Future DSN Capabilities

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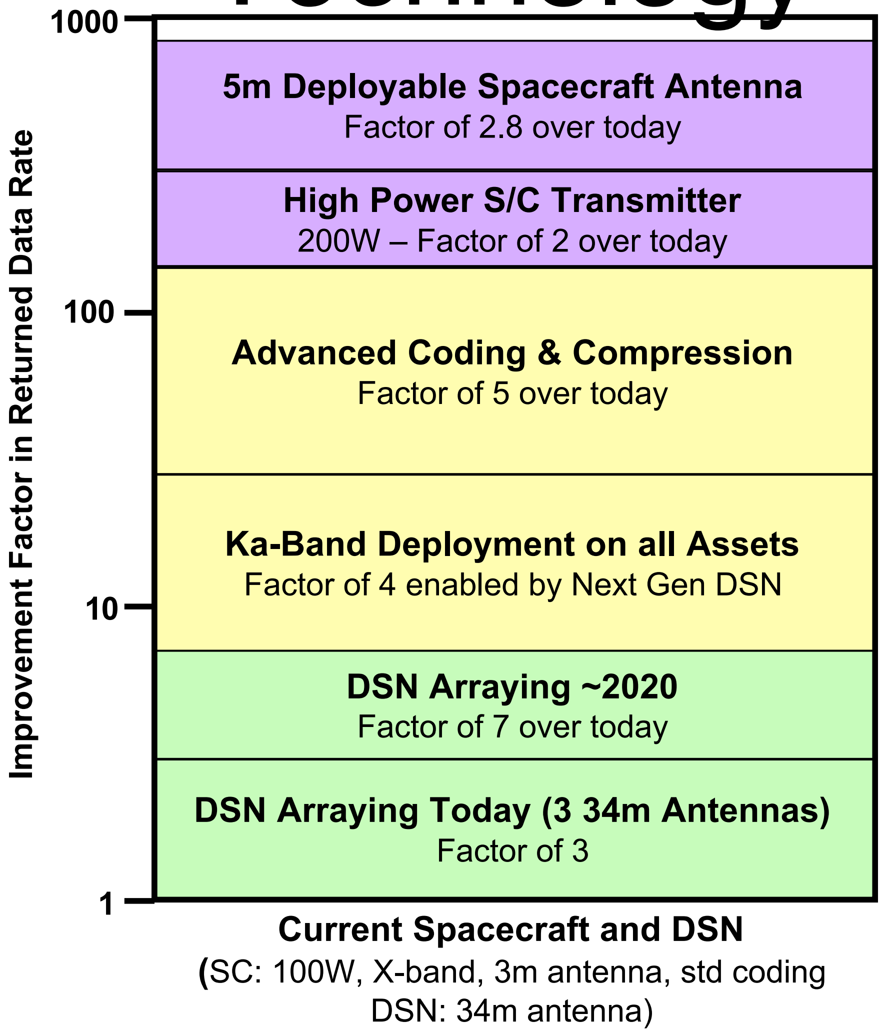
Areas for Discussion

- Downlink data rates
- Uplink data rates
- Spectrum considerations
- Navigation

Downlink Data Rates

- Currently limited to ~ 6 Mbps
  - MRO: X-band, 100W s/c transmitter, 3m s/c antenna. 34m ground antenna
  - Developing Universal Space Transponder, S, X, Ka-bands
    - Ready for flight validation 3-5 years
    - 150 Mbps
- DSN internal capability:
  - Today, 25 Mbps
  - ~FY12 100Mbps

