Spacecraft Navigation using the VLBA

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Why do VLBI of Spacecraft?

Doppler and Ranging gives accurate distance to spacecraft
   Not always enough for accurate navigation, especially linear orbit.

VLBI gives accurate position on plane of sky
   Orthogonal to ranging, and critical in some cases
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Good news: Results even more accurate than anticipated.
Bad news: NASA has not yet decided to use VLBA for next
Mars mission (and many others) for navigation.
Phase Referencing to a Spacecraft

Alternate scans between calibrator and target

Use calibrator scans to determine clock local troposphere etc, bandpass

Other special calibrations (measure residual troposphere path delay)

Transfer calibrator phase to the target(s)
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Spacecraft ‘normal’ telemetry signal is no different than a bright source with a dominant somewhat variable spectral line. >1 Jy, ~20 kHz wide, point source.

But, may have large, changing position error (100 mas, 10 mas/hr in beginning) wrt to input orbit.
Getting Spacecraft Positions

Make image of the target (spacecraft)
   offset from phase center is spacecraft offset from input orbit,
   assuming calibrator position is perfect.

Accuracy about ($<$0.03 mas * cal-target separation in deg) 8 GHz
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JPL Navigators DO NOT BELIEVE image position offsets!
Depends on accuracy of correlator model which use:
  Orbit transfer from JPL to VLBA
  Curved wavefront
  Solar and planetary gravitational bending
  Parallax terms

Product to Navigators is measured TOTAL delay difference between calibrator
and target (same as for EVN, VLBA astrometric work)
Delay difference = Correlator model delay + calibrated delays
  + target phase / 2πν₀
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Target phase must not have any 2π ambiguities!==good images)
Other arrays use group delays (phase slope with frequency)
Phoenix Observing Strategy
Observing Sequence:
1 min on quasar
1 min on Phoenix
1 min on Odyssey, MRO in-beam

Last two days before landing:
Phoenix, Odyssey, MRO in-beam (<6’)

Three-hour sessions  8.4-8.6 GHz
Ionosphere correction somewhat important
Table of Phoenix position errors based on Navigator analysis of VLBA delay data compared with best final spacecraft orbit
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* Calibrator is J0823+2223
* In beam

(1) Calibrator is J0823+2223
(2) Calibrator is J0842+1835

0.025 mas = 0.025 mas =
30 m at Mars
# VLBA-Phoenix Position/Delay Analysis

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Quasar-Phoenix accuracy limited by ICRF position uncertainty. Phoenix-orbital accuracy limited only by angular separation. Useful for any planet with orbiting spacecraft.
Other Considerations

Occasionally need fast time response, <12 hours
e-VLBA (behind e-EVN), but MK, BR, HN critical stations

Upgrade VLBA to 33/8 GHz dual system:
NASA future telemetry frequency of 33 GHz.
8 GHz for Ionosphere correction
Move ICRF to 33 GHz (see poster)
Investigate phase stability, certainty of results
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Seamless operation that even JPL personnel could handle
  Observation planning and strategy
  Quick feed from telescopes into software correlator
  Data reduction pipeline in AIPS,
    special calibrations, images, delay determination

Transport delays to Navigation Package
  Analysis of ranging and VLBI data.
Next Mars Mission  MSL

Preparing to support Mars Science Laboratory Mission

Potential calibrators along path of MSL in 2011
Collaboration between NASA/NRAO not yet supported

2M US$/year for ~25% of time for spacecraft/calibrator observations

Full e-VLBA capability

New 32-35 GHz receivers

Reason???? Such high accuracy not needed
   Wind effect on Mars landing larger than 100 m
   DSN 3-element array is good enough

Less impetus for high frequency ICRF

Still, other spacecraft programs
   Determine Cassini position to establish Saturn ephemeris
Conclusions

Spacecraft Quasar accuracy similar to usual phase reference accuracy better quasar position accuracy needed.

If planet has an existing radio emitter, much more accurate positions of spacecraft wrt planet can be obtained.

Phase referencing can use ‘normal’ spacecraft telemetry signals.

Technique useful to use spacecraft for solar system dynamics.