Lecturer Series

ASTRONOMY

FH Astros

UNIVERSITY OF APPLIED SCIENCES UPPER AUSTRIA

Kurt.Niel@fh-wels.at - August 2017

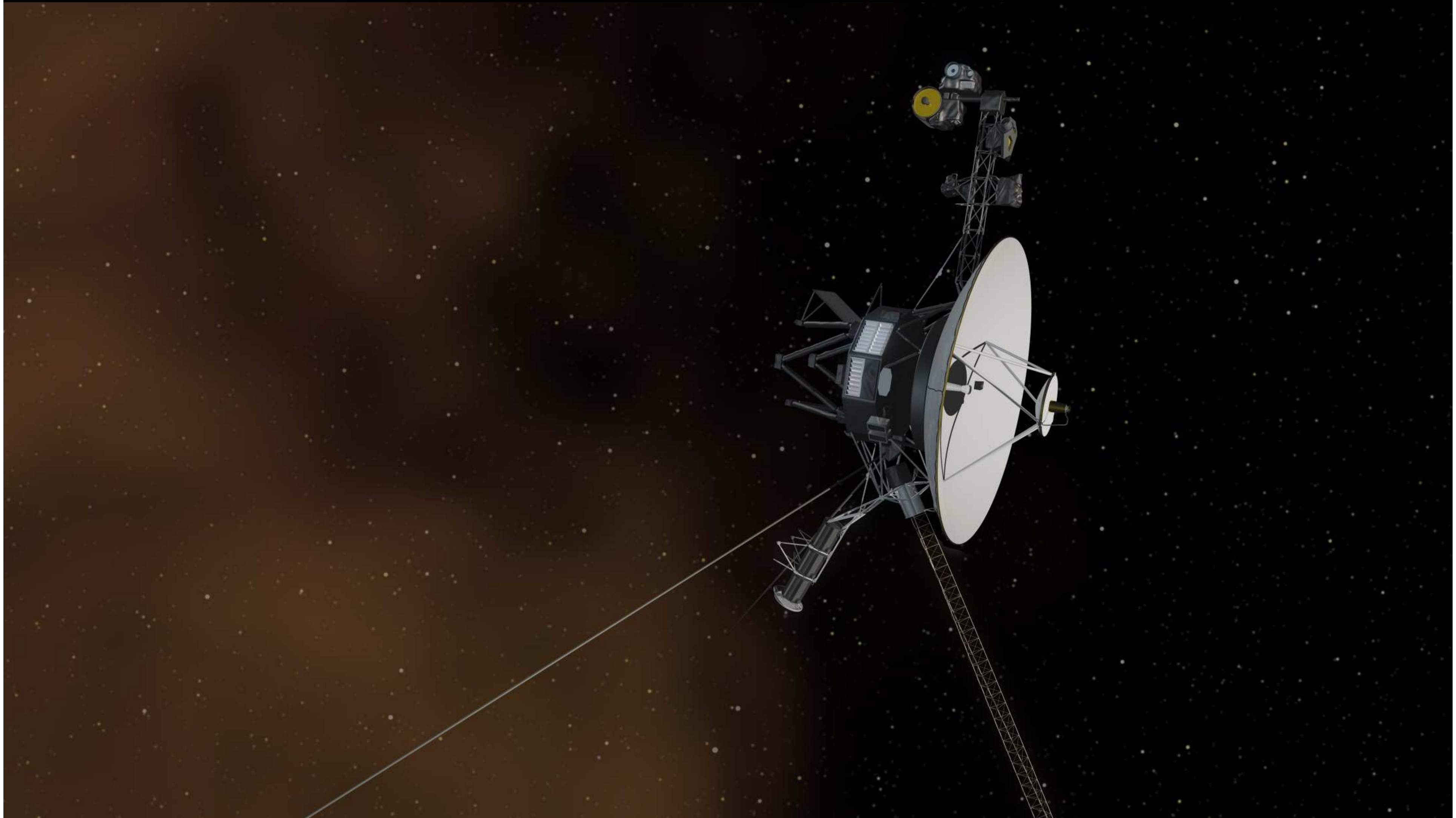
Lecturer Series

ASTRONOMY

FH Astros

Telecommunication with Space Craft

Kurt Niel (University of Applied Sciences Upper Austria)



VOYAGER 1, 2 Start 1977; now end of solar system (139 AU[1]) – c 19:16:55 h)

Technical data (communication via Deep Space Network DSN)

- Launch mass 835 - 733 kg (loosing weight / fuel consumption)
- Power supply Radioisotope thermoelectric generator (3 pcs.) - 315 W
- Antenna 3.7 m High Gain paraboloid
- Transmission power 6.6 W – 18 W

Transmission channel:

- Uplink S-Band (2.7 – 3.5 GHz) - 16 b/s
- Downlink X-Band (8.4 – 8.5 GHz) - 160 b/s normal / **1.4 kb/s high-rate**

E.g. Plasma Wave Subsystem PWS

- Recording per week 48 s PWS-signal
  with 115.2 kb/s on Digital Tape Recorder DTR
- These data are received every 6 months via 70 m DSN

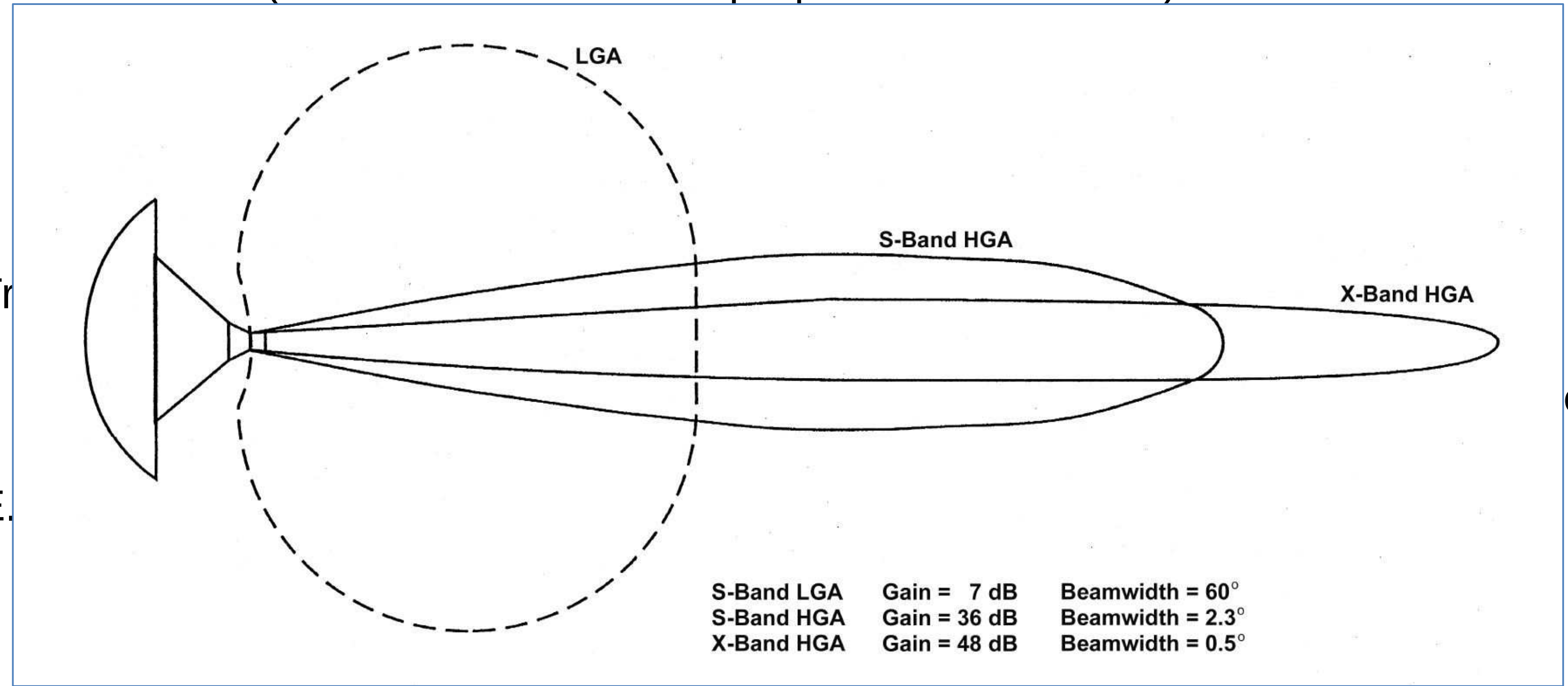
E.g. Imaging Science Subsystem ISS (switched off 1990 to save power)

- resolution (BW-Camera with filter wheel) per channel
  895 x 848 Pixel = 758 960 Byte → **transmission 1:15 h per channel**

[1]) AU - astronomical unit = 149.6 Mio km (Distance Sun - Earth)

VOYAGER 1, 2 Start 1977; now end of solar system (139 AU[1)] – c 19:16:55 h)

Technical data (communication via Deep Space Network DSN)