Downlink Data Rates: Technology



Downlink Data Rates: Back of the Envelope

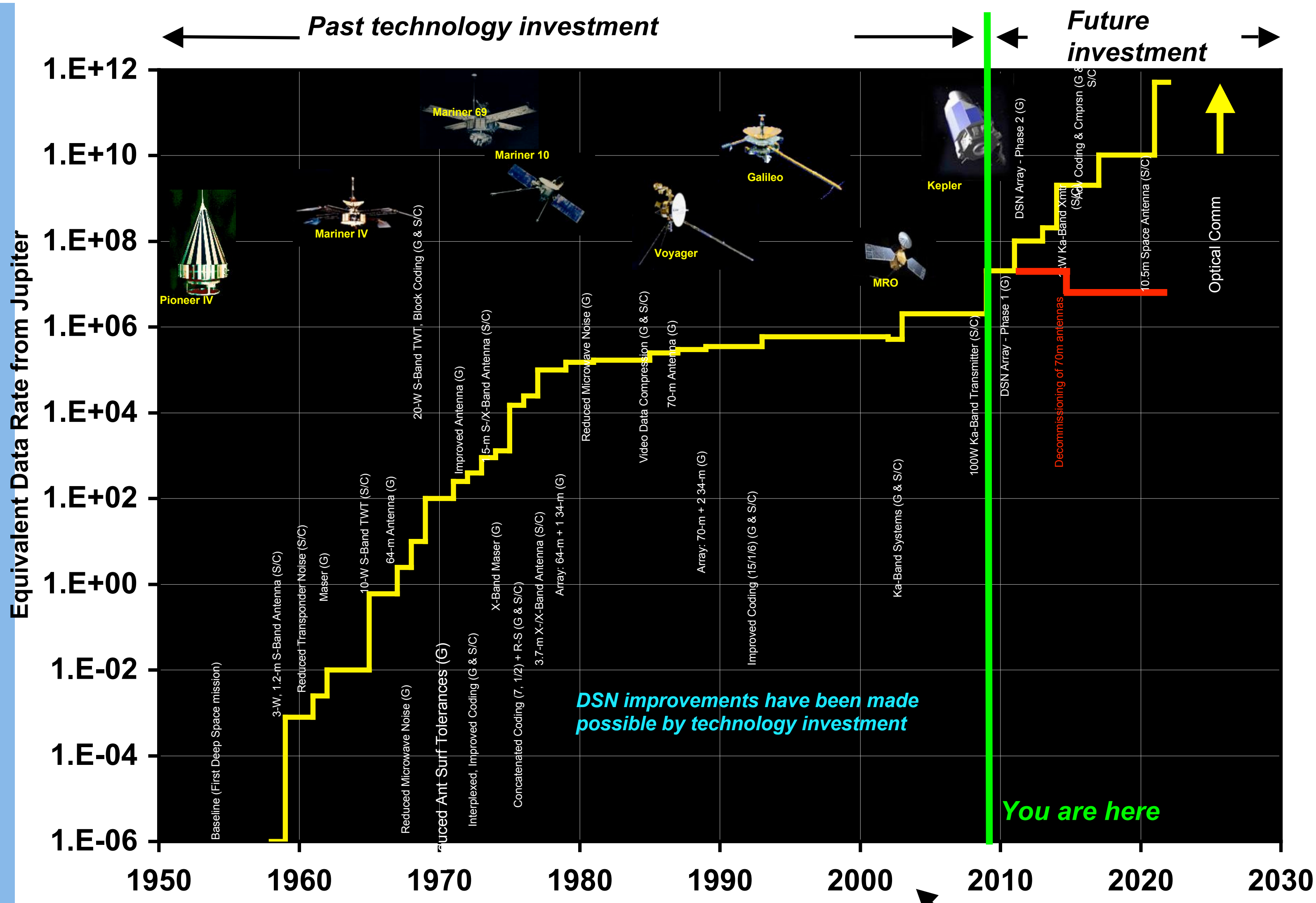
Mission	Data Rate [Mbps]	Frequency	Ground Antenna Equivalent Aperture [m]	s/c TX Power [W]	s/c Antenna Diameter [m]
MRO –today	6	Ka	34	35	3
MRO- what might have been. I.	24	Ka	70	35	3
MRO- what might have been. II.	120	Ka	70	180	3
Next Gen Mars Mission	330	Ka	70	180	5
Next Gen Mars Mission	1200	Ka	70	180	10

Note: All the technologies/capabilities exist today except for the 10m Ka band s/c antenna

