JET PROPULSION LABORATORY **INTEROFFICE MEMORANDUM**

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SUBJECT: SPK file for comet C/2013 A1 (Siding Spring), Orbit Solution 46

This memorandum presents the ephemeris file for comet C/2013 A1. JPL orbit solution 46 fits 597 optical observations from Oct 4, 2012 to Mar 4, 2014. The file provides the nominal trajectory of C/2013 A1 from 2001-Jan-1 to 2016-Jan-01 and is available in SPK format.

OVERVIEW

Comet C/2013 A1 is going to experience a close encounter with Mars on Oct 19, 2014 at a distance of 135,000 km ± 5000 km from the planet center. There is increasing interest in analyzing the close encounter both for the comet nucleus and the dust tail. To support such analysis we generated an ephemeris file in SPK format (NAIF Document 168.0) describing the trajectory of C/2013 A1's nucleus in the time interval from 2001-Jan-1 to 2016-Jan-1.

METHOD

We examined all available ground-based optical astrometry (Right Ascension and Declination angular pairs) as of Mar 14, 2014. To remove biased contribution from individual observatories we conservatively excluded from the orbital fit batches of more than four observations in the same night and biases larger than 0.5 arcseconds, and batches of three or four observations showing biases larger than 1 arcsecond. We also adopted the outlier rejection scheme of Carpino et al. 2013 with $\chi_{rej} = 2$. To the remaining 597 optical observations we applied the standard one arcsecond data-weights used for comet astrometry. Figure 1 shows the residuals of C/2013 A1 observations.

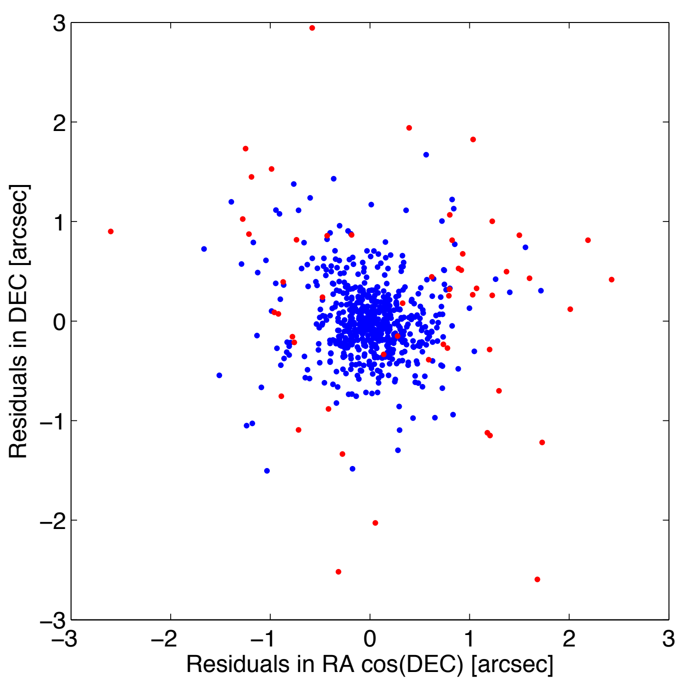

Figure 1. Residuals of C/2013 A1's observations. Blue dots correspond to the observation included in the fit, red dots to deleted observations.

The dynamical system used for the orbit solution and SPK file numerical integration is the nominal one currently used by JPL's Horizons ephemeris system (http://ssd.jpl.nasa.gov/horizons.cgi) and JPL's Small-Body Database (http://ssd.jpl.nasa.gov/sbdb.cgi). Namely, we accounted for:

- Solar and planetary perturbations from JPL planetary ephemerides DE431 (Folkner et al. 2014);
- Perturbations from the 16 most massive bodies in the main asteroid belt (Farnocchia 2014);
- Solar relativistic term.

No significant nongravitational forces were evident in the astrometric data and so the corresponding orbit solution 46 is ballistic.

Table 1. J2000 heliocentric ecliptic orbital parameters of JPL orbit solution 46. Numbers in parentheses indicate the 1σ formal uncertainties of the corresponding (last two) digits in the parameter value.

Epoch (TDB)	2013 Aug 1.0
Eccentricity	1.0006045(61)
Perihelion distance (au)	1.3990370(73)
Time of perihelion passage (TDB)	2014 Oct 25.3868(14)
Longitude of node (deg)	300.974337(84)
Argument of perihelion (deg)	2.43550(33)
Inclination (deg)	129.026659(32)

The SPK file was produced by numerically integrating the heliocentric equations of motion described above and merging the resulting output file with the DE431 planetary ephemeris and the current MAR097 Martian ephemeris solution (Jacobson 2012).

CLOSE APPROACH DATA

Table 2 contains information about the close encounter between C/2013 A1 and Mars. C/2013 A1 passes through Mars's orbital plane 69 minutes before the close approach epoch, while Mars passes through C/2013 A1's orbital plane with a delay of 99 minutes. The Minimum Orbit Intersection Distance (MOID) is the minimum distance between the orbit of the comet and the orbit of Mars. The MOID points on the two orbits are not on the line of nodes. Mars arrives at the minimum distance point 101 min after the close approach epoch, while C/2013 A1 arrives at the minimum distance point 70 min before the close approach.

Table 2. Close approach data.