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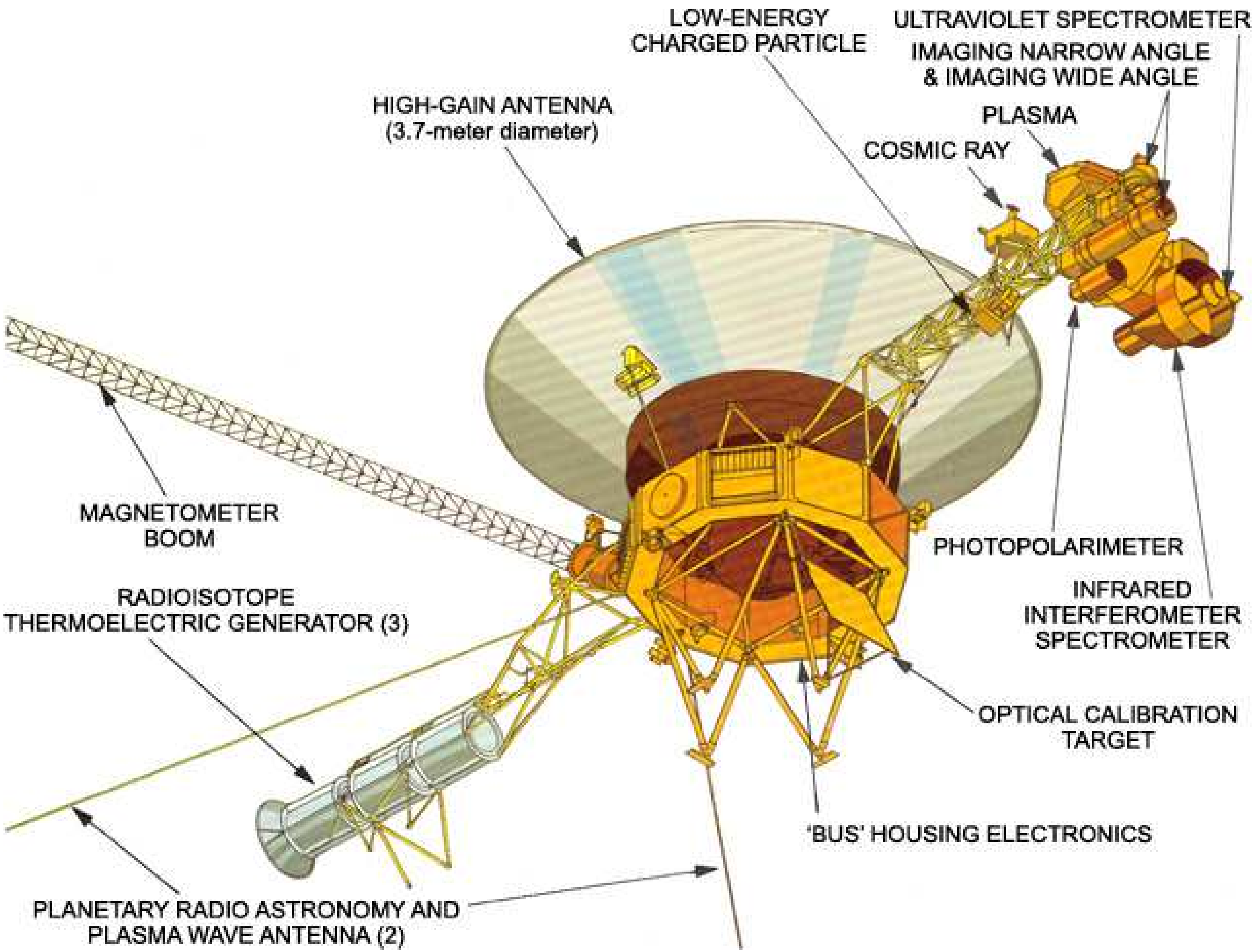

LOW-ENERGY CHARGED PARTICLE
ULTRAVIOLET SPECTROMETER
IMAGING NARROW ANGLE & IMAGING WIDE ANGLE
HIGH-GAIN ANTENNA (3.7-meter diameter)
PLASMA
COSMIC RAY
MAGNETOMETER BOOM
PHOTOPOLARIMETER
RADIOISOTOPE THERMOELECTRIC GENERATOR (3)
INFRARED INTERFEROMETER SPECTROMETER
OPTICAL CALIBRATION TARGET
'BUS' HOUSING ELECTRONICS
PLANETARY RADIO ASTRONOMY AND PLASMA WAVE ANTENNA (2)

BASICS (SOME) TELECOMMUNICATION

- Free space loss
- Antenna gain
- Signal to noise ratio
- Bit error vs. Signal to noise ratio
- Receivers noise

$$S_{dB} = 10.\log S$$

$$P_{dBm} = 10.\log P_{mW}$$

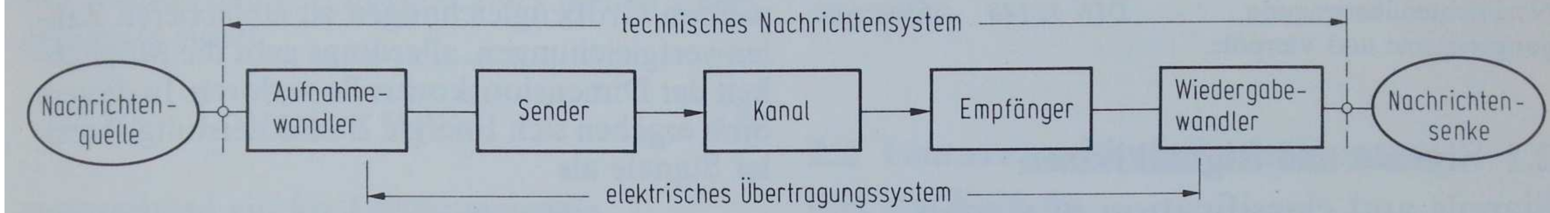


Bild 1. Allgemeines Schema einer Nachrichtenübertragung

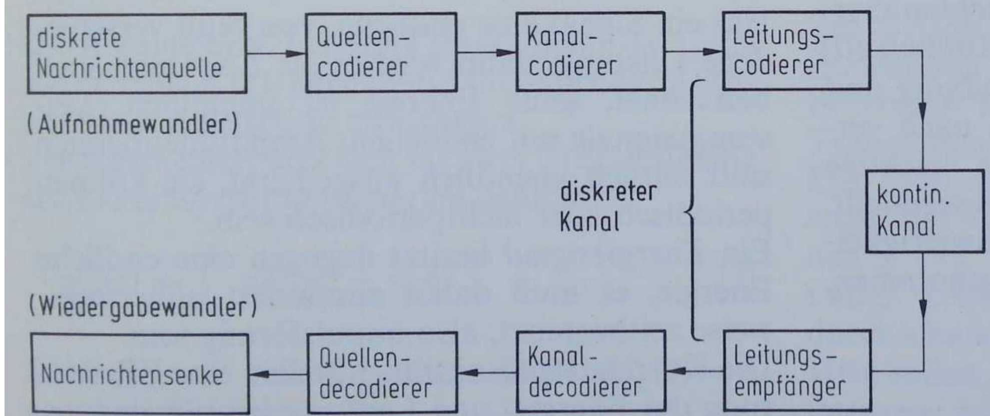


Bild 2. Schema eines digitalen Übertragungssystems

1) Received power
(isotropic)

$$P_{ri} = S.A_W = \frac{P_{ti}}{4\pi r^2} \cdot \frac{\lambda^2}{4\pi}$$

P_{ri} .. Received power isotropic [W]
S .. Radiation power density [W/m²]
A_w .. Effective antenna area
P_{ti} .. Transmitted power isotropic [W]
r .. Distance sender > receiver [m]
λ .. Wavelength [m]

2) Free space loss
(isotropic antennas)

$$F_i = \frac{P_{ti}}{P_{ri}} = \left(\frac{4\pi r.f}{c}\right)^2$$

F_i .. Free space loss [1]
P_{ti} .. Transmitted power isotropic [W]
P_{ri} .. Received power isotropic [W]
r .. Distance sender > receiver [m]
f .. Frequency [Hz]
c .. Light speed [m/s]

$$F_{i,dB} = 10\log(F_i)$$
$$F_{i,dB} = 20\log(r) + 20\log(f) - 147{,}55$$

Connection	Frequency	Distance	Free space loss isotropic
TV-Satellite	S-Band – 3 GHz	36 000 km	193 dB
Rosetta	S-Band – 3 GHz	1,4 AU = 214 Mio km	269 dB
Voyager	S-Band – 3 GHz	48,6 AU = 7 290 Mio km	296 dB
Voyager	X-Band – 8 GHz	48,6 AU = 7 290 Mio km	308 dB
Voyager	S-Band – 3 GHz	133,0 AU = 20 000 Mio km	308 dB

3) *Friis*-Transmission-equation

$$\frac{P_r}{P_t} = G_t G_r \left(\frac{\lambda}{4\pi r}\right)^2$$

$$\frac{P_r}{P_t} = \frac{G_t G_r}{F_i}$$

P_t .. Transmission power [W]
P_r .. Receiving power [W]
G_t .. Antenna gain sender
G_r .. Antenna gain receiver
r .. Distance sender > receiver [m]
λ .. Wavelength [m]

4) Antenna gain paraboloid

$$G = \frac{4\pi}{\lambda^2} . A . \eta_{eff}$$

$$G = \left(\pi \frac{d}{\lambda}\right)^2 . \eta_{eff}$$

G .. Antenna gain [1] [dB]
λ .. Wavelength [m]
A .. Antenna area [m²]
d .. Antenna aperture [m]
η_{eff} .. Effectiveness 0,8..0,99 [1]

G [dBi] .. Gain against isotropic antenna

5) Received power

$$P_{r,dBm} = P_{t,dBm} + G_{t,dB} + G_{r,dB} - F_{i,dB}$$

6) Received power gap over power density of the receivers noise N_0

$$P_{r,dBm}/N_0 = P_{r,dBm} - N_0$$

… Measure of „usability“ of the receiver signal

7) Transmission rate
(Shannon-Hartley)

$$C = B.log_2\,(1 + \frac{S}{N})$$

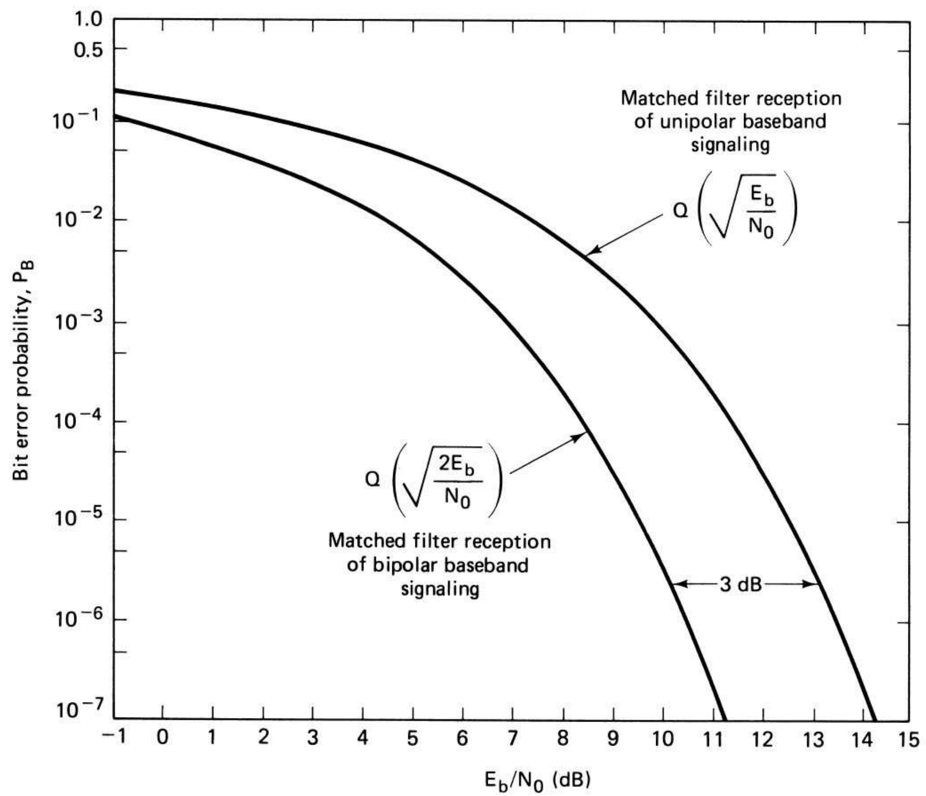
C .. Ideal transmission rate [bps]
B .. Bandwidth [Hz]
S .. Signal power [W] od. [$\sqrt{V}$]
N .. Noise power [W] od. [$\sqrt{V}$]
S/N .. Signal to noise ration [1] [dB]

