How to improve the orbit model of Phobos using observations with ALMA?

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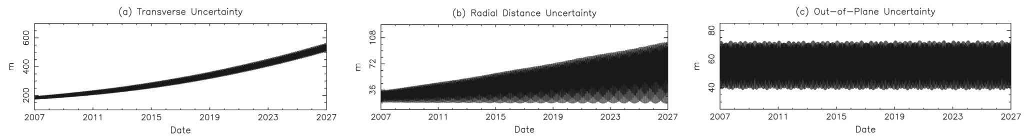
1. Why improve the orbit of Phobos?

The fly-bys of Phobos by the Mars Express mission have provided the opportunity to observe the moon in detail, using all Mars Express instruments. The closer fly-bys (67 km on March 3, 2010) have analyzed the gravity field, by measuring the pull from Phobos. The gravity data analysis is however constrained by the precise knowledge of the position of Phobos. The need to improve this information has been clearly identified, in order to access to higher-order gravity field coefficients. The long-term evolution of Phobos would also be much improved with a better ephemeris.

2. Latest orbit model

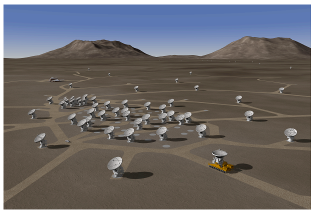
The current best orbit model of Phobos, MAR085 - provided by JPL, has an estimated error that is greater than 1 km (Jacobson 2010), and this precision depends on the accuracy of the position measurements of Phobos. The error of the model also increases with time because of the uncertainty of the orbital period, increasing the position error along the orbital track (transverse error).

The following plots show the variation with time of the expected transverse, radial distance and out-of-plane uncertainties (Jacobson 2010).



3. Observing Phobos with ALMA

The Atacama Large Millimeter Array (ALMA) is a radio interferometer currently being built in the Chilean Atacama desert. With its high-altitude and very dry observing site, its frequency coverage down to the sub-millimeter and its long baselines (up to 17 km), ALMA will do precise astrometric observations (Lestrade 2008) to an accuracy <0.001". These data will significantly improve the orbit models of many solar system objects.



Our first objective is to improve the knowledge of the orbit of Phobos by at least a factor 2, from 1km down to 500m. This can be achieved before completion of the project even with a maximum baseline length of a few kilometers. As more antennas are added and baseline lengths are extended, the sub-milliarcsec position of Phobos will be obtained.

The first antennas have been positioned relatively close to each other (25-500m), to obtain the best sensitivity at large scales. For a short period of time, we have moved one antenna 2km away from the others, and carried out some test observations. However, we have not had baselines long enough yet to start demonstrating the capabilities of ALMA in astrometry.

The best astrometric resolution (or position accuracy) of an interferometer is given by:

$$\sigma_{\alpha\delta} = \frac{1}{2\pi} \times \frac{1}{SNR} \times \frac{\lambda}{B}$$

The resolution increases with longer baselines (B), shorter wavelengths and higher SNR. The ratio lambda/B corresponds to the size of the beam of the interferometer, which tells about its capacity to resolve the details of the object. So a high position accuracy can be obtained even if the object is not resolved, as long as the SNR is high.

Assuming Phobos radiates like a black body, its flux density is given by (using Rayleigh-Jeans approximation):

$$S(Jy) = 5.1 \times 10^{-8} T \theta_E \theta_P / \lambda^2$$

θ_E and θ_P are the apparent equatorial and polar diameters of the object in arcsec. T is the effective temperature, obtained by:

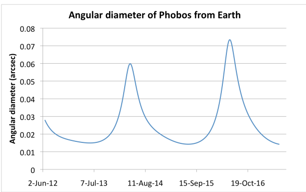
$$T_E(K) = 277(1-A)^{1/4} d^{-1/2}$$

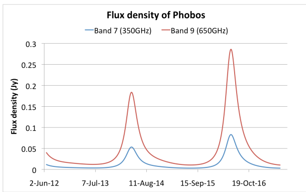
A is the albedo and d is the distance to the Sun.

The flux density increases with shorter wavelengths and larger angular diameter.

Everything converges towards the semi-obvious: observing Phobos at the higher ALMA bands (band 7 -> 350GHz and band 9 -> 650 GHz), and when it is closer to Earth.

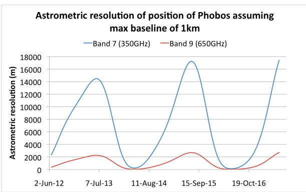
The following plots show the variation of the angular diameter of Phobos for the next 5 years, and the flux density at bands 7 and 9 (assuming an albedo of 0.07):

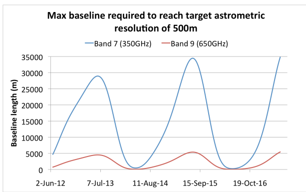




The two best periods for observation will be around March-April 2014 and around June-July 2016.

The following plots show the variation with time of the best astrometric resolution possible given a max baseline of 1km, and the max baseline required to reach the target astrometric resolution of 500m. Note: we assumed a measurement rms of 1mJy for both bands; in practice, the rms at band 9 will be a bit higher than at band 7, so the astrometric resolutions at both bands will be closer.





It is not sure yet which max baseline will be available around March-June 2014. It is very likely though that it will be larger than 5km, which is the minimum required to reach our target resolution of 500m.

We will use a calibrator (point source) to determine the coordinates of Phobos. The technique is called "phase referencing" and is used regularly in Very Long Baseline Interferometry (VLBI). The position of Phobos will be determined by measuring the phase offset with respect to that calibrator, so the final astrometric resolution will depend on the accuracy of the position of the calibrator and on the stability of the phase between the two objects.

For the calibrator, we will use a VLBI source, whose coordinates are already known with great accuracy. As for the phase stability, we will use the WVR correction to remove most of the "wet component"; will remain mainly the fluctuations due to the "dry component".

(Each antenna has a Water Vapor Radiometer, or WVR, observing the water line at 183 GHz. From these measurements, we determine the quantity of water vapor along the line of sight, and the equivalent, additional, path length. This path length is then converted into a phase offset, which is removed from the phase actually measured. We have tested successfully the WVR correction on baselines up to 2km. It is expected to become even more useful on longer baselines.)

4. Other option: occultations

Out of curiosity, we've searched for possible occultations of VLBI quasars by Phobos, between now and Feb 2015. Our catalog contained about 2700 sources. Unfortunately, we didn't find any.

5. Bibliographic references

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