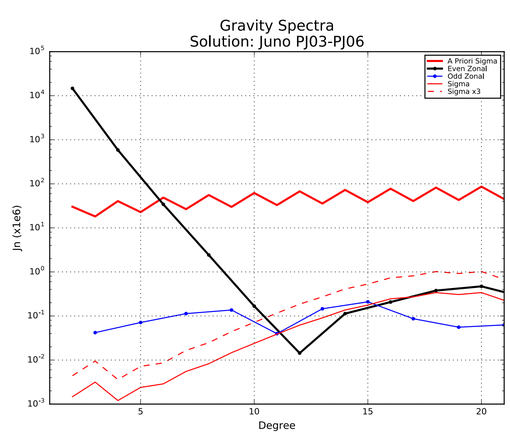

Figure 2: Jupiter Gravity Spectra.

3. Saturn Gravity Field

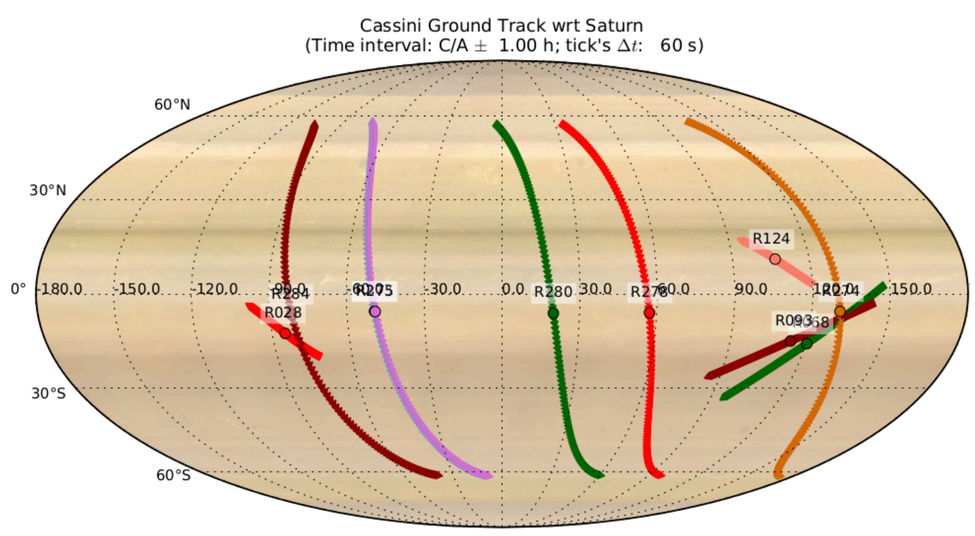

Figure 3: Cassini ground track with Saturn.

The 15th of September of 2017, Cassini finished its mission plunging into Saturn.

Doppler data from the proximal orbits; R273, R274, R275, R278, R280 and R284 were combined in a multi-arc fit to estimate the gravity field of Saturn.

	Value x10^{+06}	3σx10^{+06}
J_2	16290.593	0.061
J_3	0.017	0.043
J_4	-935.307	0.065
J_5	-0.188	0.073
J_6	86.340	0.089
J_7	0.032	0.086
J_8	-14.636	0.138
J_9	0.265	0.156
J_{10}	4.577	0.255

Table 2: Estimated gravity field coefficients under the 7x7 gravity field hypothesis (unnormalized).

	Value x10^{+06}	3σx10^{+06}
J_2	16290.570	0.018
J_3	0.043	0.013
J_4	-935.302	0.034
J_5	-0.264	0.037
J_6	86.314	0.077
J_7	0.0170	0.072
J_8	-14.671	0.149
J_9	0.181	0.153
J_{10}	4.537	0.268

Table 3: Estimated gravity field coefficients under the acoustic modes hypothesis (unnormalized).

Surprisingly, the gravity field of Saturn resulted to be very different from Jupiter. Assuming a purely zonal field and a non-zero quadrupole, Cassini's tracking data show strong signatures in the vicinity of the closest approach, so different strategies were adopted to fit the data:

- Non-zonal harmonics: a full 7x7 gravity field is necessary to fit the data (strong winds).
- Acoustic modes: a time-variable zonal field can fit the data to the noise level.

Both the approaches cause similar secular effects on the ephemerides.

4. The Satellites of Saturn

The dynamical behaviour of planetary satellites holds key information on the properties of both the satellites themselves and the central body.

Is possible to improve the satellite ephemerides doing a "global fit" using the data of both proximal orbits and the satellite flybys. The proximal orbits provide information about the gravity field of the central body while the flybys constrain the orbits of the satellites.