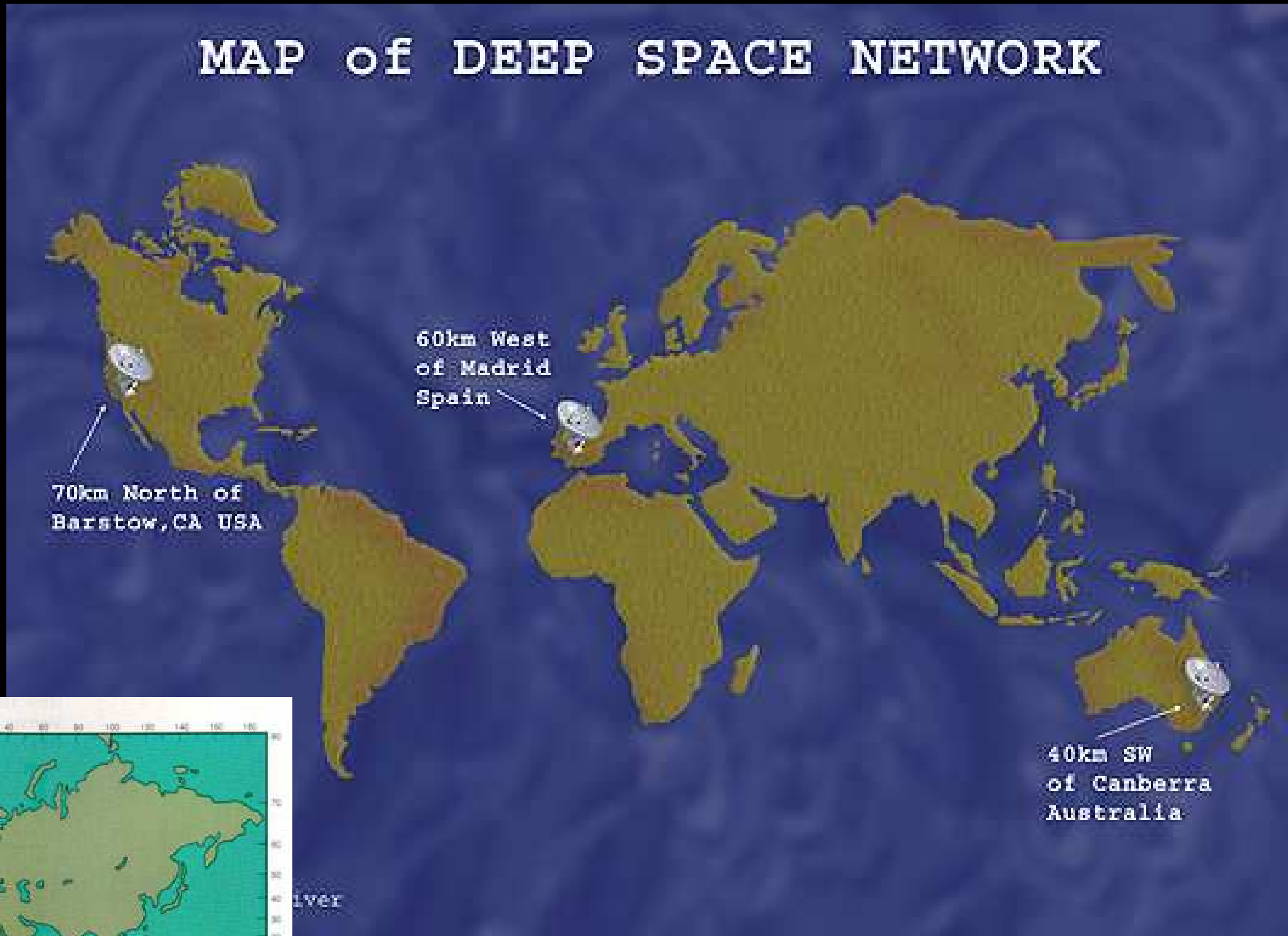
8) Bit error rate = measure for the quality of the transmission of one channel
(number of errors per time unit) - measurement

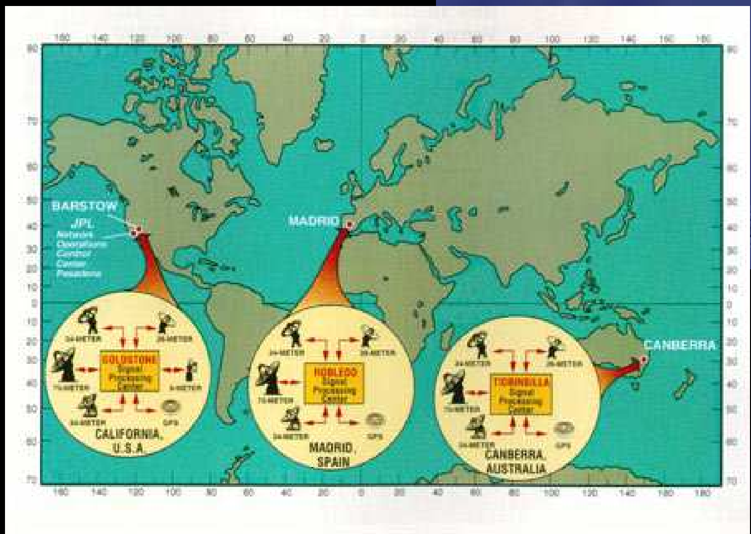
9) Bit error probability
(probability for appearance of a bit error)
- calculation

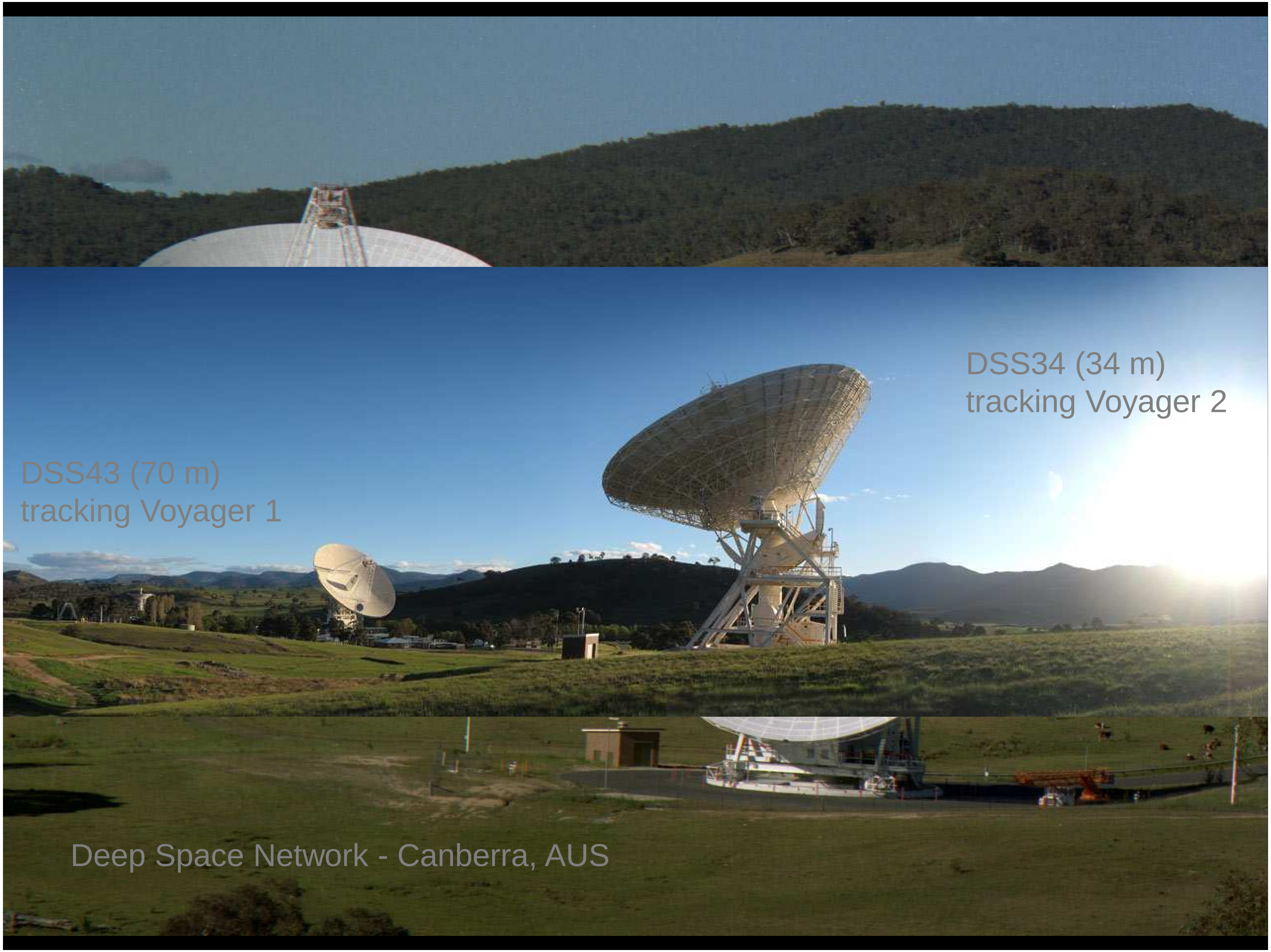
P_B .. Bit error probability
E_b .. Energy of information bit
N_0 .. Spectral noise power density

… Hint that by increasing gap received power to receivers noise the bit error probability decreases.




MAP of DEEP SPACE NETWORK
60km West
of Madrid
Spain
70km North of
Barstow,CA USA
40km SW
of Canberra
Australia


BARSTOW
JPL
MADRID
CANBERRA
GOLDSTONE
CALIFORNIA, U.S.A.
MADRID, SPAIN
CANBERRA, AUSTRALIA


DSS34 (34 m)
tracking Voyager 2
DSS43 (70 m)
tracking Voyager 1
Deep Space Network - Canberra, AUS

CARRIER DESIGN

(*„Descanso"-Document*)

- Earth → Spacecraft 2.1 GHz

Table 5-2. Voyager 2 uplink carrier design control table.

