

# A Simpler Procedure for Specifying Solar System Objects in Phase 2

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Observations of Solar System objects in Service Mode require a special procedure. Observers preparing Observing Blocks must submit a detailed ephemerides file for each target for the whole duration of the observability period, which can sometimes be the entire ESO Period. These ephemerides files are ASCII files and follow a strict format, compatible with the VLT parameter file format. We present a simple web service that is now available to replace the former two-step process.

## ESO ephemerides requirements

As with many other telescopes, Very Large Telescope (VLT) observations done at a non-sidereal tracking rate require a special procedure at the VLT. In Visitor Mode (VM), each visiting astronomer is responsible for updating both the coordinates and the apparent motion of the target at the time of execution of an Observing Block (OB), prepared with the Phase 2 Proposal Preparation tool (P2PP). In this case, the choice of source of ephemerides, and its format, is at the discretion of the visiting astronomer.

The situation is different in Service Mode (SM), where the staff at Paranal execute OBs prepared weeks in advance by remote astronomers. The procedure set by ESO for Phase 2 preparation in the case of moving targets thus includes the submission of an ephemeris file together with each OB. Both the content and format of these ephemerides files are strictly defined. The ESO Phase 2 web pages<sup>1</sup> document these requirements thoroughly. We limit the description here to the core of these files.

Figure 1. The PAF query form, hosted at IMCCE and ESO. Here, ephemerides are requested for (134340) Pluto, from Paranal, for the entire Period 97, with a time step of 10 minutes. The PAF parameters refer to cut-off on target airmass ( $\leq 1.5$ ) and the Sun's elevation ( $\leq 0$  degrees) to display ephemerides.

For each OB, the ephemerides file lists the successive coordinates and apparent motion of the target, for the whole duration of its observability period. The apparent displacement of the target cannot exceed 30 arcseconds between two consecutive entries (3 arcseconds in the case of SINFONI, due to its much smaller acquisition field of view). As a result, such files may contain up to several thousand entries.

The coordinates are requested as topocentric astrometric equatorial coordinates, at J2000 equinox (International Celestial Reference Frame). The VLT telescope control system corrects for precession, nutation, annual aberration and atmospheric refraction, and coordinates should not be submitted as apparent coordinates.

## Ephemerides computation at IMCCE

The Bureau des longitudes, created during the French Revolution by the law of Messidor 7, year 3 by the Convention Nationale, is the academy responsible of the definition of the French national ephemerides. The practical realisation of these ephemerides is entrusted to the Institut de mécanique céleste et de calcul des éphémérides (IMCCE). Aside from the official astronomical and nautical ephemerides publications<sup>2</sup>, the IMCCE releases ephemerides computations through its website.

The ephemerides of planets and small Solar System objects (SSOs) are computed in a quasi-inertial reference frame, taking into account post-Newtonian approximations. The geometric positions of the major planets and the Moon are provided by INPOP planetary theory (Fienga et al., 2014). Those of small SSOs (asteroids, comets, Centaurs, trans-Neptunian objects) are calculated by numerical integration of the  $N$ -body perturbed problem (Gragg–Bulirsch–Stoer algorithm: Bulirsch & Stoer, 1966; Stoer & Bulirsch, 1980), with the exception of the natural satellites, for which positions are obtained from dedicated solutions of their motion, e.g., Lainey et al. (2007, 2004a, b) for Mars and Jupiter, Vienne & Duriez (1995) for Saturn, Laskar & Jacobson (1987) for Uranus, and Le Guyader (1993) for Neptune. The typical accuracy of asteroid and comet ephemerides are at the level of tens of milli-arcseconds, mainly due to the accuracy of their osculating elements.

In 2005, the IMCCE started to implement Virtual Observatory (VO) compliant interfaces in its ephemerides services (Thuillot et al., 2005). A web portal<sup>3</sup> describes the various services, such as Solar System object identification (SkyBoT: Berthier et al., 2009), or general ephemerides computation (Mirade: Berthier et al., 2009). All our services are accessible via web services (based on the SOAP and HTTP POST method) which allows interaction between the application and the

services via HTTP request and web forms, and are integrated in several VO-compliant software packages, such as the well-distributed Aladin Sky Atlas (Bonnarel et al., 2000). We describe below an extension of the Miriade ephemerides generator to simply and quickly generate ephemerides files compliant with ESO Phase 2 requirements.

### A simple solution for Phase 2 preparation

We have implemented the strict VLT parameter file format (PAF) as one of the possible outputs of the Miriade VO ephemerides generator. This makes it easy to generate a fully PAF-compliant ephemerides file by setting the `-paf` Params option within the Miriade web service.

In order to reduce the final number of entries, the service includes a test on two parameters: the target airmass and the Sun's elevation above the horizon. Only entries satisfying both conditions (target above a threshold airmass, and Sun

below a threshold elevation) are reported by the service. The default thresholds are an airmass of 2.6 and an elevation of 0 degrees, i.e., sunset and sunrise.

We have also developed a simple query form, hosted on both the IMCCE<sup>4</sup> and ESO<sup>5</sup> websites, in which users need only fill in the target (helped by the auto-completion Application Program Interface [API] of our SsODNet<sup>6</sup> service), the observatory (Paranal or La Silla), the time span and time interval of the ephemerides entries, and, optionally, the thresholds for entry selection (see Figure 1). The code source of this query form can be provided upon request<sup>7</sup>, and copy-pasted into any web page, the computations being carried out at IMCCE.

### References

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### Links

- <sup>1</sup> Moving targets in Phase 2: <https://www.eso.org/sci/observing/phase2/SMSpecial/MovingTargets.html>
- <sup>2</sup> Publications of IMCCE: [http://www.imcce.fr/en/publications/publications\\_officielles.html](http://www.imcce.fr/en/publications/publications_officielles.html)
- <sup>3</sup> IMCCE VO Web Portal: <http://vo.imcce.fr/>
- <sup>4</sup> IMCCE ephemerides query form: <http://vo.imcce.fr/webservices/miriade/?forms>
- <sup>5</sup> ESO Phase 2 ephemerides query form: <http://www.eso.org/sci/observing/phase2/SMSpecial/MovingTargets.html>
- <sup>6</sup> SsODNet target name autocompletion: <http://vo.imcce.fr/webservices/ssodnet/>
- <sup>7</sup> Query form source code: <http://vo.imcce.fr/webservices/miriade/?clients>