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,
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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 / $2\pi\nu_0$

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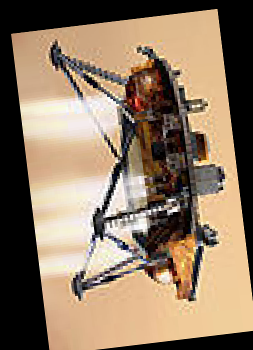
Target phase must not have any 2π ambiguities!==good images)
Other arrays use group delays (phase slope with frequency)

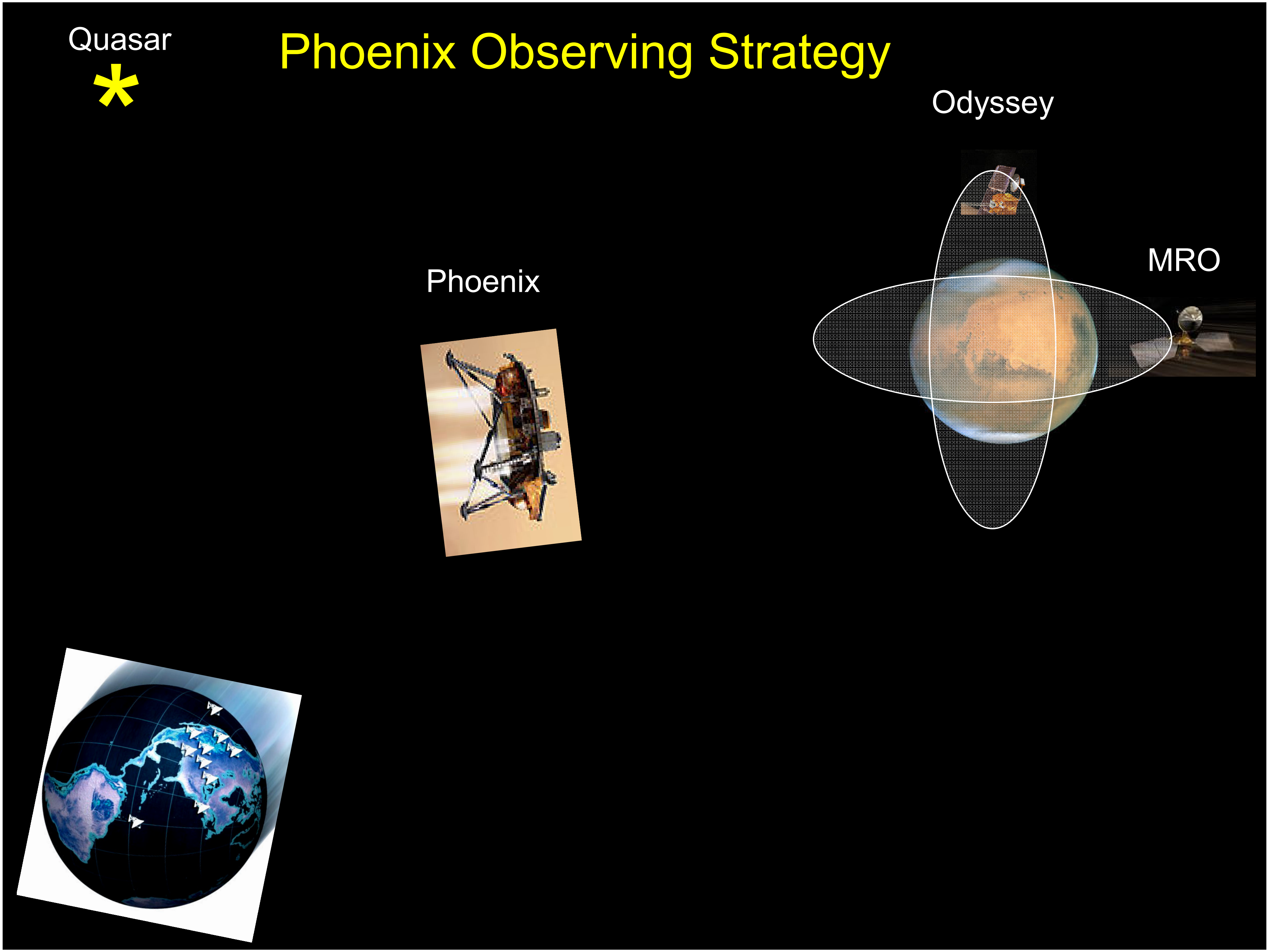
Quasar

*

Phoenix Observing Strategy

Phoenix




Quasar
Phoenix Observing Strategy
Odyssey
MRO
Phoenix

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

VLBA-Phoenix Position/Delay Analysis

Table of Phoenix position errors based on Navigator analysis of VLBA delay data compared with best final spacecraft orbit