Voy 2 (JSX), 70m/18 kW/12 Hz, 0 dB Rng, 0 dB Cmd, Clr Wthr
X-Band TWT LP, HGA/NLC, 160 bps Coded, 2-Way Radio Losses

Spacecraft 2 — Station 43
Time in Mission 96/001/00/00 — Time from Epoch 35065 00:00

	Parameter	Design	Fav Tol	Adv Tol	Mean	Variance
	Transmitter Parameters					
	1) RF Power, dBm	72.55	0.50	–0.50	72.6	0.04
	Power Output = 18.0 kW					
	Transmit Circuit Loss, dB	0.00	0.00	0.00	0.0	0.00
Aperture 70 m	2) Antenna Gain, dBi	62.10	0.30	–0.70	61.9	0.08
	Elev Angle = 58.01 deg					
	3) Pointing Loss, dB	–0.03	–0.03	–0.03		
	Path Parameters					
	4) Space Loss, dB	–296.18			–296.2	0.00
	Freq = 2113.31 MHz					
	Range = 7.273+09 km					
	= 48.62 AU					
	5) Atmospheric Attenuation, dB	–0.04	0.00	0.00	0.0	0.00
	Receiver Parameters					
	6) Polarization Loss, dB	–0.12	0.12	–0.18		
Aperture 3.7 m	7) Antenna Gain, dBi	34.60	0.39	–0.39	34.5	0.03
	8) Pointing Error, dB	–0.10	0.10	–0.10	–0.1	0.00
	Limit Cycle, deg	0.05	–0.05	0.00		
	Angular Errors, deg	0.00	0.00	0.00		
	9) Rec Circuit Loss, dB	0.00	0.00	0.00	0.0	0.00
Receiver noise	10) Noise Spec Dens, dBm/Hz	–166.71	–0.10	0.16	–166.7	0.00
	Operating Temp, K	1545.00	–34.00	59.00		
	Hot Body Noise, K	0.00	0.00	0.00		
Necessary gap for bit error safety	11) Carr Thr Noise, BW, dB-Hz	12.72	–0.24	0.23	12.7	0.01
	Power Summary					
	12) Rcvd Power, P_t, dBm (1+2+3+4+5+6+7+8+9)				–127.4	0.16
	13) Rcvd P_t/N_0, dB-Hz (12–10)				39.2	0.16
	14) Ranging Suppression, dB	0.00	0.00	0.00	0.0	0.00
	15) Command Suppression, dB	0.00	0.00	0.00	0.0	0.00
	16) Carr Pwr/Tot Pwr, dB (14–15)				0.0	0.00
	17) Rcvd Carr Pwr, dBm (12+16)				–127.4	0.16
Remaining gap for bit error safety	18) Carr SNR in 2BLO, dB (17–10–11)				26.5	0.17
					2.0S =	0.80

CARRIER DESIGN

(„*Descanso“-Document*)

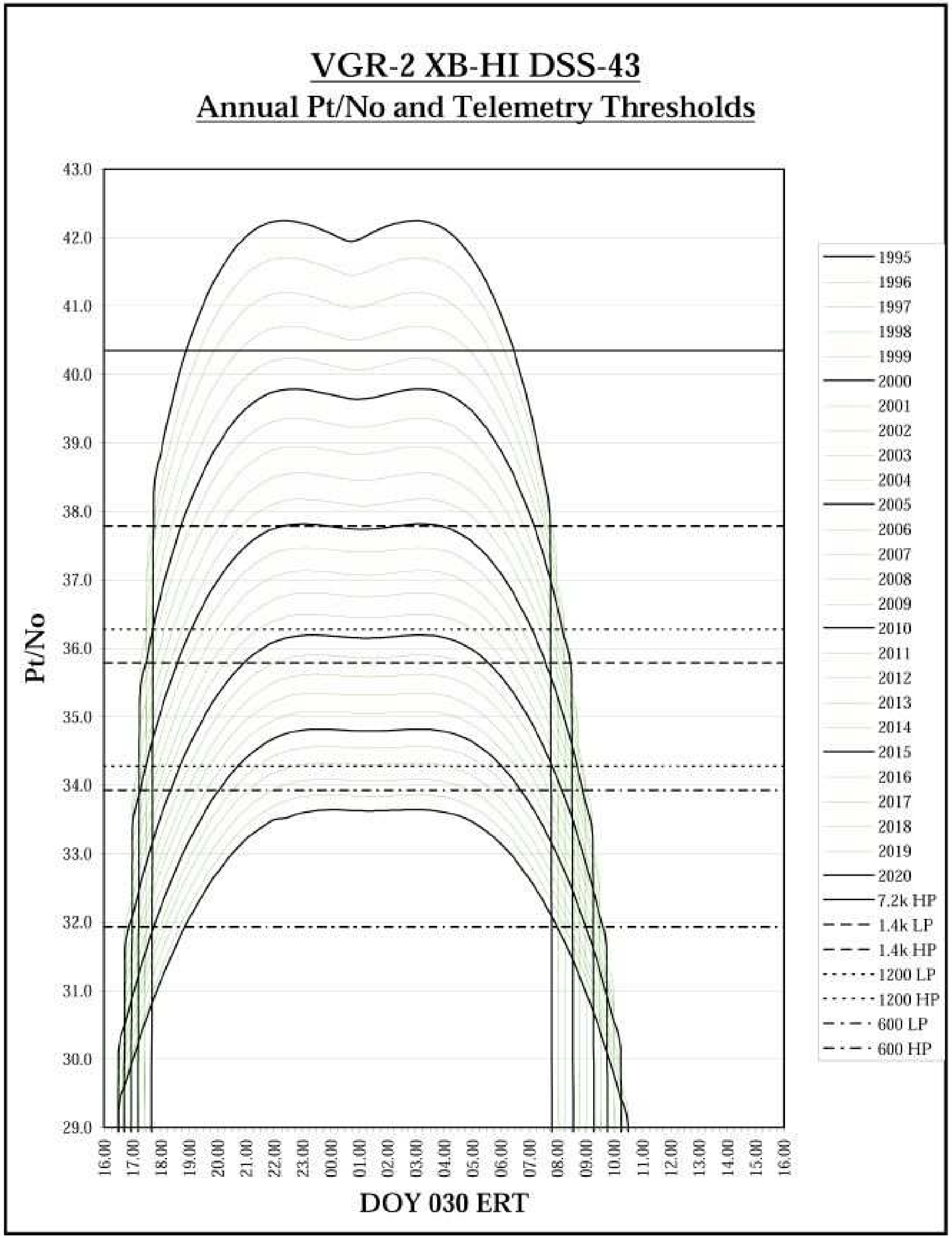
- Spacecraft → Earth
  8.4 GHz

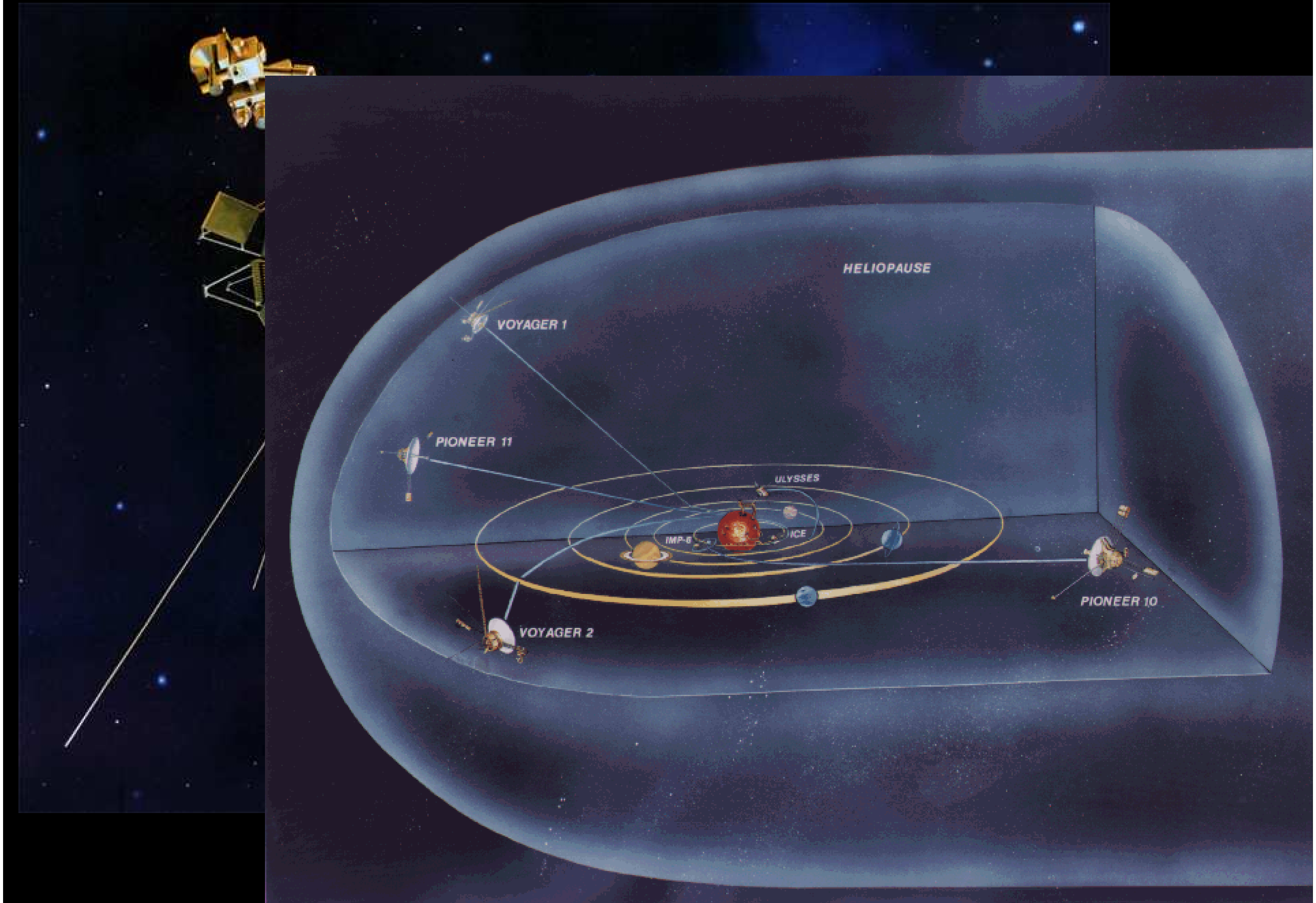
Table 5-3. Voyager 2 downlink carrier design control table.

