

Vorlesungsreihe  
**ASTRONOMIE**

FH Astros  
Wintersemester 2015



## Die FH Astronomen – der gemeinsame Schreibtisch

Wir bewohnen den Elfenbeinturm zu unserer gedankenverlorenen Erbauung.

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[FHAstros.wordpress.com](http://FHAstros.wordpress.com)

Vorlesungsreihe  
**ASTRONOMIE**

FH Astros  
Wintersemester 2015



12. Oktober 2015 – 18:00 Uhr, FH Wels, A1

**Kommunikation mit Raumfahrzeugen / Funktechnik** (Kurt Niel)

16. November 2015 – 18:00 Uhr, FH Wels, A1

Space Robotics – Projects on ISS (in English)

(Atsushi Ueta, JAXA – Japan Aerospace Exploration Agency)

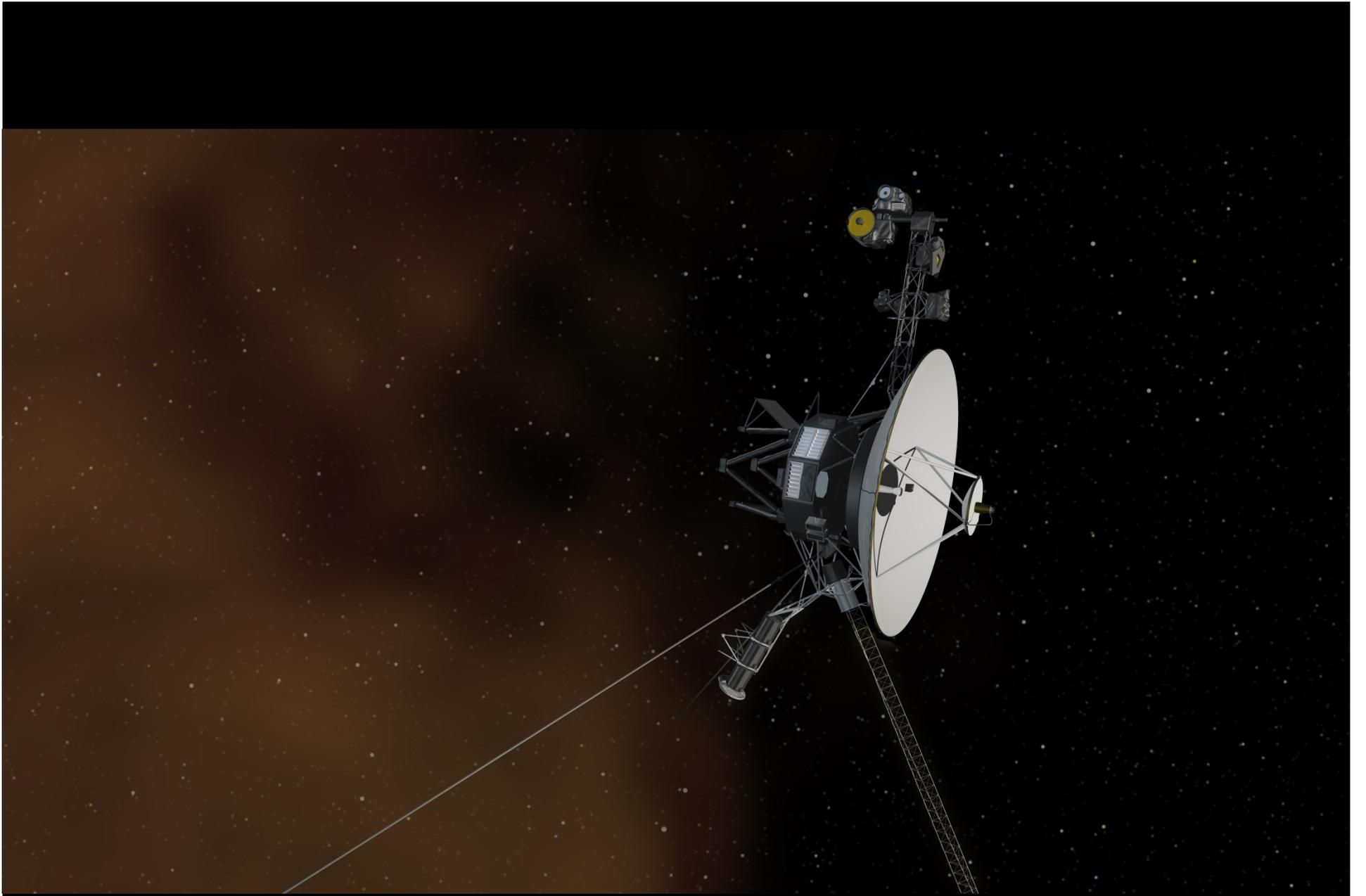
14. Dezember 2015 – 18:00 Uhr, FH Wels, A1

Astronomische Navigation (Wolfgang Steiner)

25. Jänner 2016 – 18:00 Uhr, FH Wels, A1

Entwicklung der Transportraketen ab Sputnik bis Space X

(Eugen Reichl, EADS – European Aeronautic Defence and Space Company)