Close approach epoch (± 3σ)	2014 Oct 19 18:30 (TDB) ± 3 min 2014 Oct 19 18:29 (UTC) ± 3 min
Close approach distance (± 3σ)	135,000 km ± 5000 km
V-infinity	55.96 km/s
MOID	27,400 km
Node crossing distance	27,600 km
Epoch at which Mars crosses C/2013 A1's orbital plane	2014 Oct 19 20:09 (TDB) 2014 Oct 19 20:08 (UTC)
Epoch at which C/2013 A1 crosses Mars's orbital plane	2014 Oct 19 17:21 (TDB) 2014 Oct 19 17:20 (UTC)
Epoch at which Mars arrives at the MOID point	2014 Oct 19 20:11 (TDB) 2014 Oct 19 20:10 (UTC)
Epoch at which C/2013 A1 arrives at the MOID point	2014 Oct 19 17:20 (TDB) 2014 Oct 19 17:19 (UTC)

Figure 2 gives a geometric view of the close encounter on the b-plane, i.e., the plane normal to the asymptotic incoming velocity of C/2013 A1 with respect to Mars. For more details on the b-plane and the corresponding reference frame see Valsecchi et al. 2003. TDB is Barycentric Dynamical Time.

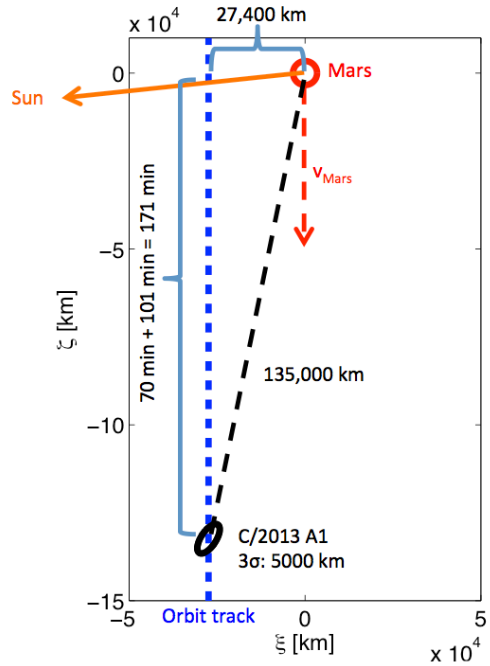

Figure 2. Geometric view of the close encounter. The 3σ uncertainty ellipse of C/2013 A1, the orbit of C/2013 A1, the position of the Sun with respect to Mars, and the velocity of Mars are projected on the b-plane.

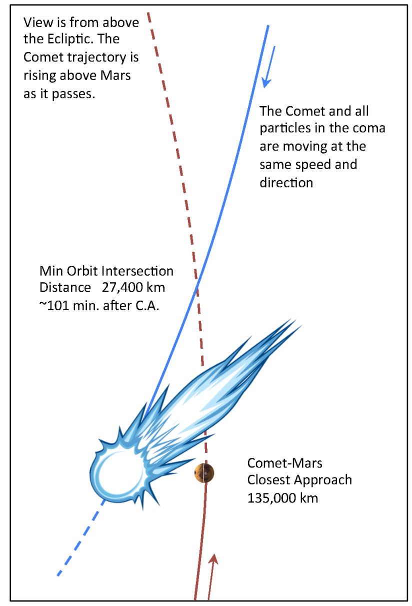

Figure 3. Illustration of the close encounter showing a general overview of the timing and geometry.

The uncertainties in the radial-transverse-normal reference frame at the closest approach are 1200 km, 3700 km, and 200 km. However, unusually large nongravitational accelerations could cause statistically significant deviations.

Figure 3 is an illustration providing an overview of the encounter geometry. The comet trajectory originates below the ecliptic plane, crosses the Mars orbit plane, then passes above and Sunward of Mars at closest approach.

Table 3 contains the relative velocity between C/2013 A1 and Mars 100 min after the close approach epoch in the Earth Mean Equator and Equinox J2000 (EME2000) and Mars Mean Equator J2000 (MME2000) reference frames. This vector can be used as a preliminary representation of the velocity of the comet particles around the time of close approach. This vector moves very slowly (<0.001 deg/day) near the close approach, and the variation in velocity between particles will be negligible. The reverse direction represents the direction that comet particles will be coming from as viewed from any object in the vicinity (e.g., orbiters, landers, etc.). The time of the estimated maximum dust flux will be provided by the Mars Program Office based on the April 4th delivery from the comet modeling groups.

Table 3. Relative velocity between C/2013 A1 and Mars at epoch 2014 Oct 19 20:10 (TDB). Numbers in parentheses indicate the 1σ formal uncertainties of the corresponding (last two) digits in the parameter value.

	X (km/s)	Y (km/s)	Z (km/s)	RA (°)	DEC (°)
EME2000	-40.62915(17)	-35.44452(19)	14.996403(82)	-138.89884(27)	15.543308(79)
MME2000	-53.561802(24)	13.97586(25)	8.23060(10)	165.37591 (25)	8.45719(11)

SCHEDULED UPDATES

Because of the low solar elongation, it is currently difficult to observe C/2013 A1. We plan on updating C/2013 A1's orbit by July 2014 when observing conditions are favorable and several new observations are expected.

EPHEMERIS FILE

The SPK file is available on the Solar System Dynamics Group public ftp server. The full path of the file is shown below.

ftp://ssd.jpl.nasa.gov/pub/xfr/c2013a1_s46_merged_DE431.bsp (Binary SPK format)

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