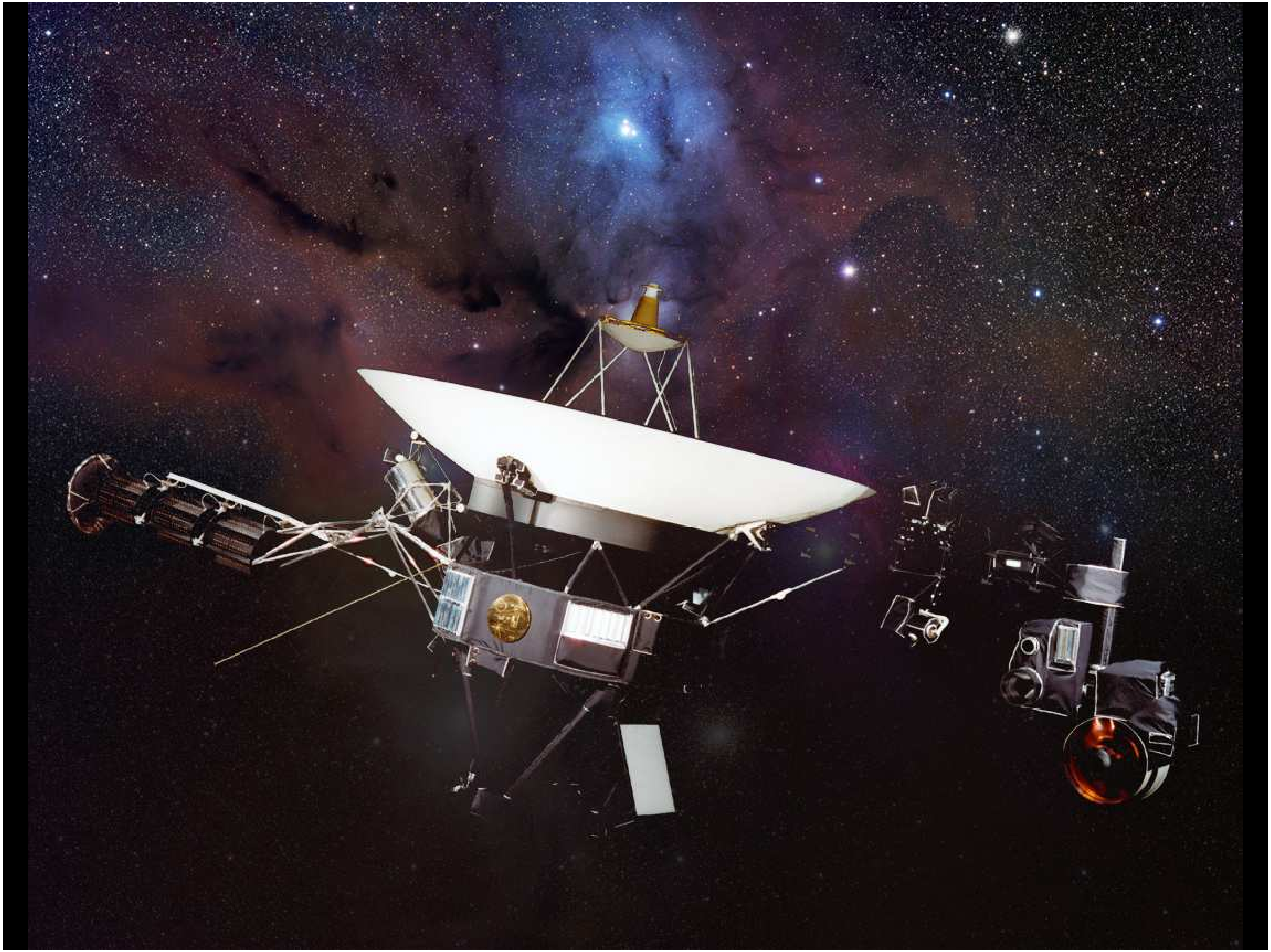
Note	Voy 2 (JSX), 70m/18 kW/12 Hz, 0 dB Rng, 0 dB Cmd, Clr Wthr X-Band TWT LP, HGA/NLC, 160 bps Coded, 2-Way Radio Losses					
	Spacecraft 2 Time in Mission 96/001/00/00		Station 43 Time from Epoch 35065 00:00			
		Design	Fav Tol	Adv Tol	Mean	Variance
	Transmitter Parameters					
	1) RF Power to Antenna, dBm				40.9	0.04
12.3 W	Transmitter Power, dBm	40.90	0.50	–0.50	40.9	0.04
	Transmit Circuit Loss, dB	0.00	0.00	0.00	0.0	0.00
	2) Antenna Circuit Loss, dB	0.00	0.30	0.00	0.0	0.00
Aperture 3.7 m	3) Antenna Gain, dBi	48.20	0.26	–0.26	48.2	0.01
	4) Pointing Error, dB	–0.10	0.10	–0.10	–0.1	0.00
	Limit Cycle, deg	0.05	–0.05	0.00		
	Angular Errors, deg	0.00	0.00	0.00		
	Path Parameters					
	5) Space Loss, dB Freq = 8415.00 MHz Range = 7.273+09 km = 48.62 AU	–308.19			–308.2	0.00
	6) Atmospheric Attenuation, dB	–0.04	0.00	0.00	0.0	0.00
	Receiver Parameters					
	7) Polarization Loss, dB	–0.08	0.08	–0.11		
Aperture 70 m	8) Antenna Gain, dBi	74.01	0.60	–0.60	73.7	0.14
	9) Pointing Loss, dB	–0.20	0.20	–0.20		
Receiver noise	10) Noise Spec Dens, dBm/Hz	–185.35	–0.97	0.80	–185.4	0.09
	Total System Noise Temp, K	21.12	–4.24	4.24		
	Receiver Temperature, K	13.20	–3.00	3.00		
	Ground Contribution, K	2.88	–3.00	3.00		
	Galactic Contribution, K	2.68	0.00	0.00		
	Atmospheric Contrib, K	2.36	0.00	0.00		
	Hot Body Noise, K	0.00	0.00	0.00		
	Elev Angle = 58.01 deg					
Necessary gap for bit error safety	11) Carr Thr Noise, BW, dB-Hz	14.77	–0.46	0.41	14.8	0.03
	Power Summary					
	12) Rcvd Power, P_t, dBm (1+2+3+4+5+6+7+8+9)				–145.5	0.19
	13) Rcvd P_t/N_0, dB-Hz (12–10)				39.9	0.28
	14) Ranging Suppression, dB	–0.22	0.05	0.05	–0.2	0.00
	15) Telemetry Suppression, dB	–6.02	0.16	–0.17	–6.0	0.00
	16) Carr Pwr/Tot Pwr, dB (14+15)				–6.2	0.00
	17) Rcvd Carr Pwr, dBm (12+16)				–151.7	0.20
Remaining gap for bit error safety	18) Carr SNR in 2BLO, dB (17–10–11)				19.0	0.31
					2.0S =	1.10

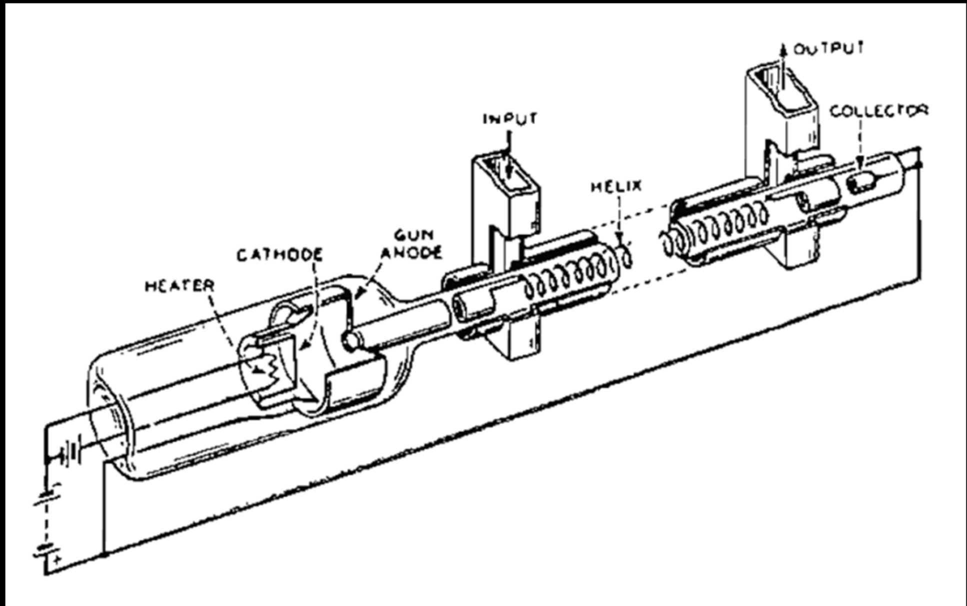
LONG TERM FORECAST 1995 until 2020

- Downlink
- Signal get weaker due to increasing distance
- Transmission rate decreasing du to necessary transmission safety




HELIOPAUSE
VOYAGER 1
PIONEER 11
ULYSSES
IMP-8
ICE
PIONEER 10
VOYAGER 2





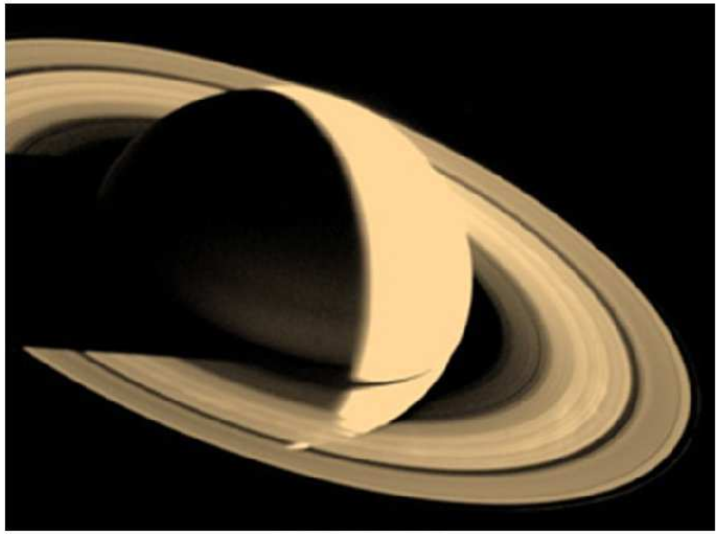
TWTA
Travelling Wave Tube Amplifier
Power amplifier for transmitter
S-/X-Band

