

# Future DSN Capabilities

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17 November 2009

# Areas for Discussion

- Recap of the last decade
- Downlink data rates
- Uplink data rates
- Spectrum considerations
- Navigation

# How Far Have We Come?

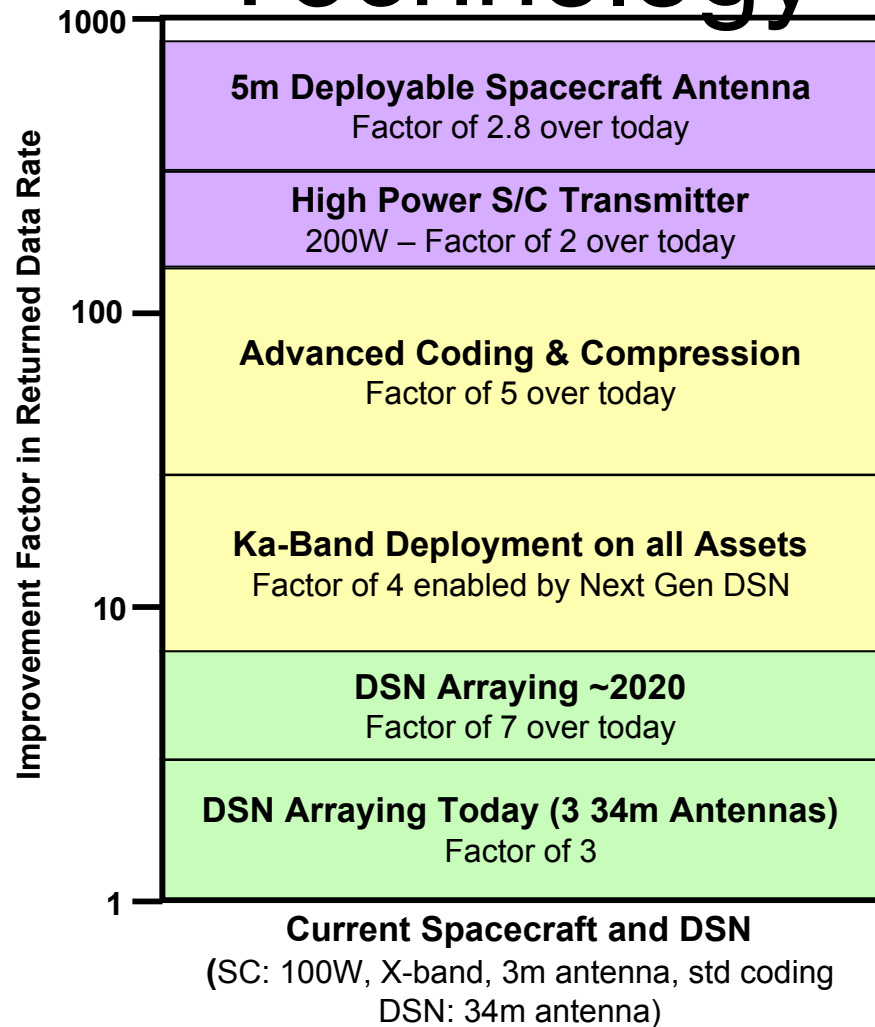
Here are a few of the improvements to the DSN since 2001 when Code S got the responsibility:

- Availability of the various antennas has gone from 94% to >99%
- The reliability has also increased. Missions used to schedule multiple passes to ensure data dumped completely and properly. For example, Stardust scheduled 17 passes to downlink the encounter data. DSN captured it in a single pass.
- DSN is tracking more spacecraft with the same number of antennas [~ 5%; this would be higher but we now schedule maintenance which in turn has led to the higher availability and reliability]
- Data turnaround time. It used to take a day to a week to turn the data around. Now data is available for museums and the press in about one hour.
- Reduced the number of people working on the DSN.
  - JPL: 460 → 265 FTE's [there are still 942 people that touch the DSN during a year.]
  - Madrid: 145 → 120
  - C. Canberra: 145 → 120
  - Monrovia operations [near Pasadena], cost reduction of some 5M/year in labor costs and rent reduction
- Added Ka band
  - For deep space: Kepler and others going forward
  - For near Earth: LRO, JWST etc [backup for GN to ensure mission success]
- Adding Disruption Tolerant Networking è beginning of a true network management structure. Will also be required for Ka band and optical to mitigate weather and other outages.
- Adding high power uplink tubes and arrayed uplink to back up the 70m dish [i.e.- eliminate a single point of success] and enhance emergency comm. capabilities
- **All this on a budget that has remained constant in dollars yet lost 40% of its buying power over the last 7+ years.**