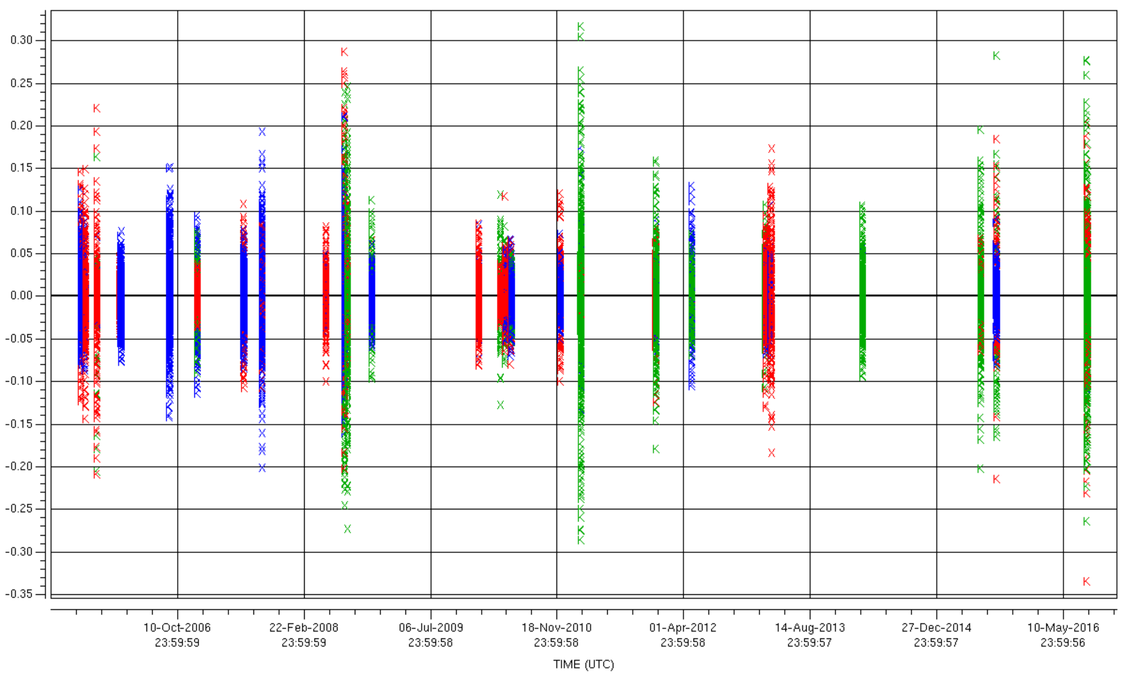

Figure 6: Residuals of the Cassini mission.

We succeeded in fitting all the data from Cassini gravity flybys, prior to the proximal orbits, obtaining good residuals comparable to local analysis, using a simplified model of the system, without adding the models of the rings or the gravitational tides interactions, using the SATORBINT integrator. We concluded that the addition of Saturn old flybys provided the greatest improvement.

5. The Satellites of Jupiter

Part of the research activity planed for the following year is the analysis of the tracking data acquired during the flybys of the Jupiter satellites of the Galileo mission, which studied the Jupiter system for 8 years since its arrival on December 1995. Unfortunately, due to some major problems with its main high gain antenna, tracking data are available only at S Band.

The activity will be focused on the pre-processing and analysis of all the Doppler data acquired when the flybys of the Galilean moons occurred, using the improved Juno's gravity field of Jupiter, and the calibration of the Io torus if possible, to constraint the gravity solution of the Galilean satellites and the ephemeris of the system. This activity will be carried on at NASA's Jet Propulsion Laboratory, working within the Radio Science System Group.

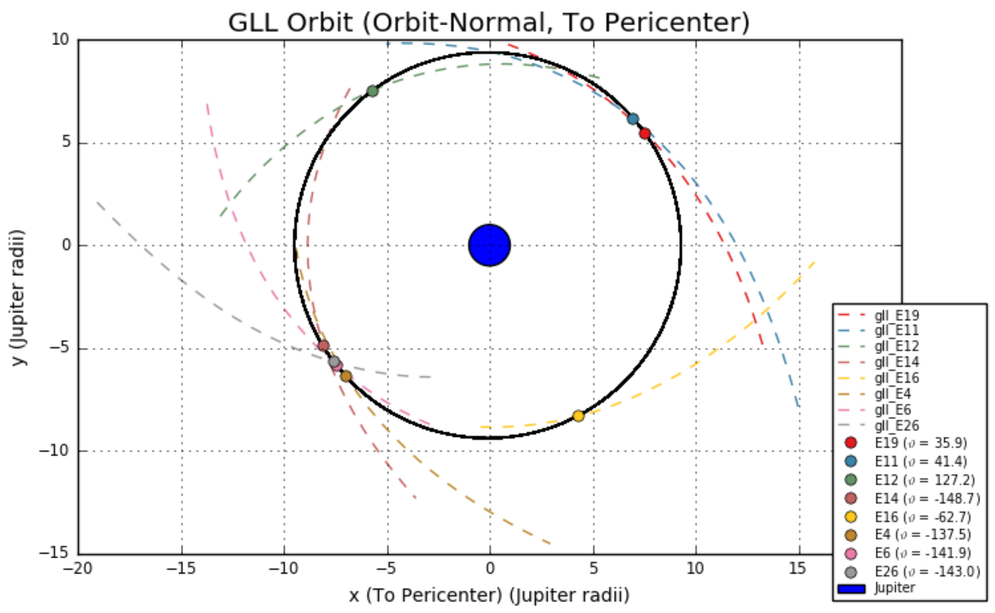

Figure 7: Galileo flybys of Europa.

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