MARINER (11-12) JUPITER /SATURN
VOYAGER 1 & 2

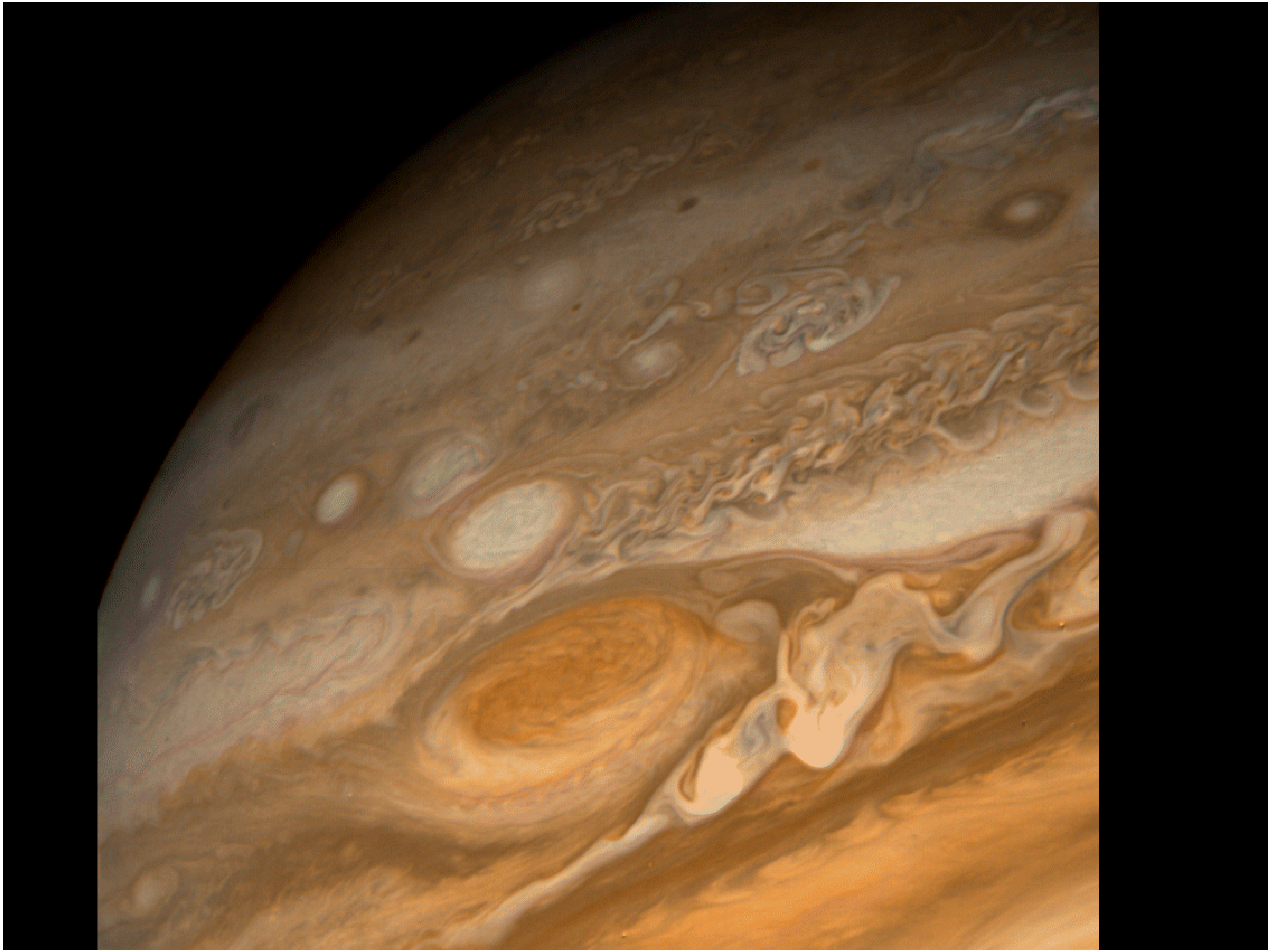
VOYAGER VIDICON (1977)

Explorering Jupiter, Saturn, Uranus, Neptune and Interstellar space.

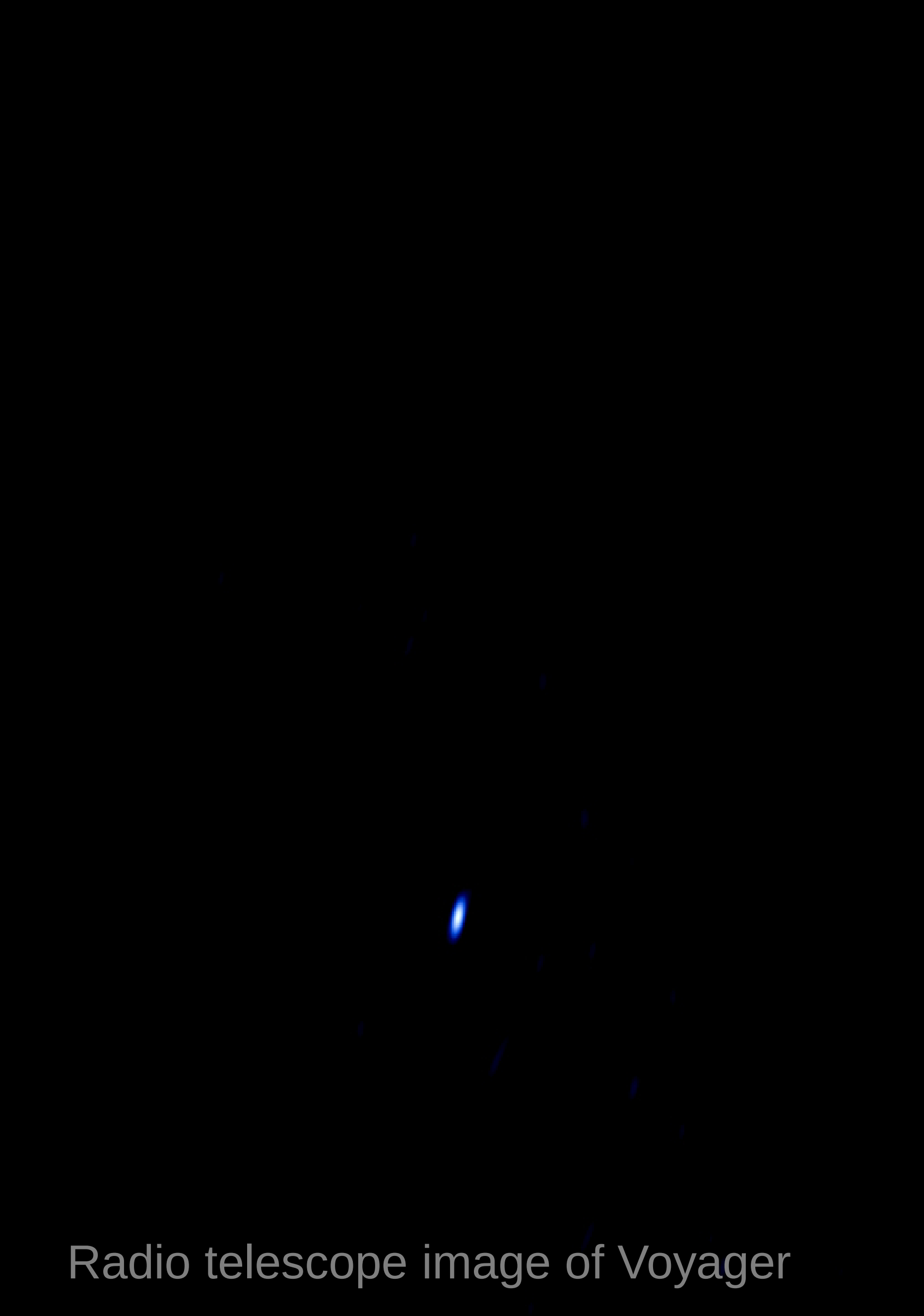
JUPITER



SATURN



14th February 1990 – back view to earth



Radio telescope image of Voyager

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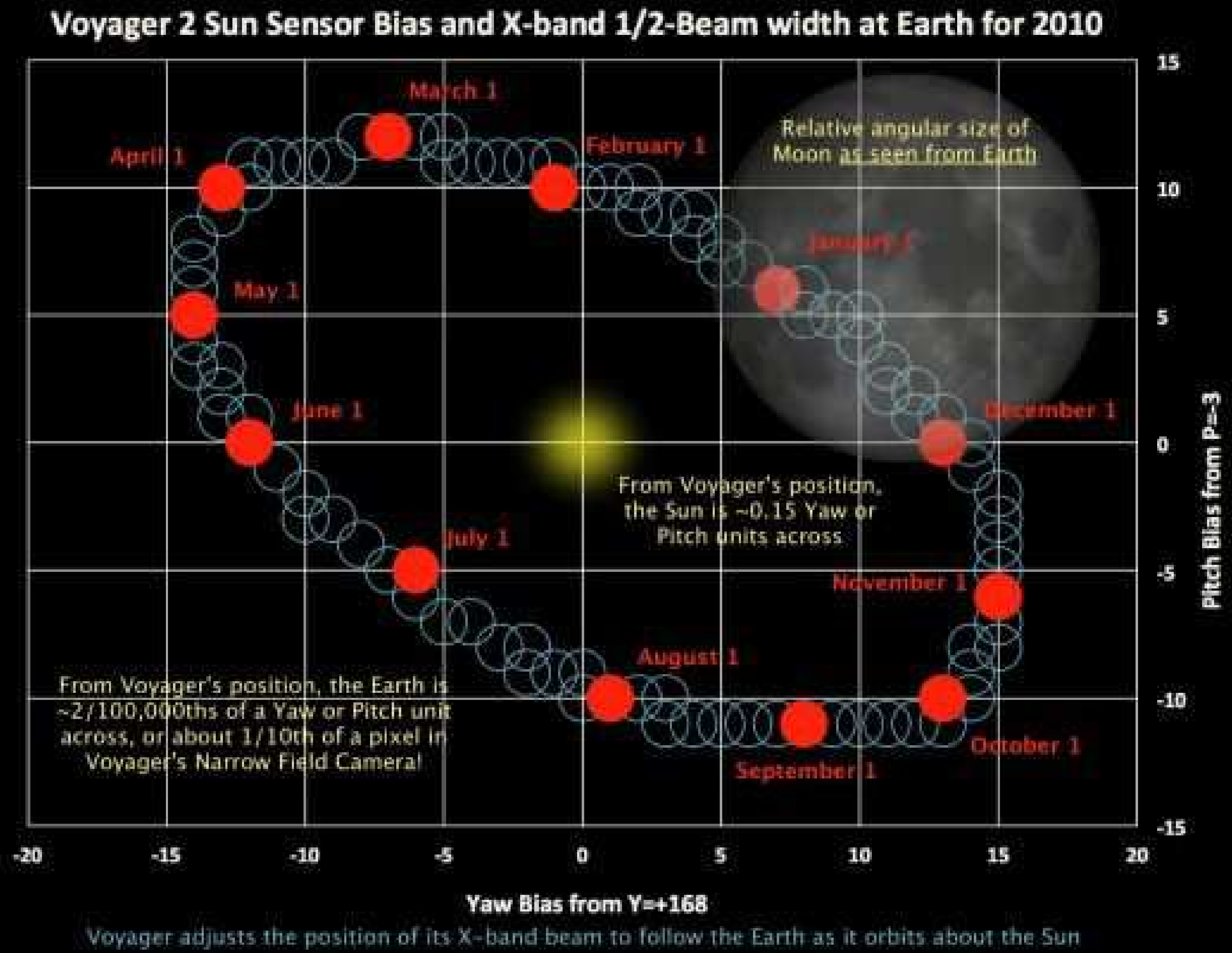