# 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

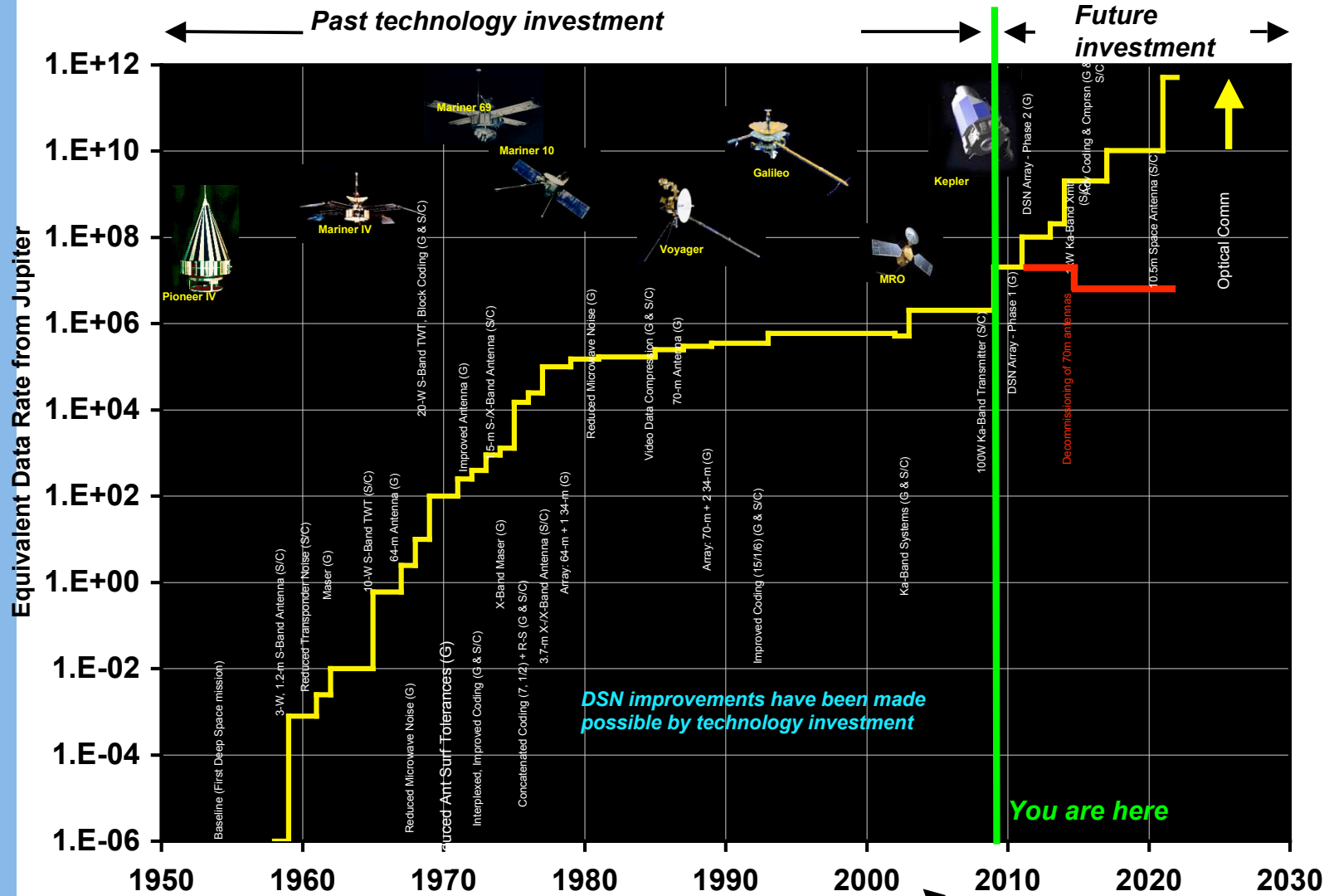
Mission	Data Rate [Mbps]	Frequency	Ground Antenna Equivalent Aperture [m]	s/c TX Power [W]	s/c Antenna Diameter [m]
MRO –today	6	Ka	34	35	3
MRO- what might have been. I.	24	Ka	70	35	3
MRO- what might have been. II.	120	Ka	70	180	3
Next Gen Mars Mission	330	Ka	70	180	5
Next Gen Mars Mission	1200	Ka	70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