Kurt.Niel@fh-wels.at - 12.10.2015

## VOYAGER 1, 2 Start 1977; jetzt am Rand Sonnensystem (133 AU<sup>1)</sup> – c 17:28:36 h)

Technische Daten (Funk via Deep Space Network DSN)

- Gewicht 835 - 733 kg (leichter wg. Treibstoffverbrauch)
- Energieversorgung Radioisotop Thermoelektrischer Generator (3 Stk.) - 315 W
- Antenne 3,7 m High Gain Parabolspiegel
- Sendeleistung 6,6 W – 18 W

Übertragungskanal:

- 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**

Bsp. Plasma Wave Subsystem PWS

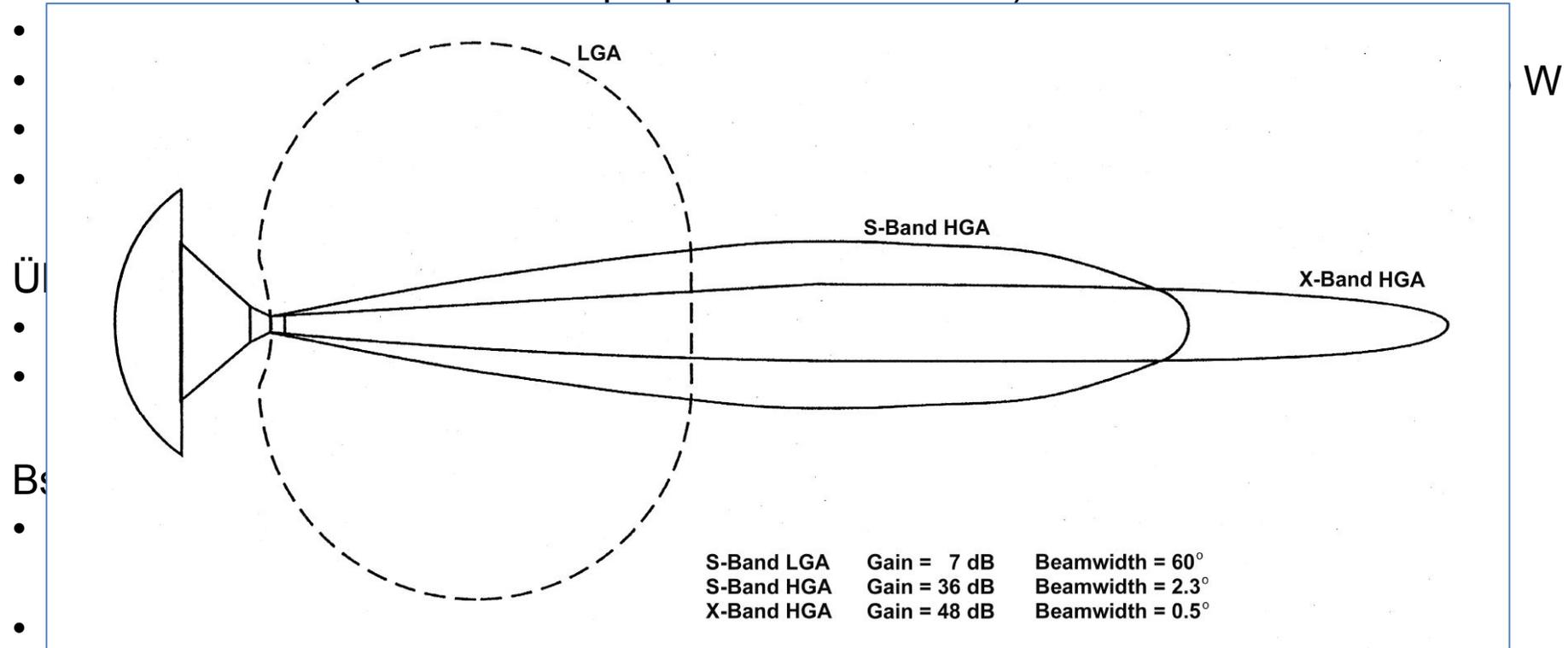
- Aufzeichnung je Woche 48 s PWS-Signal mit 115,2 kb/s auf Digital Tape Recorder DTR
- diese Daten werden alle 6 Monate über 70 m DSN empfangen

Bsp. Bildübertragung

- Auflösung (SW-Kamera mit Filterrad) je Kanal  
895 x 848 Pixel = 758 960 Byte → **Übertragungsdauer 1:15 h je Kanal**

