Surveying potential cruise fly-by opportunities for an Ice Giant mission

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We present a systematic approach to analyse rapidly fly-by opportunities for the cruise phase of a mission to an Ice Giant. Such flyby would provide a unique opportunities to characterise Jupiter Trojans, Centaurs, or Jupiter Family comets.

A mission to an Ice Giant (Neptune and/or Uranus) will be among the ones examined by NASA's next Planetary Sciences and Astrobiology Decadal survey. ESA was exploring in 2018-2019 a potential collaboration to a NASA-led mission to an ice giant and has carried out a concurrent engineering design study [1] for possible European contributions. In this study, a dual launch in 2031 was contemplated; after a Jupiter swingby in late 2032, one orbiter would go to Uranus while the second one would reach Neptune.

The long cruise of a mission to Uranus and or Neptune would provide an excellent opportunity scientific investigations like heliophysics science [2], [3], [4]. In addition, it could provide an unexpected chance to visit an unexplored small body.

Examples of such flybys by missions to the outer solar system are well known. To mention some, the Rosetta spacecraft performed two flybys of asteroid, 2867 Steins and 21 Lutetia [5]; Galileo performed fly-bys of 951 Gaspra and 243 Ida (these images provided the first direct confirmation of an asteroid moon, Dactyl) [6] and Cassini-Huygens performed a more humble fly-by of 2685 Masursky at about 0.011 AU.

In general flyby targets can only be chosen after launch from a list of candidates according to scientific interest, fly-by geometry, operational feasibility and the additional cost of propellant for the trajectory modifications [7]. The expected results from such observations include: the rotational properties of the target including the astrometric refinement of their orbit, the determination of their spin state and pole direction, global characteristics such as shape, volume, mass and bulk density, surface physical properties and morphology, detailed chemical and mineralogical characterization, effects of the space weathering on surface properties due to the solar wind interactions and exploration of the target's environment and activity.
We took a cruise trajectory to Neptune used in ESA's CDF study to search for a candidate flyby, as a check whether the science return of such mission could be enhanced. In this study, we checked whether a quick assessment of flyby opportunities for a candidate trajectory was possible.

In our analysis, we considered to search for JupiterTrojans, Centaurs, TransNeptunian Objects, and Jupiter-Family Comets [8]. The description provided for each family (sorted by orbit type) is the following:

For a preliminary assessment, we decided to use data from the JPL Small-Body Database Search Engine [9]. From the database we selected a total of 12507 bodies for which we retrieved the data in SPICE format (Spacecraft Kernel) [10]. To do so systematically, we used a Julia based client wrapper to Horizons [11] and then we took advantage of the SPICE Toolkit capabilities to perform a Closest Approach (CA) search for each body and obtain the time and distance of the event. We present preliminary results of our study hereby.

The results provide us with some interesting figures. The histogram below - table and in Figure 1 - provides a wider view of the resulting distribution of objects as a function of the CA distance.

<table>
<thead>
<tr>
<th>Distance Bin (AU)</th>
<th>0-0.1</th>
<th>0.1-0.5</th>
<th>0.5-1.0</th>
<th>1.0-2.0</th>
<th>2.0-100.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of objects</td>
<td>1</td>
<td>7</td>
<td>12</td>
<td>42</td>
<td>12444</td>
</tr>
</tbody>
</table>

We selected some examples that are provided in the following table:

<table>
<thead>
<tr>
<th>Body Name</th>
<th>Family</th>
<th>Body ID</th>
<th>Inclination (deg)</th>
<th>CA (AU)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shoemaker-Levy 9</td>
<td>JFC</td>
<td>1000183</td>
<td>5.982</td>
<td>0.16</td>
</tr>
<tr>
<td>335P/Gibbs</td>
<td>JFC</td>
<td>1003007</td>
<td>7.27</td>
<td>0.07</td>
</tr>
<tr>
<td>P/2015 TP200</td>
<td>JFC</td>
<td>1003474</td>
<td>8.77</td>
<td>0.38</td>
</tr>
<tr>
<td>2013 CT160</td>
<td>C</td>
<td>3667711</td>
<td>16.76</td>
<td>0.46</td>
</tr>
<tr>
<td>2019 TP13</td>
<td>C</td>
<td>3985102</td>
<td>4.93</td>
<td>0.44</td>
</tr>
</tbody>
</table>

The ongoing analysis shows that there is only one interesting result for the current trajectory: comet 335P/Gibbs. Such flyby could only be compared with the before mentioned Cassini 2685 Masursky at about 0.011 AU, in such case we would be seven times further and with such a rapid scenario we could already identify a potential flyby. Figure 2 shows a simulation of a theoretical Ice Giants flyby with 335P/Gibbs.
We repeat that this report is a very preliminary and approximate result, an updated will be given at the time of the conference. The main purpose of this contribution was to prove that such studies are feasible and can later help to optimise the trajectory design and the target selection process for fly-by opportunities. We plan to conduct such search with other mission such as JUICE and also to expand the catalogue of bodies for which we will conduct such searches.