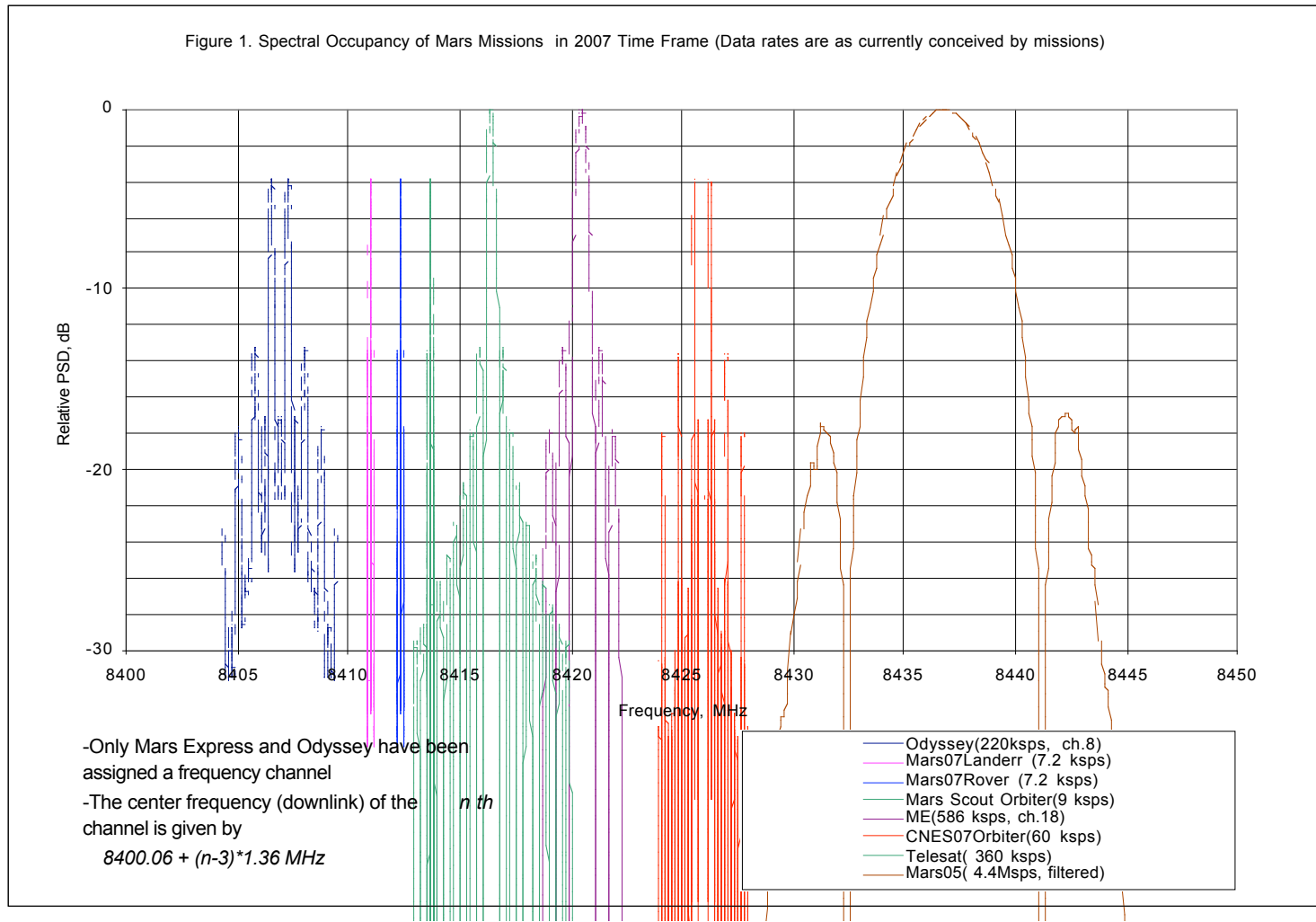
DSN arrives in Code S



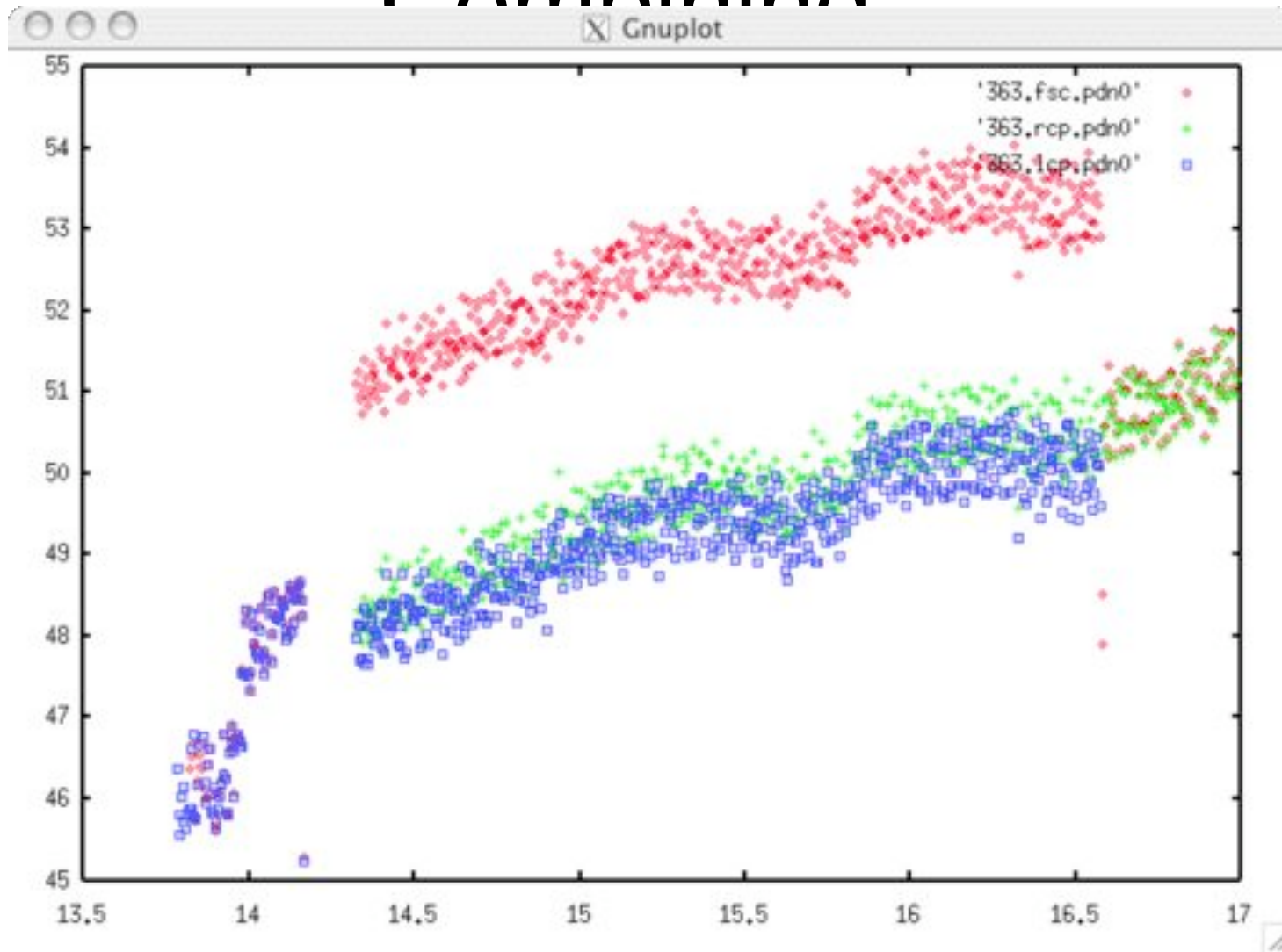
# Uplink Data Rates

- 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



# 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  $\mu$ as)

# Navigation: VLBA Overview

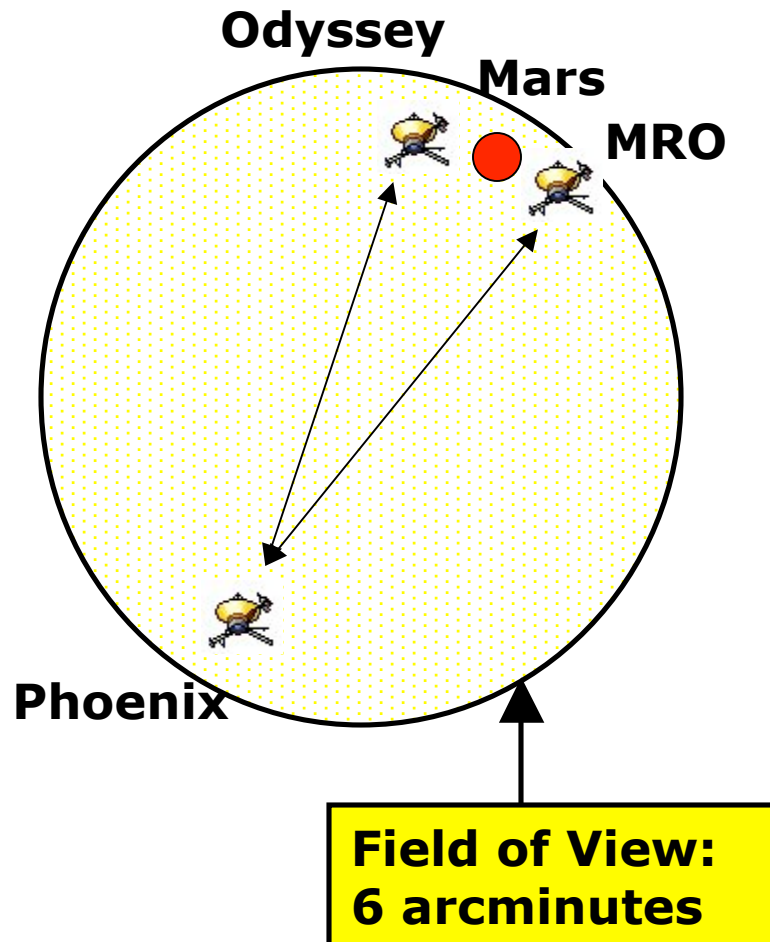


- 10 antennas, baselines from a few hundred to 8,000 km
  - X-band (8.4 GHz) installed, X/Ka (8/33 GHz) possible
  - Routine dynamic observing
- 
- Astrometric accuracy 10-100  $\mu$ as (tens of m at Mars)
  - Demonstrated s/c capability w/ Cassini, Mars missions
  - Current multi-s/c demos w/ Phoenix & 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  $\sim 1$  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

$\Delta$  (orbiters – Phoenix) = 0.3 nrad = 60  $\mu$ 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 ephemerides.