Downlink Data Rates: Detailed Chart

	Data Rate Today		Data Rate ~2020		Data Rate ~2030		
Spacecraft Capabilities	3m Antenna X-Band 100 W Xmitter		3m Antenna Ka-Band 180 W Xmitter		5m Antenna Ka-band 200 W Xmitter		1m Optical 1550 nm 50 W Xmitter
DSN Antennas	1 x 34m	3 x 34m	1 x 34m	Equiv to 3 x 34m	1 x 34m	Equiv to 7 x 34m	10m Optical
Mars (0.6 AU)	7 Mbps	20 Mbps	400 Mbps	*1.2 Gbps	*1.3 Gbps	*9.3 Gbps	5.5 Gbps
Mars (2.6 AU)	355 Kbps	1 Mbps	21 Mbps	64 Mbps	71 Mbps	*500 Mbps	300 Mbps
Jupiter	83 Kbps	250 Kbps	5 Mbps	15 Mbps	16 Mbps	115 Mbps	70 Mbps
Saturn	24 Kbps	71 Kbps	1.4 Mbps	4 Mbps	4.7 Mbps	33 Mbps	19 Mbps
Neptune	3 Kbps	8 Kbps	160 Kbps	470 Kbps	520 Kbps	3.7 Mbps	2.2 Mbps