Voyager 2 Sun Sensor Bias and X-band 1/2-Beam width at Earth for 2010
March 1
April 1
February 1
Relative angular size of Moon as seen from Earth
January 1
May 1
June 1
December 1
From Voyager's position, the Sun is ~0.15 Yaw or Pitch units across
July 1
November 1
August 1
From Voyager's position, the Earth is ~2/100,000ths of a Yaw or Pitch unit across, or about 1/10th of a pixel in Voyager's Narrow Field Camera!
October 1
September 1
15
10
5
0
-5
-10
-15
Pitch Bias from P=-3
-20
-15
-10
-5
0
5
10
15
20
Yaw Bias from Y=+168
Voyager adjusts the position of its X-band beam to follow the Earth as it orbits about the Sun


SPACECRAFT CURRENTLY TRACKED AT GOLDSTONE
Voyager 1
Cassini
Stereo A & B
MRO
Mars Odyssey
MOM
Cluster 1, 2, 3 & 4
SOHO
MAVEN
Dawn
New Horizons
Mars Exploration Rover
Spitzer
MSL
Wind
Rosetta
Kepler
Planet C
Mars Express
Chandra
GOES
LRO
MMS 1-4
JUNO
ACE
Themis C
Geotail
Kurt.Niel@fh-wels.at - August 2017

SCaN Current Network

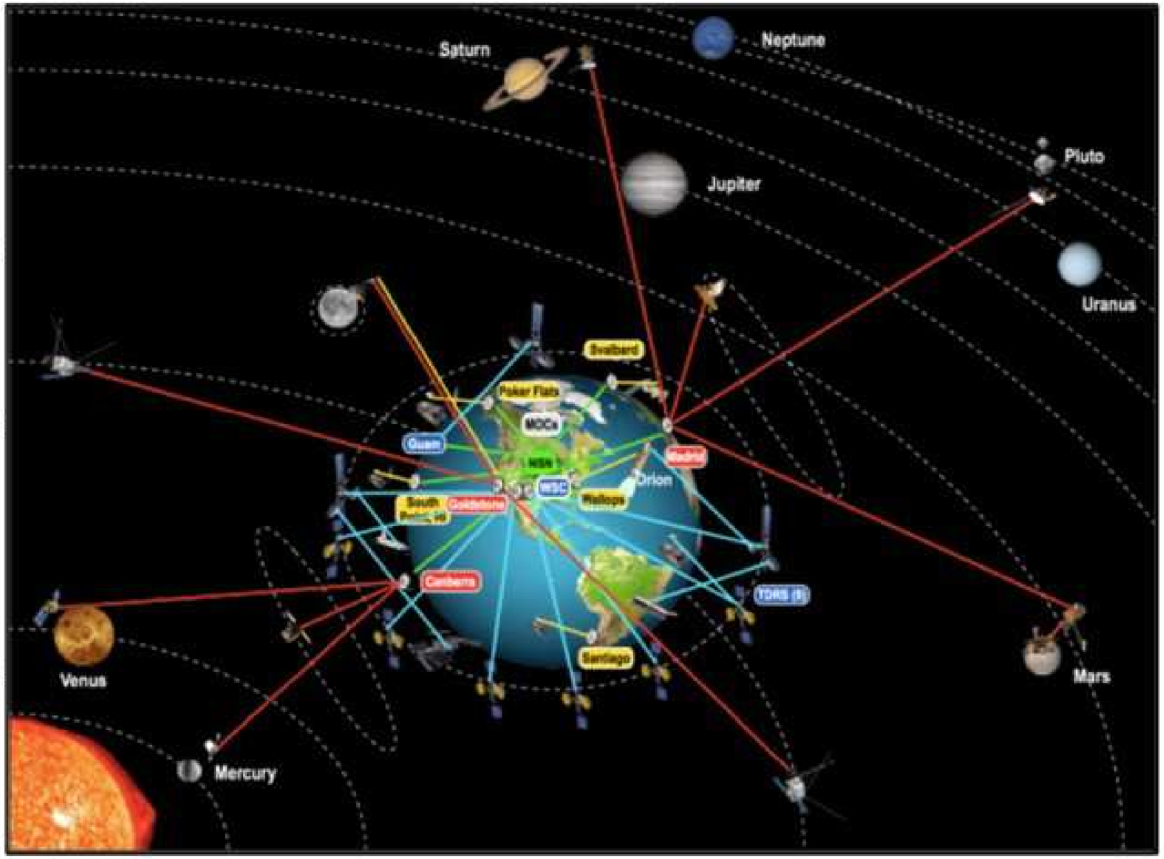
The current NASA space communications architecture embraces three operational networks that collectively provide communications services to supported missions using space-based and ground-based assets

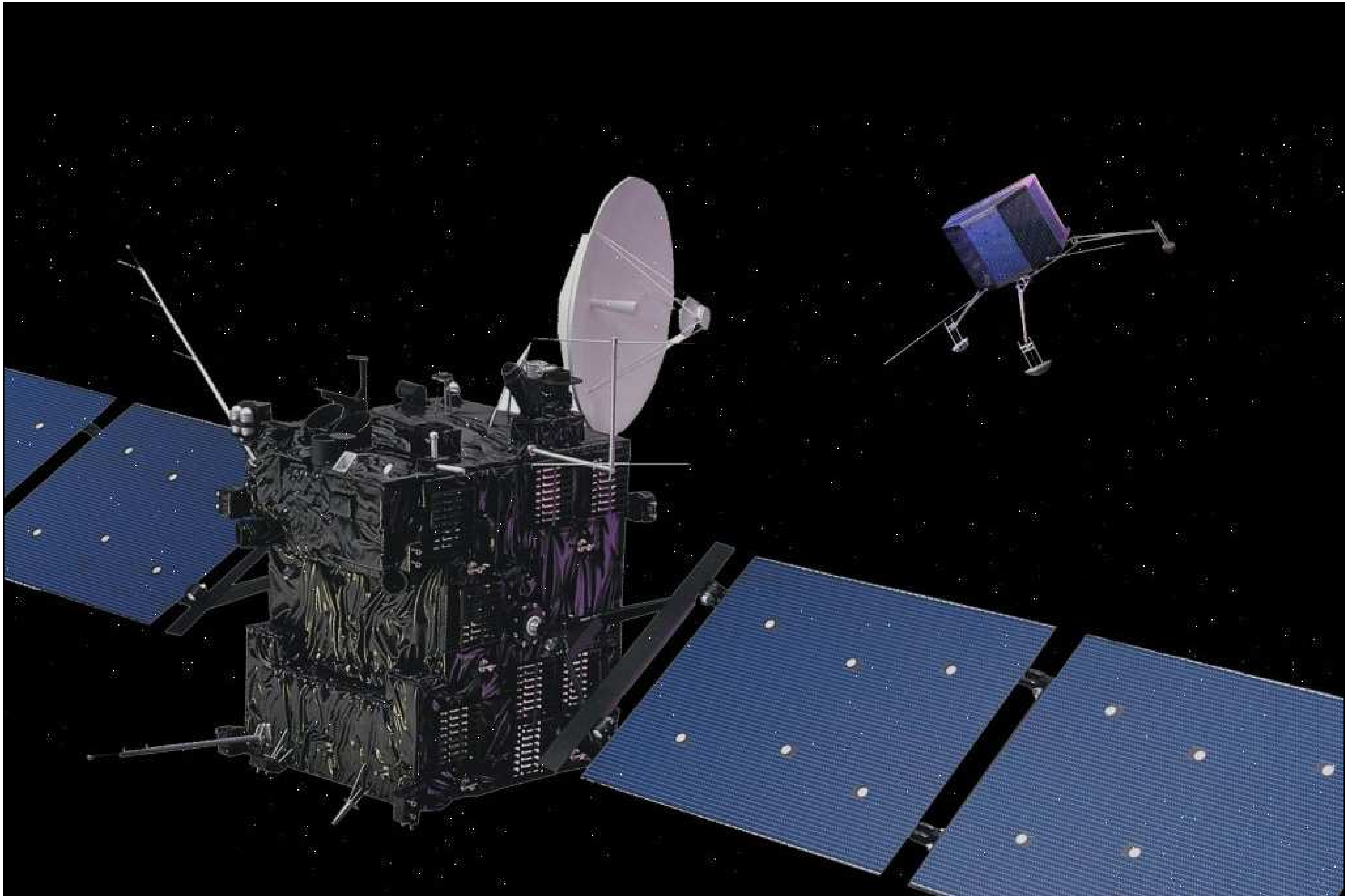
Near Earth Network - NASA, commercial, and partner ground stations and integration systems providing space communications and tracking services to orbital and suborbital missions

Space Network - constellation of geosynchronous relays (TDRSS) and associated ground systems

Deep Space Network - ground stations spaced around the world providing continuous coverage of satellites from Earth Orbit (GEO) to the edge of our solar system

NASA Integrated Services Network (NISN) – no longer part of SCaN – managed by OCIO; provides terrestrial connectivity





Kurt.Niel@fh-wels.at - August 2017

ROSETTA Start 2005; end September 2016 (going down to 67P)

Technical data (communication via Deep Space Network DSN + ESA/Perth)

• Launch mass	1 670 kg + propellant 1 500 kg
• Power supply	Solar array (2 x 32 m²) 850 W (3.4 AU) / 395 W (5.25 AU)
• Antennas	2.2 m High Gain paraboloid + 0.8 m Medium Gain paraboloid + 2 omnidirectional Low Gain
• Transmission power	28 W RF X-Band TWTA + 2 x 5 W RF S/X-Band

Transmission channel Rosetta:

• Uplink	S-Band (2.7 – 3.5 GHz) - 5-20 kb/s
• Downlink	X-Band (8.4 – 8.5 GHz) - 22 kb/s