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Date	Cal-Phoenix Separation (deg)	Orbiters-Phoenix Separation (deg)	Phoenix Acc from Cal Rel (mas)		Phoenix Acc from Cal Abs (mas)	Phoenix Acc from Orbiters Abs (mas)
Mar 01	2.3(1)	3.1	0.20	+	0.25	0.33
May 14	1.4(2)	1.8	0.09	+	0.15	0.20
May 17	1.5	1.3	0.13	+	0.15	0.14
May 19	1.6	0.8	0.08	+	0.15	0.07
May 22	1.8	0.22	0.10	+	0.15	0.05
May 23	1.8	0.14	0.06	+	0.15	0.03
May 25	1.9	0.06 *	0.09	+	0.15	0.02
May 26	1.9	0.02 *	0.11	+	0.15	0.015

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

* In beam

0.025 mas = 30 m at Mars

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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)
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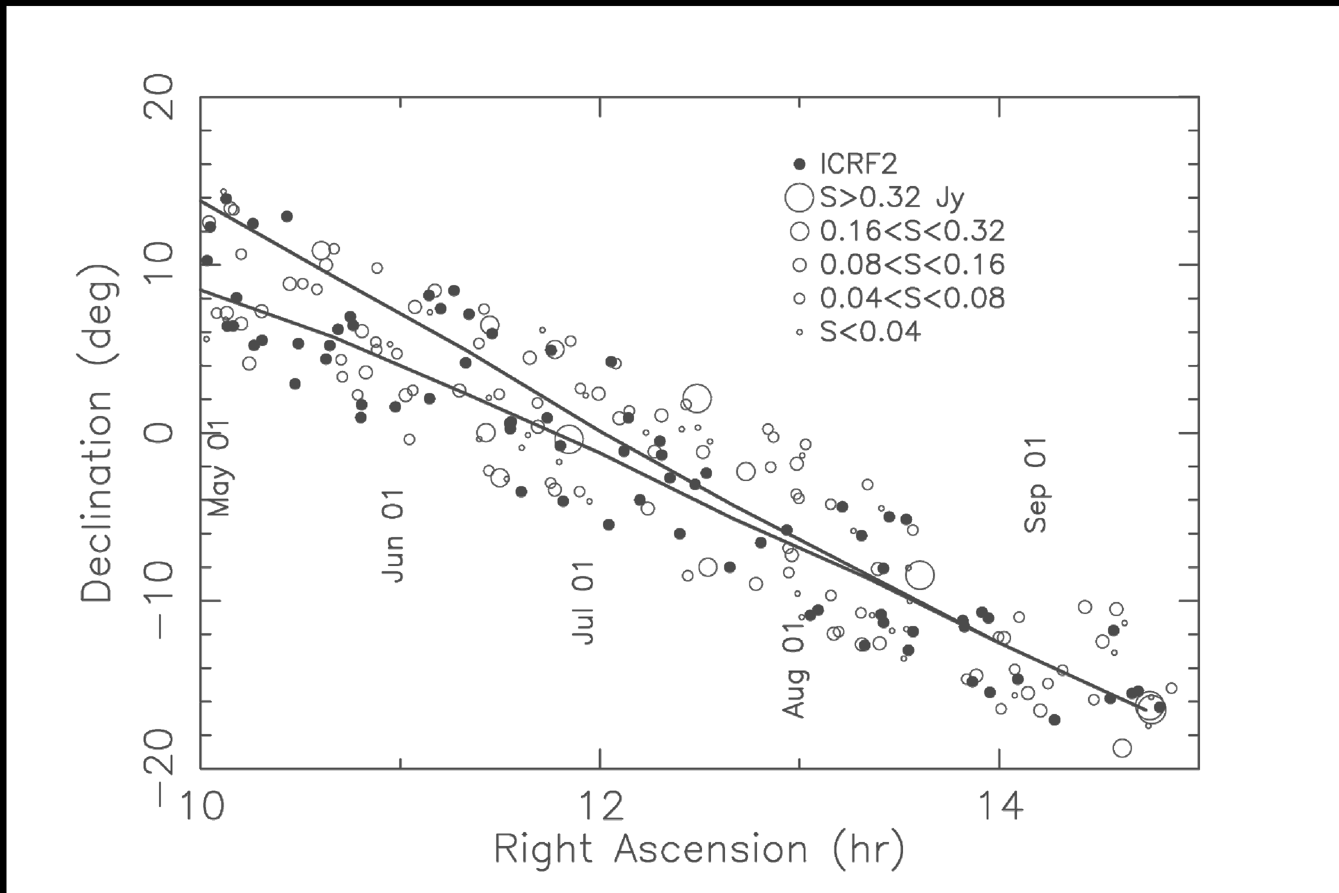
Seamless operation that even JPL personnel could handle
- Observation planning and strategy
- Quick feed from telescopes into software correlator
- Data reduction pipeline in AIPS,
  - special calibrations, images, delay determination

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.