- 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  $10 \mu\text{as}$  for 3 of 6 epochs;  $0.05 \text{ nrad} = 2$  orders of magnitude better than current capabilities
  - This corresponds to 70m at Saturn



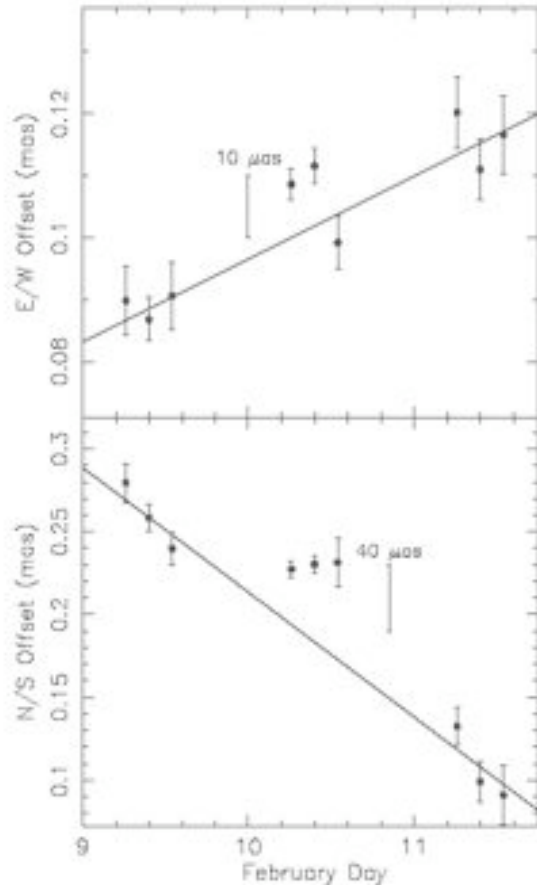
# Navigation: Future

- 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,  $\sim 10x$ , 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 assumed Cassini orbit.
- The slight offset of the positions on Feb 10 from the line are caused by the gravitational bending by Saturn of the 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 of about 5 millimeters/sec from the orbit we were given.
- The scatter in the position offset when you remove the slope and the gravitational effects are about 0.008 mas = 60 meters at Saturn.