Downlink Data Rates

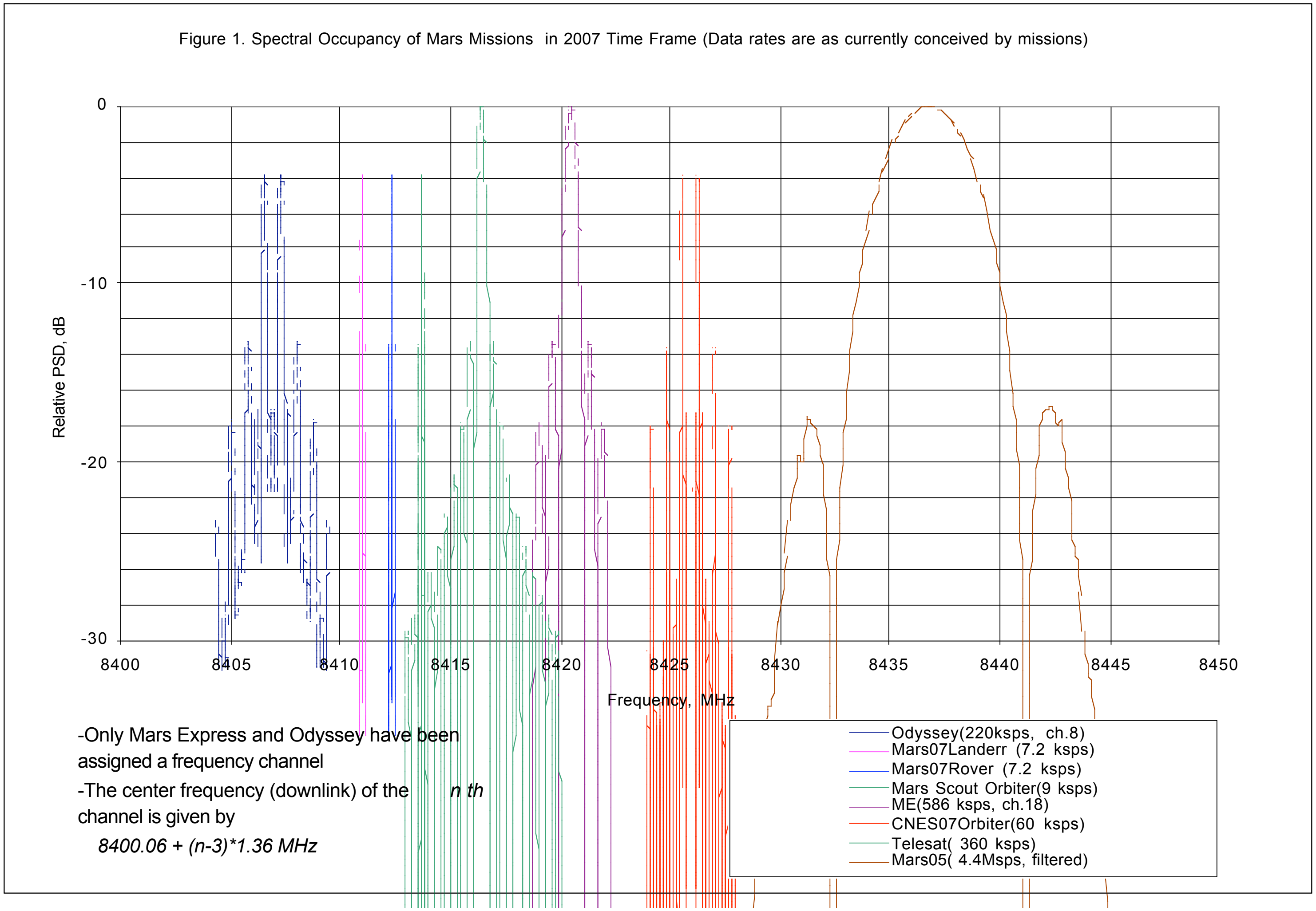


DSN arrives in Code S

Uplink Data Rates

- Today
  - 2 kbps routine
  - Can do 125 kbps [tested with the Across The Universe uplink in Feb 09]
- Coming:
  - UST h/w can handle 16-24 Mbps; link margin will moderate this
  - DSN internally does not have the capability to transmit at such high rates [no reqt to date]s