PHILAE Undocking from Rosetta and landing at 67P: 12.11.2014
then stuck on rocks

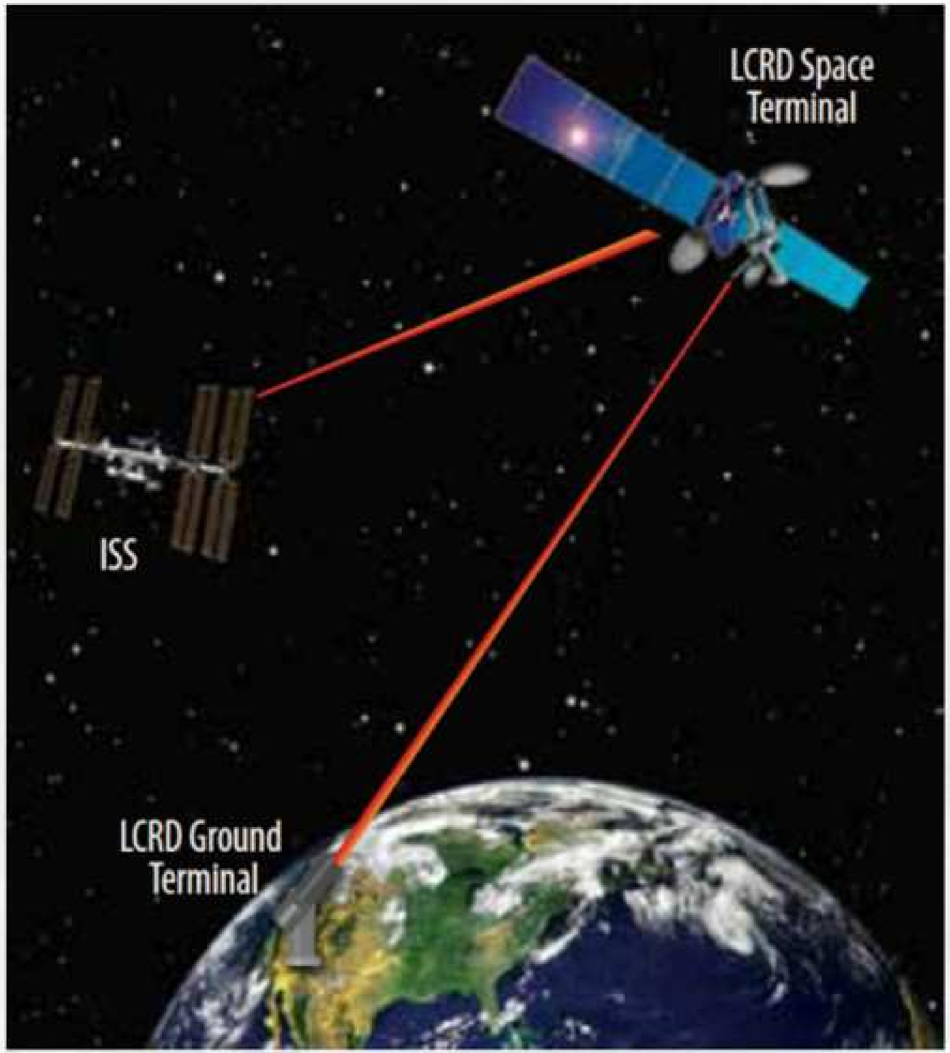
Technical data (transmitting relay Rosetta within max. 100 km distance):

- Launch mass: 100 kg
- Power supply: Solar array 2.2 m² (32 W) filling 140 Wh battery + 970 Wh non-rechargeable battery
- Antenna: patch 1 dBi
- Transmission power: 1 W RF S-Band transmitter

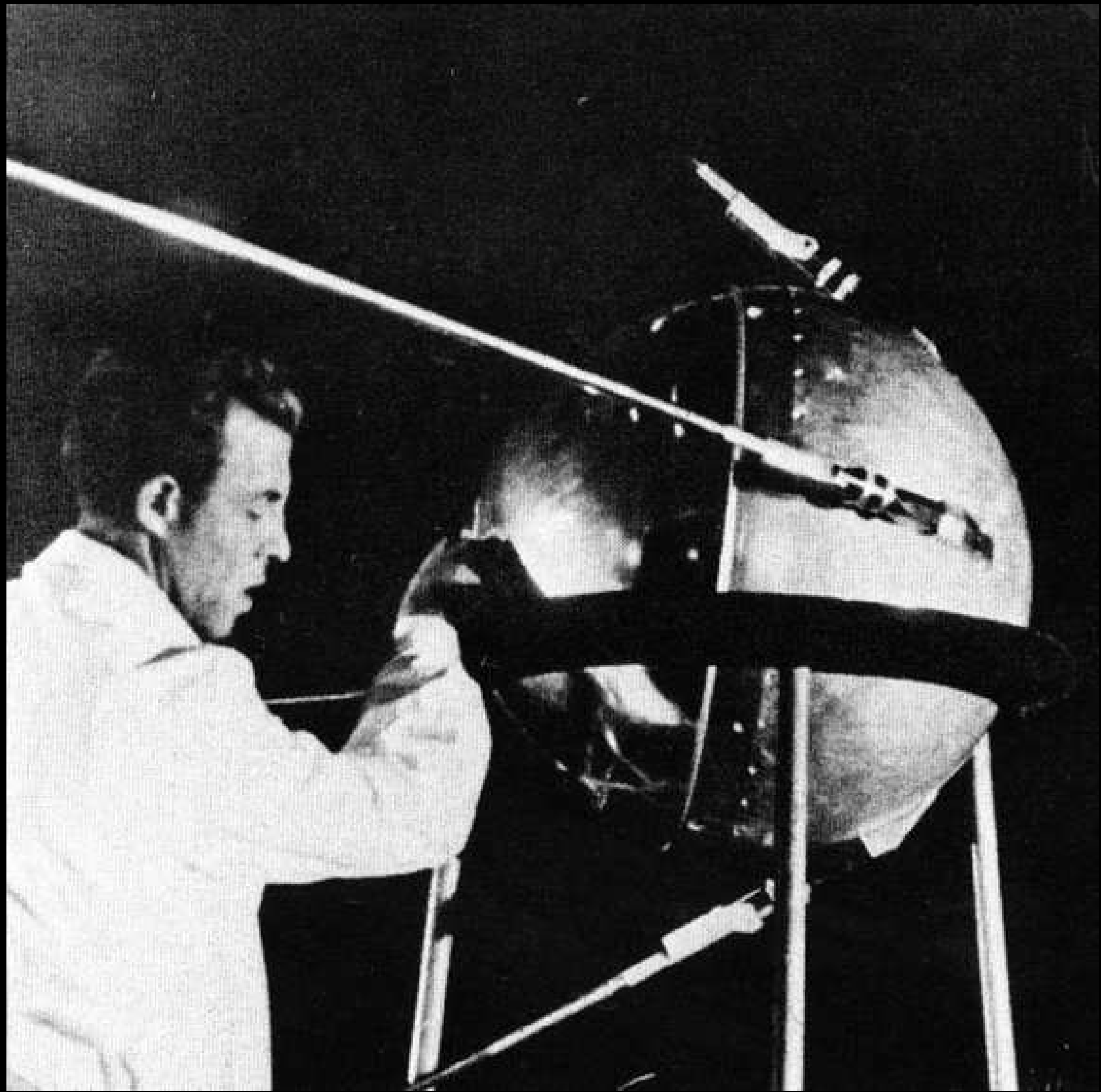
Lunar Laser Communication Demo

- Lunar Laser Communications Demo (LLCD) to fly on Lunar Atmosphere and Dust Environment Explorer (LADEE)
- Launch Readiness Date: August 2013 from Wallops Flight Facility, VA on Minotaur V
  - One month transfer
  - One month commissioning
    - 250 km orbit
    - LLCD operation demonstrating 600 Mbps downlink
    - Spacecraft and science payloads checkout
  - Three months science
    - 50 km orbit
    - Three science payloads
      - Neutral Mass Spectrometer
      - UV Spectrometer
      - Lunar Dust Experiment

Laser Communications Relay Demo (LCRD)



- LCRD will fly in 2017 and demonstrate optical communication for possible inclusion in NASA's Next Generation Tracking and Data Relay Satellite (TDRS).
- LCRD will be a network node with two optical terminals based on the LLCD design.
- Data transfer will be at variable data rates up to 2.8 Gbps.
- Onboard processing will implement DTN protocols to help address atmospheric conditions.



SOUND PROBES FROM SPACE

1) Sputnik 1 (Oct. 1957) – Orbit 238 – 947 km; 20/40 MHz CW
http://www.dd1us.de/sounds/DL3PD%20Alois%20-%2001%20-%20Sputnik%201%20first%20satellite%20reduced.mp3

2) Sputnik 2 (Nov. 1957) – Orbit 320 – 1770 km; heart beat dog Laika
http://www.dd1us.de/sounds/02%20traguardo%20l'infinito%20heart%20of%20Laika%20in%20Sputnik%202%20in%20the%204th%20orbit.mp3

3) Vostok 1 (Apr. 1961) – voice Jurij Gagarin
http://www.dd1us.de/sounds/DL3PD%20Alois%20-%2006%20-%20Juri%20Gagarin%20first%20man%20in%20Space%20reduced.mp3

4) Mercury Atlas 6 (Feb. 1962) – voice John Glenn
http://www.dd1us.de/sounds/Mercury-6_Zero-G.mp3

5) Apollo 13 (Apr. 1970) – way to moon
http://www.dd1us.de/sounds/apollo-13%20houston%20we%20have%20had%20a%20problem.mp3

6) Voyager (Jul. 1979) – Plasma Wave Subsystem near Jupiter
https://www.youtube.com/watch?v=5j5IObIReqk

7) EME ham radio (1995) – OE2AXH via 6.4 m paraboloid
http://www.dd1us.de/sounds/EME_5GHZ6_OH2AUE_7_ssb.mp3

8) Rosetta (2014?) – magnetic field oscillations of 67P/Churyumov/Gerasimenko
http://www.dd1us.de/sounds/manuel_senfft_-_a_singing_comet.mp3

Ham radio on the International Space Station
http://www.ariss.org
UK ham radio educational satellite
http://warehouse.funcube.org.uk

SOURCES

NASA Voyager Mission Status
- https://jpl.nasa.gov/voyager/mission/status/

NASA Deep Space Network DSN
- http://eyes.nasa.gov/dsn/dsn.html
- Goldstone (CA, USA), Madrid (E), Canberra (AUS)

NASA Space Communication and Navigation
- http://www.spacecomm.nasa.gov

Twitter @NSFVoyager2

„Descanso“-Document: `Descanso4--Voyager_new.pdf`

→ JPL „Voyager Telecommunications“, R. Ludwig, J. Taylor, March 2002

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- http://www.ariss.org

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- http://warehouse.funcube.org.uk

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- http://www.dd1us.de