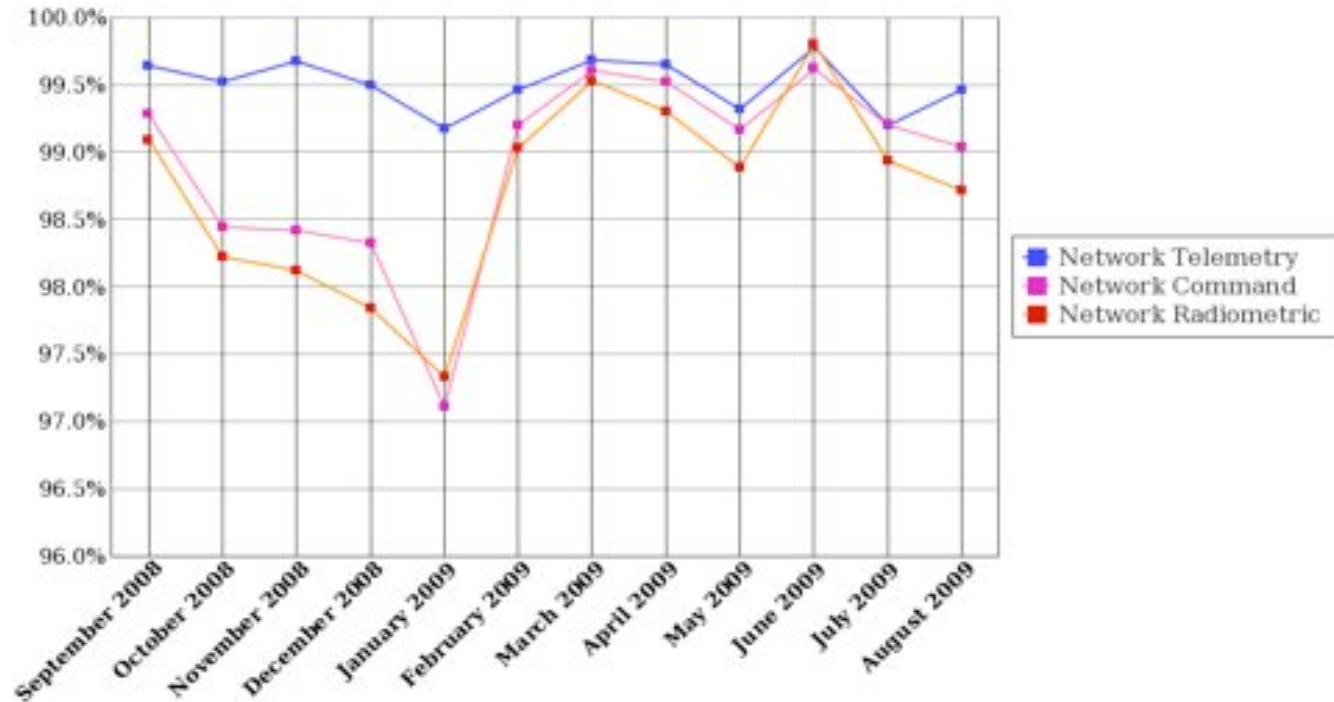
# DSN Network Availability

– September 2008 through August 2009 (Fiscal Months) –

12-Month Rolling Average

Commitment: 95%

Fiscal Month	September 2008	October 2008	November 2008	December 2008	January 2009	February 2009	March 2009	April 2009	May 2009	June 2009	July 2009	August 2009	Total
Network Telemetry	99.64%	99.52%	99.67%	99.50%	99.17%	99.46%	99.69%	99.65%	99.32%	99.77%	99.20%	99.46%	99.51%
Network Command	99.28%	98.45%	98.42%	98.33%	97.11%	99.20%	99.61%	99.52%	99.17%	99.62%	99.20%	99.03%	98.96%
Network Radiometric	99.09%	98.22%	98.12%	97.84%	97.33%	99.03%	99.53%	99.30%	98.89%	99.80%	98.94%	98.72%	98.78%



# DSN Network Telemetry Availability

## – March 23, 2009 thru September 20, 2009 –

Mission	Network Weekly Telemetry Delivery																																	Total	Mission	Lost																																																					
	2009.13	2009.14	2009.15	2009.16	2009.17	2009.18	2009.19	2009.20	2009.21	2009.22	2009.23	2009.24	2009.25	2009.26	2009.27	2009.28	2009.29	2009.30	2009.31	2009.12	2009.31	2009.32	2009.33	2009.34	2009.35	2009.36	2009.37	2009.38	2009.39	2009.40	2009.41	2009.42	2009.43				2009.44	2009.45	2009.46	2009.47	2009.48	2009.49	2009.50	2009.51	2009.52	2009.53	2009.54	2009.55	2009.56	2009.57	2009.58	2009.59	2009.60	2009.61	2009.62	2009.63	2009.64	2009.65	2009.66	2009.67	2009.68	2009.69	2009.70	2009.71	2009.72	2009.73	2009.74	2009.75	2009.76	2009.77	2009.78	2009.79	2009.80	2009.81	2009.82	2009.83	2009.84	2009.85	2009.86	2009.87	2009.88	2009.89	2009.90	2009.91	2009.92	2009.93	2009.94	2009.95	2009.96
<b>Total</b>																																		<b>10,185</b>	<b>Total</b>	<b>10,185</b>																																																					
ACE																																		181	ACE	181																																																					
CAS																																		1,308	CAS	1,308																																																					
CHI																																		132	CHI	132																																																					
CHDR																																		405	CHDR	405																																																					
CLU1																																		6	CLU1	6																																																					
CLU2																																		183	CLU2	183																																																					
CLU3																																		22	CLU3	22																																																					
CLU4																																		15	CLU4	15																																																					
DAWN																																		462	DAWN	462																																																					
DIF																																		60	DIF	60																																																					
GO14																																		0	GO14	0																																																					
GTL																																		96	GTL	96																																																					
INTG																																		17	INTG	17																																																					
KEPL																																		194	KEPL	194																																																					
LCRO																																		14	LCRO	14																																																					
LRO																																		40	LRO	40																																																					
M010																																		715	M010	715																																																					
MAP																																		61	MAP	61																																																					
MER1																																		10	MER1	10																																																					
MER2																																		19	MER2	19																																																					
MEX																																		158	MEX	158																																																					
MRO																																		1,496	MRO	1,496																																																					
MSGR																																		484	MSGR	484																																																					
MUSC																																		85	MUSC	85																																																					
NHPC																																		6	NHPC	6																																																					
SDU																																		10	SDU	10																																																					
SELE																																		0	SELE	0																																																					
SOHO																																		528	SOHO	528																																																					
STA																																		827	STA	827																																																					
STB																																		181	STB	181																																																					
STF																																		695	STF	695																																																					
TDR1																																		13	TDR1	13																																																					
TDR7																																		0	TDR7	0																																																					
TDR8																																		0	TDR8	0																																																					
THB																																		0	THB	0																																																					
THC																																		0	THC	0																																																					
ULYS																																		268	ULYS	268																																																					
VEX																																		0	VEX	0																																																					
VGR1																																		958	VGR1	958																																																					
VGR2																																		527	VGR2	527																																																					
WIND																																		9	WIND	9																																																					