Spectrum Considerations: Need To Go To Ka Band

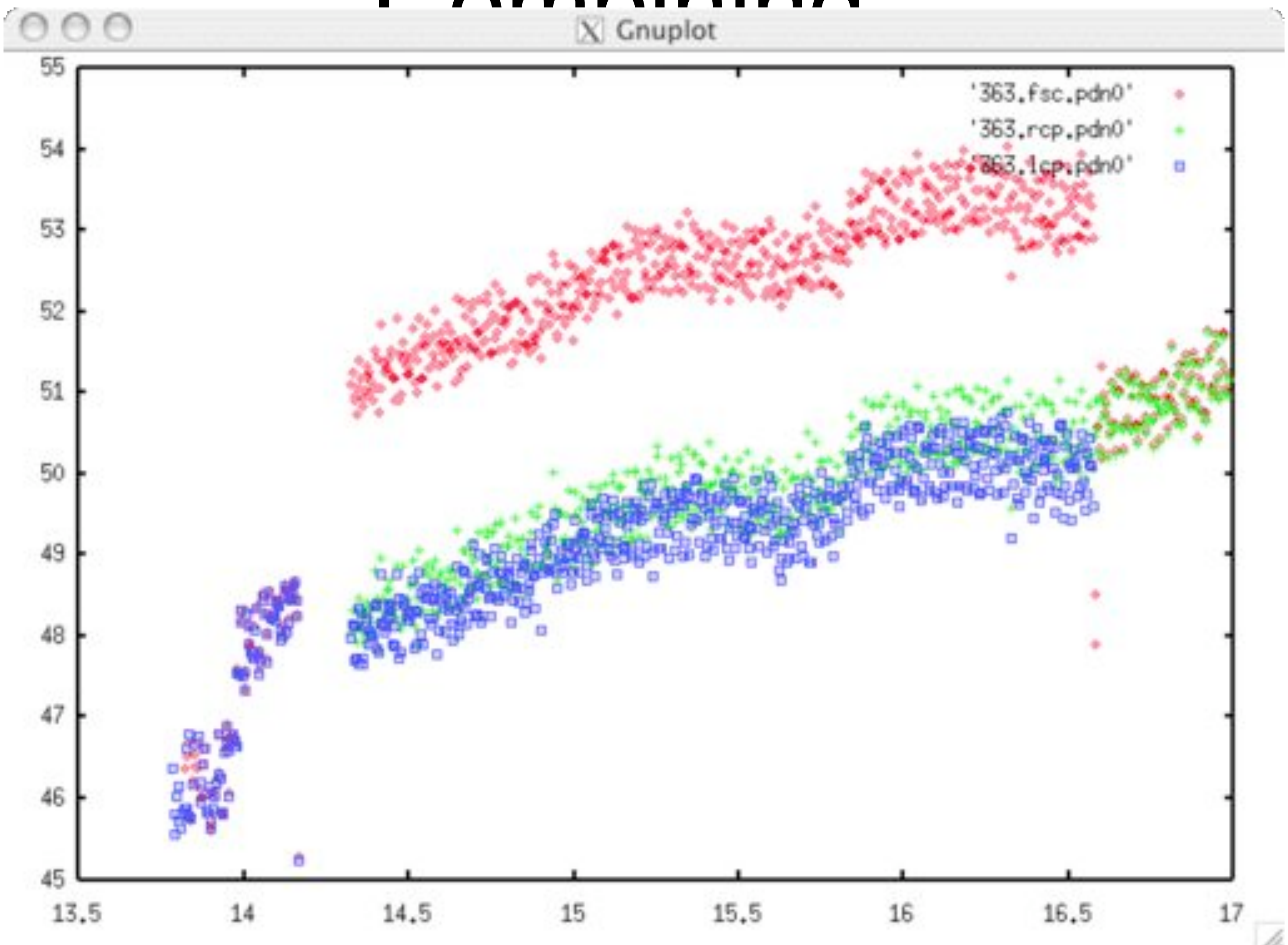


-Only Mars Express and Odyssey have been assigned a frequency channel

-The center frequency (downlink) of the *n th* channel is given by

*8400.06 + (n-3)*1.36 MHz*

Spectrum: Polarization Combining



Navigation

- Emphasis on precision landing
  - Enhances all deep space navigation operations
- Currently; promise 5 nrad (=1 mas) accuracy
  - Usually deliver 2 nrad
- Phoenix test with VLBA:
  - Result 0.3 nrad; will get to 0.1 nrad (=20 μas)

Navigation: VLBA Overview

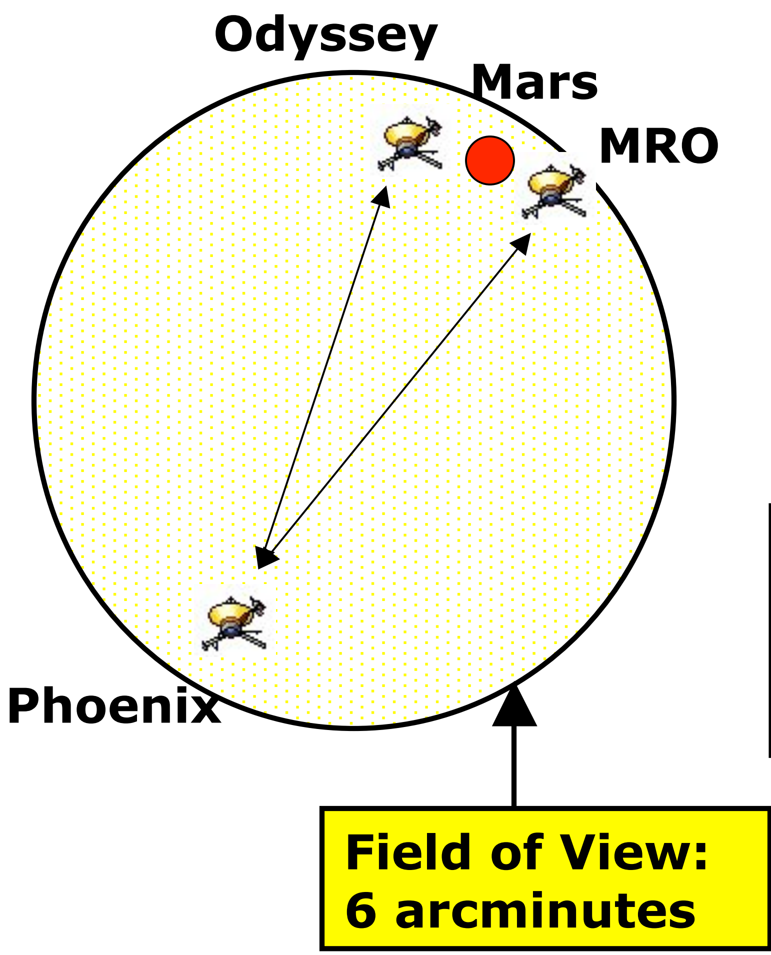
- 10 antennas, baselines from a few hundred to 8,000 km
- X-band (8.4 GHz) installed, X/Ka (8/33 GHz) possible
- Routine dynamic observing

- Astrometric accuracy 10-100 _as (tens of m at Mars)
- Demonstrated s/c capability w/ Cassini, Mars missions
- Current multi-s/c demos w/ Phoenix & Mars orbiters

Navigation: VLBA Benefits for Spacecraft Nav.

1. Establish and maintain inertial reference frame
2. Build dense Ka band quasar catalog on ecliptic
   - Critical for Ka band accuracy
   - Requires substantial observing time
   - Monitor quasars within ~1 degree of trajectory
3. Routine access to negative declinations
4. Navigation possible without stopping telemetry (due to short/long baseline mix)
5. Reduced risk from switching transmission modes on spacecraft
6. Low operations cost

Navigation: Phoenix



Absolute nav precision: 2-5 nrad today

DSN Level 1's call for 0.1 nrad in 2020

_ (orbiters – Phoenix) = 0.3 nrad = 60 _as =50 m on approach; better accuracy in same field of view

Navigation: Cassini test

- DSN is also charged with determining and maintaining the planetary ephemeredes.
- Currently, there is no tie of the outer planets to the quasar reference frame.
  - Rectifying using Cassini as a target source for VLBA
  - observations begun in 2006
- Results: accuracy, better than 10 μas for 3 of 6 epochs; 0.05 nrad = 2 orders of magnitude better than current capabilities
  - This corresponds to 70m at Saturn

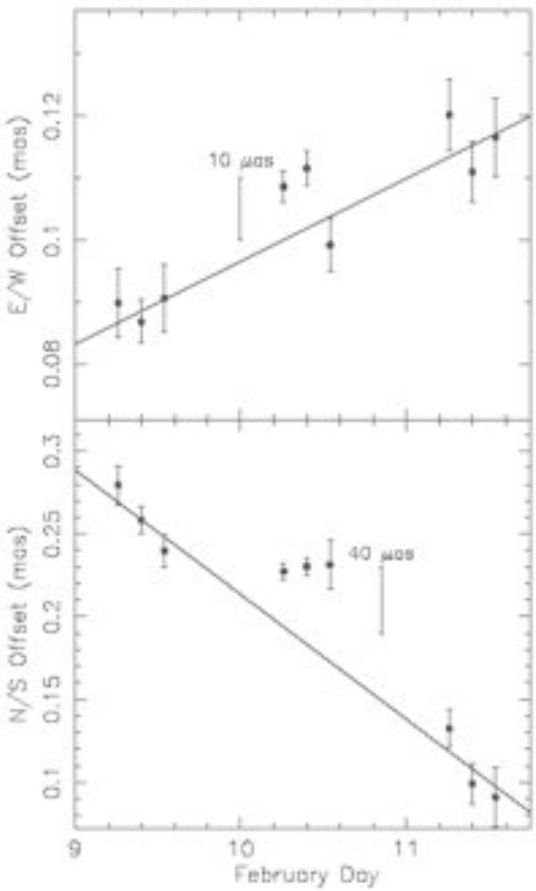
Navigation: Future

- NASA, NSF, and USNO are entering into an agreement to use the VLBA on a routine basis for spacecraft navigation, the inertial reference frame, and Earth orientation parameters
- Start date: FY2011

Summary

- Deep Space Navigation capabilities are improving dramatically
- Deep Space Downlink Rates are poised to increase modestly, ~10x, over the next decade
  - COULD increase orders of magnitude more with infused technology
- Deep Space Uplink Rates likely to remain at 2 kbps for the decade
  - COULD increase orders of magnitude

Backup: Cassini Expt Data



- plot of the measured separation of Cassini - quasar
  - J1112+0724, made with the VLBA at 8 GHz.
- The observations were made on Feb 9, 10, 11/09.
  - Each obs was 6 hours long and a position was determined every two hours, three on each day.
- The Cassini-source separation varied from 2' to 5‘
  - so all were in-beam on all days.
- The solid line shows the linear fit of the separation
  - on Feb 9 and 11. This is caused by a very small offset in the ass Cassini orbit.
- The slight offset of the positions on Feb 10 from the l are caused by the gravitational bending by Saturn of quasar when it passed 1.3‘ away.
  - This is the effect we wanted to measure.
  - The offset we measured agrees with GR.
  - Einstein is always correct.
- The average slope implies a residual drift of Cassini about 5 millimeters/sec from the orbit we were given.
- The scatter in the position offset when you remove th slope and the gravitational effects are about 0.008 mas = 60 meters at Saturn.