**COLOR KEY**

x >= 95%

x >= 92% / x < 95%

X < 92%

No Tracking

11/17/09

# DSN Network Command Availability

## – March 23, 2009 thru September 20, 2009 –

**Network Weekly Command Delivery**

Mission	2009.12	2009.14	2009.16	2009.18	2009.17	2009.19	2009.20	2009.21	2009.22	2009.23	2009.24	2009.25	2009.26	2009.27	2009.28	2009.29	2009.30	2009.31	2009.12	2009.13	2009.14	2009.15	2009.16	2009.17	Total	Lost	
<b>Total</b>	95.9	95.9	95.9	95.9	95.4	95.7	95.9	95.3	95.1	95.3	95.7	95.9	95.3	95.7	95.9	95.9	95.3	95.7	95.9	95.3	95.2	95.6	95.7	95.3	95.3	<b>9,536</b>	
ACE	95.9	95.9	95.9	95.9	95.4	95.7	95.9	95.3	95.1	95.3	95.7	95.9	95.3	95.7	95.9	95.9	95.3	95.7	95.9	95.3	95.2	95.6	95.7	95.3	95.3	164	164
CAS	95.9	95.9	95.9	95.9	95.4	95.7	95.9	95.3	95.1	95.3	95.7	95.9	95.3	95.7	95.9	95.9	95.3	95.7	95.9	95.3	95.2	95.6	95.7	95.3	95.3	213	213
CH1	95.9	95.9	95.9	95.9	95.4	95.7	95.9	95.3	95.1	95.3	95.7	95.9	95.3	95.7	95.9	95.9	95.3	95.7	95.9	95.3	95.2	95.6	95.7	95.3	95.3	161	161
CHDR	95.9	95.9	95.9	95.9	95.4	95.7	95.9	95.3	95.1	95.3	95.7	95.9	95.3	95.7	95.9	95.9	95.3	95.7	95.9	95.3	95.2	95.6	95.7	95.3	95.3	307	307
DAWN	95.9	95.9	95.9	95.9	95.4	95.7	95.9	95.3	95.1	95.3	95.7	95.9	95.3	95.7	95.9	95.9	95.3	95.7	95.9	95.3	95.2	95.6	95.7	95.3	95.3	866	866
DIF	95.9	95.9	95.9	95.9	95.4	95.7	95.9	95.3	95.1	95.3	95.7	95.9	95.3	95.7	95.9	95.9	95.3	95.7	95.9	95.3	95.2	95.6	95.7	95.3	95.3	45	45
GO14																									100.0	0	
INTG	95.9	95.9	95.9	95.9	95.4	95.7	95.9	95.3	95.1	95.3	95.7	95.9	95.3	95.7	95.9	95.9	95.3	95.7	95.9	95.3	95.2	95.6	95.7	95.3	95.3	37	37
KEPL	95.9	95.9	95.9	95.9	95.4	95.7	95.9	95.3	95.1	95.3	95.7	95.9	95.3	95.7	95.9	95.9	95.3	95.7	95.9	95.3	95.2	95.6	95.7	95.3	95.3	355	355
LCRO																									100.0	147	147
LRO																									100.0	52	52
M010	95.9	95.9	95.9	95.9	95.4	95.7	95.9	95.3	95.1	95.3	95.7	95.9	95.3	95.7	95.9	95.9	95.3	95.7	95.9	95.3	95.2	95.6	95.7	95.3	95.3	826	826
MAP	95.9	95.9	95.9	95.9	95.4	95.7	95.9	95.3	95.1	95.3	95.7	95.9	95.3	95.7	95.9	95.9	95.3	95.7	95.9	95.3	95.2	95.6	95.7	95.3	95.3	136	136
MER1	95.9	95.9	95.9	95.9	95.4	95.7	95.9	95.3	95.1	95.3	95.7	95.9	95.3	95.7	95.9	95.9	95.3	95.7	95.9	95.3	95.2	95.6	95.7	95.3	95.3	28	28
MER2	95.9	95.9	95.9	95.9	95.4	95.7	95.9	95.3	95.1	95.3	95.7	95.9	95.3	95.7	95.9	95.9	95.3	95.7	95.9	95.3	95.2	95.6	95.7	95.3	95.3	120	120
MEX	95.9	95.9	95.9	95.9	95.4	95.7	95.9	95.3	95.1	95.3	95.7	95.9	95.3	95.7	95.9	95.9	95.3	95.7	95.9	95.3	95.2	95.6	95.7	95.3	95.3	93	93
MRO	95.9	95.9	95.9	95.9	95.4	95.7	95.9	95.3	95.1	95.3	95.7	95.9	95.3	95.7	95.9	95.9	95.3	95.7	95.9	95.3	95.2	95.6	95.7	95.3	95.3	982	982
MSGR	95.9	95.9	95.9	95.9	95.4	95.7	95.9	95.3	95.1	95.3	95.7	95.9	95.3	95.7	95.9	95.9	95.3	95.7	95.9	95.3	95.2	95.6	95.7	95.3	95.3	830	830
MUSC																									100.0	100	100
NHPC																									100.0	524	524
SDU																									100.0	0	0
SELE																									100.0	0	0
SOHO	95.9	95.9	95.9	95.9	95.4	95.7	95.9	95.3	95.1	95.3	95.7	95.9	95.3	95.7	95.9	95.9	95.3	95.7	95.9	95.3	95.2	95.6	95.7	95.3	95.3	1,287	1,287
STA	95.9	95.9	95.9	95.9	95.4	95.7	95.9	95.3	95.1	95.3	95.7	95.9	95.3	95.7	95.9	95.9	95.3	95.7	95.9	95.3	95.2	95.6	95.7	95.3	95.3	1,017	1,017
STB	95.9	95.9	95.9	95.9	95.4	95.7	95.9	95.3	95.1	95.3	95.7	95.9	95.3	95.7	95.9	95.9	95.3	95.7	95.9	95.3	95.2	95.6	95.7	95.3	95.3	448	448
STF	95.9	95.9	95.9	95.9	95.4	95.7	95.9	95.3	95.1	95.3	95.7	95.9	95.3	95.7	95.9	95.9	95.3	95.7	95.9	95.3	95.2	95.6	95.7	95.3	95.3	171	171
TDR3																									100.0	16	16
TDR7																									100.0	0	0
TDR8																									100.0	0	0
THB	95.9	95.9	95.9	95.9	95.4	95.7	95.9	95.3	95.1	95.3	95.7	95.9	95.3	95.7	95.9	95.9	95.3	95.7	95.9	95.3	95.2	95.6	95.7	95.3	95.3	86	86
THC	95.9	95.9	95.9	95.9	95.4	95.7	95.9	95.3	95.1	95.3	95.7	95.9	95.3	95.7	95.9	95.9	95.3	95.7	95.9	95.3	95.2	95.6	95.7	95.3	95.3	135	135
VEX																									100.0	0	0
VGR1	95.9	95.9	95.9	95.9	95.4	95.7	95.9	95.3	95.1	95.3	95.7	95.9	95.3	95.7	95.9	95.9	95.3	95.7	95.9	95.3	95.2	95.6	95.7	95.3	95.3	20	20
VGR2	95.9	95.9	95.9	95.9	95.4	95.7	95.9	95.3	95.1	95.3	95.7	95.9	95.3	95.7	95.9	95.9	95.3	95.7	95.9	95.3	95.2	95.6	95.7	95.3	95.3	370	370
WIND	95.9	95.9	95.9	95.9	95.4	95.7	95.9	95.3	95.1	95.3	95.7	95.9	95.3	95.7	95.9	95.9	95.3	95.7	95.9	95.3	95.2	95.6	95.7	95.3	95.3	0	0

11/17/09

**COLOR KEY**

x >= 95%

x >= 92% / x < 95%  
Geldzahler

X < 92%

No Tracking

# DSN Network Radio Metric Availability

## – March 23, 2009 thru September 20, 2009 –

Network Weekly Radio Metric Delivery

Mission	2009-03-23	2009-03-30	2009-04-06	2009-04-13	2009-04-20	2009-04-27	2009-05-04	2009-05-11	2009-05-18	2009-05-25	2009-06-01	2009-06-08	2009-06-15	2009-06-22	2009-06-29	2009-07-06	2009-07-13	2009-07-20	2009-07-27	2009-08-03	2009-08-10	2009-08-17	2009-08-24	2009-08-31	2009-09-07	2009-09-14	2009-09-21	Total	Lost
<b>Total</b>																										<b>11,598</b>			
ACE																										203	ACE		
CAS																										915	CAS		
CH1																										399	CH1		
CHDR																										452	CHDR		
DAWN																										1,192	DAWN		
DIF																										64	DIF		
GO14																										0	GO14		
INTG																										20	INTG		
KEPL																										382	KEPL		
LCRO																										254	LCRO		
LRO																										33	LRO		
M010																										645	M010		
MAP																										178	MAP		
MER1																										5	MER1		
MER2																										5	MER2		
MEX																										77	MEX		
MRO																										2,115	MRO		
MSGR																										987	MSGR		
MUSC																										148	MUSC		
NHPC																										560	NHPC		
SDU																										10	SDU		
SELE																										0	SELE		
SOHO																										862	SOHO		
STA																										1,054	STA		
STB																										501	STB		
STF																										169	STF		
TDR3																										4	TDR3		
TDR7																										0	TDR7		
TDR8																										0	TDR8		
THB																										26	THB		
THC																										195	THC		
VEX																										8	VEX		
WIND																										135	WIND		

11/17/09 **COLOR KEY**  x >= 95%  x >= 92% / x < 95%  X < 92%  No Tracking

Geldzahler

# DSN Service Capabilities

## DSN Service Capabilities

Antenna Dia (m)	Type	Location	OSG No.	S-Band Uplink	ERP (dBW)	S-Band Downlink	S-GAIN / G/T (Note 2) @ 45 deg (dB)	X-Band Uplink	ERP (dBW)	X-Band Downlink	X-GAIN / G/T (Note 2) @ 45 deg (dB)	K-Band Uplink	ERP (dBW)	K-Band Downlink	K-GAIN / G/T (Note 2) @ 45 deg (dB)
26	E.O. <sup>1,4</sup>	Canberra, Australia	46	2025 - 2120 <sup>1</sup>	94.4	2200 - 2300	82.5 / 31.8	-	-	-	-	-	-	-	-
26	E.O. <sup>1,4</sup>	Madrid, Spain	66	2025 - 2120 <sup>1</sup>	94.4	2200 - 2300	82.5 / 31.8	-	-	-	-	-	-	-	-
34	BW3-1 <sup>1,3</sup>	Goldstone, CA USA	24	2025 - 2120 <sup>1</sup>	96.1	2200 - 2300	86.8 / 41.3	7145 - 7190 <sup>7</sup> 7190 - 7235 <sup>7,14</sup>	109.9	8400 - 8500	86.3 / 52.8	-	-	2921.09 <sup>1,15</sup>	77.3/54.3 <sup>1,15</sup>
34	BW3-1 <sup>1,3</sup>	Canberra, Australia	34	2025 - 2120 <sup>1</sup>	96.1	2200 - 2300	86.8 / 40.8	7145 - 7190 <sup>7</sup> 7190 - 7235 <sup>7,14</sup>	109.9	8400 - 8500	86.3 / 53.7	-	-	31800 - 32300 <sup>1,15</sup> 2923928 <sup>1,15</sup>	79.2/55.6 <sup>1,15</sup> 77.3/54.3 <sup>1,15</sup>
34	BW3-1 <sup>1,3</sup>	Madrid, Spain	54	2025 - 2120 <sup>1</sup>	96.1	2200 - 2300	86.8 / 41.2	7145 - 7190 <sup>7</sup> 7190 - 7235 <sup>7,14</sup>	109.9	8400 - 8500	86.3 / 53.7	-	-	2411524 <sup>1,15</sup> 2927110 <sup>1,15</sup>	79.2/54.6 <sup>1,15</sup> 77.3/54.3 <sup>1,15</sup>
34	BW3-2 <sup>1,3</sup>	Goldstone, CA USA	25	-	-	-	-	7145 - 7190 <sup>7</sup> 7190 - 7235 <sup>7,14</sup>	110.0	8400 - 8500	86.4 / 53.7	34200 - 34700 <sup>15</sup> 261110 <sup>1</sup>	108.8 <sup>15</sup>	31800 - 32300	79.0 / 54.1
34	BW3-2 <sup>1,3</sup>	Goldstone, CA USA	26	-	-	-	-	7145 - 7190 <sup>7</sup> 7190 - 7235 <sup>7,14</sup>	109.9	8400 - 8500	86.3 / 55.5	-	-	31800 - 32300	79.1/55.7 <sup>1,15</sup>
34	BW3-2 <sup>1,3</sup>	Madrid, Spain	55	-	-	-	-	7145 - 7190 <sup>7</sup> 7190 - 7235 <sup>7,14</sup>	110.0	8400 - 8500	86.3/55.5	-	-	31800 - 32300	79.1/55.4 <sup>1,15</sup>
34	HEP <sup>1,8</sup>	Goldstone, CA USA	18	-	-	2200 - 2300	86.0 / 40.2	7145 - 7190 <sup>7</sup>	110.1	8400 - 8500 <sup>15</sup>	86.3 / 54.0	-	-	-	-
34	HEP <sup>1,8</sup>	Canberra, Australia	40	2025 - 2110 <sup>1</sup> 2650-3000 <sup>1</sup>	77.8	2200 - 2300	86.0 / 40.2	7145 - 7190 <sup>7</sup>	110.1	8400 - 8500 <sup>15</sup>	86.3 / 54.0	-	-	-	-
34	HEP <sup>1,8</sup>	Madrid, Spain	65	2025 - 2110 <sup>1</sup> 2650-3000 <sup>1</sup>	77.8	2200 - 2300	86.0 / 39.8	7145 - 7190 <sup>7</sup>	110.1	8400 - 8500 <sup>15</sup>	86.3 / 54.0	-	-	-	-
34	H2B <sup>1</sup>	Goldstone, CA USA	27	2025 - 2120 <sup>1</sup>	77.1	2200 - 2300	54.8 / 34.7	-	-	-	-	-	-	-	-
70	D.S. <sup>5</sup>	Goldstone, CA USA	14	2110 - 2120 <sup>1,15</sup>	108.8/118.8	2270 - 2300	83.8 / 81.8	7145 - 7190 <sup>7</sup>	116.1	8400 - 8500	74.8 / 62.9	-	-	-	-
70	D.S. <sup>5</sup>	Canberra, Australia	43	2110 - 2120 <sup>1,15</sup>	108.8/118.8	2270 - 2300	83.8 / 80.9	7145 - 7190 <sup>7</sup>	116.2	8400 - 8500	74.8 / 62.9	-	-	-	-
70	D.S. <sup>5</sup>	Madrid, Spain	63	2110 - 2120 <sup>1</sup>	108.8/118.8	2270 - 2300	83.8 / 80.9	7145 - 7190 <sup>7</sup>	116.3	8400 - 8500	74.8 / 63.1	-	-	-	-

Notes:

1. These stations can be used for Earth Orbiting (Category A) missions.
2. Performance values based on 45 deg. elevation, vacuum condition & Diplexed (if possible) single band mode.
3. These stations are used for Deep Space (Category B) missions.
4. These 25M stations will be closed in the future (FY09).
5. Planned Operational Date.
6. 31800-32300 MHz.
7. Transmit power range: 200 W to 20 KW (23 to 43 dBW).
8. Transmit power range: 50 W to 200 W (17 to 23 dBW).
9. Transmit power range: 200 W to 20 KW (23 to 43 dBW).
10. Transmit power range: 20 KW to 400 KW (43 to 56 dBW).
11. Transmit power range: 50 W to 800 W (17 to 29 dBW).
12. 8200 - 8600 MHz for VLBI Service.
13. Estimated values.
14. Near-Earth spectrum.
15. 25500-27000 MHz (Ka2)



# 34m Antennas Equivalent to the Performance of a 70m

- 70m 8.4GHz G/T = 63.1 dBK (Best 70, DSS 63 Madrid)
  - 45° Elevation and Vacuum
- 34m BWG-2 G/T = 55.5 dBK (Assumes Best 34M, DSS 26 Goldstone)
  - 45° Elevation and Vacuum
- $10^{[(63.1-55.5)/10]} = 5.75$  \_ 6 reflectors @ 55.5dBK
- Additional number needed (no spares & 0.1dB combining loss) at:
  - Goldstone 3            BWG1 (-2.7dB), 2xBWG2, HEF (-1.5dB)
  - Madrid 4                BWG1 (-1.8dB), BWG2, HEF (-1.5dB)
  - Canberra 5             BWG1 (-1.8dB), HEF (-1.5dB)
  - No element similarity advantage for arraying ...
- 12m G/T = 58.9dB – 13.5dBK = 45.4dBK
  - Estimated, 45° Elevation and CD [a relative humidity measure] = 0.9 (note change from Vacuum- i.e.: assume no tropospheric effects)
- $10^{[(62.0-45.4)/10]} = 45.71$  \_ 46x 12m to “match” 70m
- $10^{[(54.4-45.4)/10]} = 7.94$  \_ 8x 12m to “match” 34m
- 70M Performance & Mission Requirements Requires up to 15 New 34M Antennas Across the 3 DSN Sites

**Geometrically, only 4 34m dishes are equivalent to a 70m- plus 1 additional to endure continual 70m capacity. To match performance of the 70m antennas, need six 34m antennas**

# Sky Coverage

- A wide field of view (FOV) is highly desirable
  - Support of S/C positioning with respect to background quasars
    - Many weak as well as strong quasars
  - Faster search and acquisition of signals
    - Large area with full G/T seen at once
    - Mitigates mechanical scanning, transient signal issues
      - E.g., S/C emerges from behind planet in wrong orbit; Mid Course Correction errors, S/C emergency
  - Potential for multiple independent electronically steered beams with one group of mechanically pointed reflectors
  - Simultaneous Tx/Rx with large light time delay and one mechanical pointing

12m elements provide about 8 times greater coverage than 34m

# Spacecraft Navigation

- Precision measurement of s/c location with respect to background quasars [ICRF and high frequency extension]
- Angular separation usually measured with VLBI
  - High potential for precision reduced by troposphere, clock sync and other errors
  - Limited mutual visibility from DSN sites
  - Very high precision measurements [Cassini, Phoenix data]
- Couple with Very Long baseline Array
  - Potential for accurate tracking most of the time
  - Having enough suitable quasars within main beam means “limiting array antenna to 12m” (D. S. Bagri, JPL, Nov. 2007)