# VOYAGER 1, 2 Start 1977; jetzt am Rand Sonnensystem (133 AU<sup>1)</sup> – c 17:28:36 h)

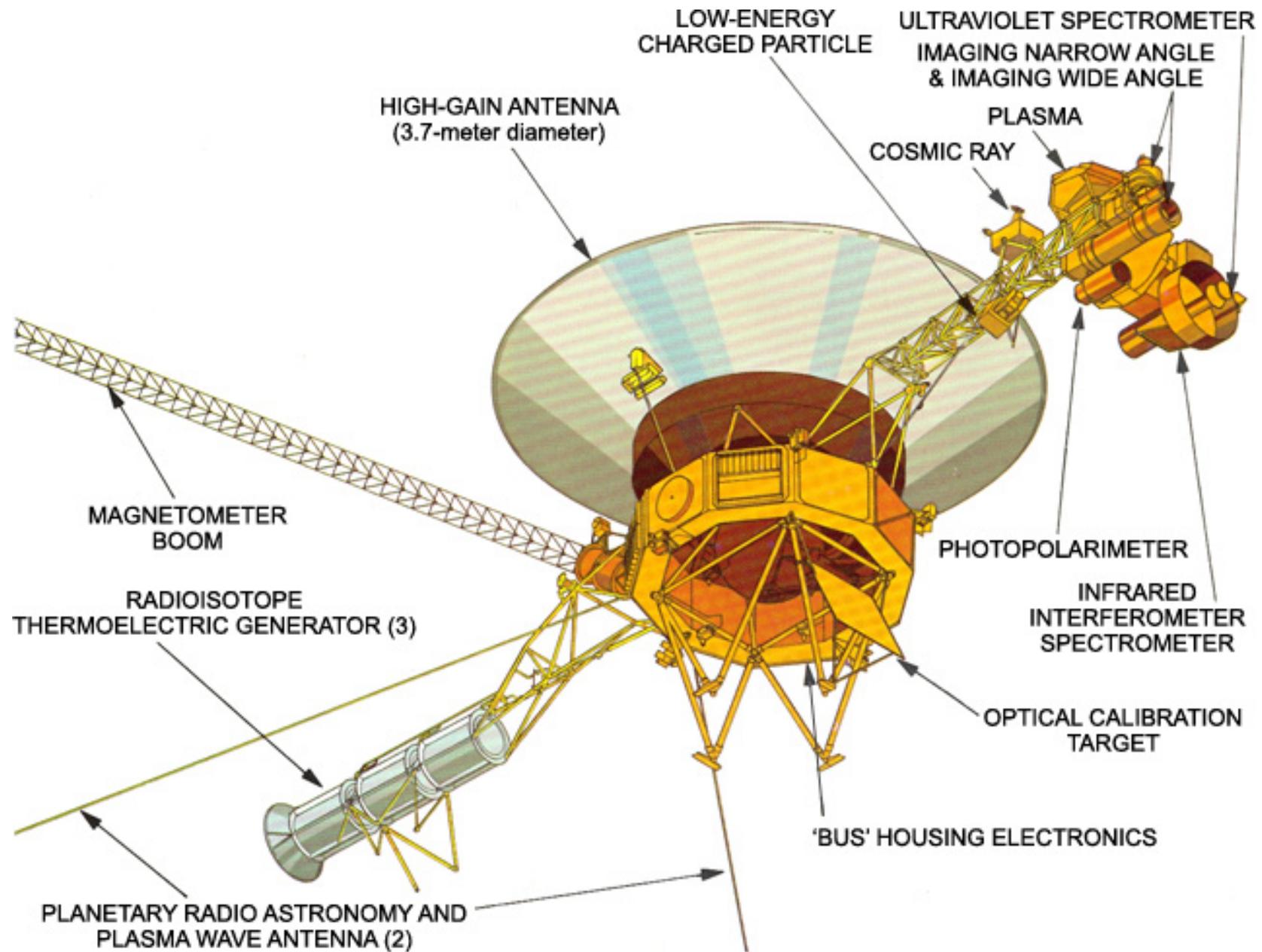
Technische Daten (Funk via Deep Space Network DSN)



Bsp. Bildübertragung

- Auflösung (SW-Kamera mit Filterrad) je Kanal  
895 x 848 Pixel = 758 960 Byte → **Übertragungsdauer 1:15 h je Kanal**

<sup>1)</sup> AU - astronomical unit = 149,6 Mio km (Abstand Erde - Sonne)

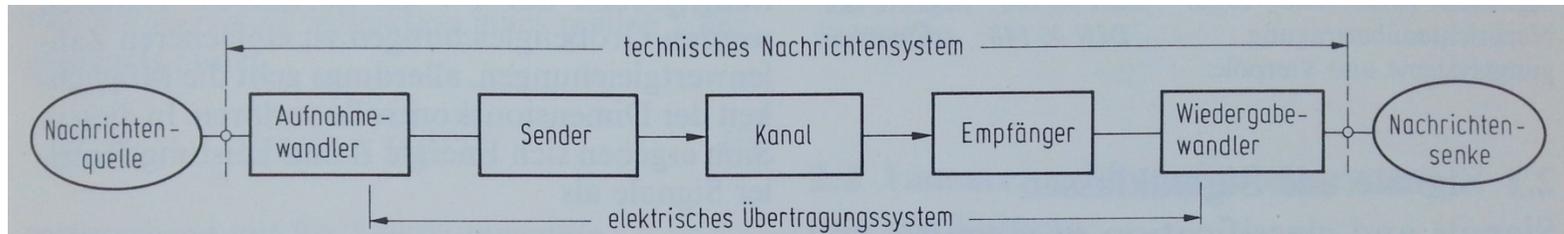


# GRUNDBEGRIFFE NACHRICHTENTECHNIK

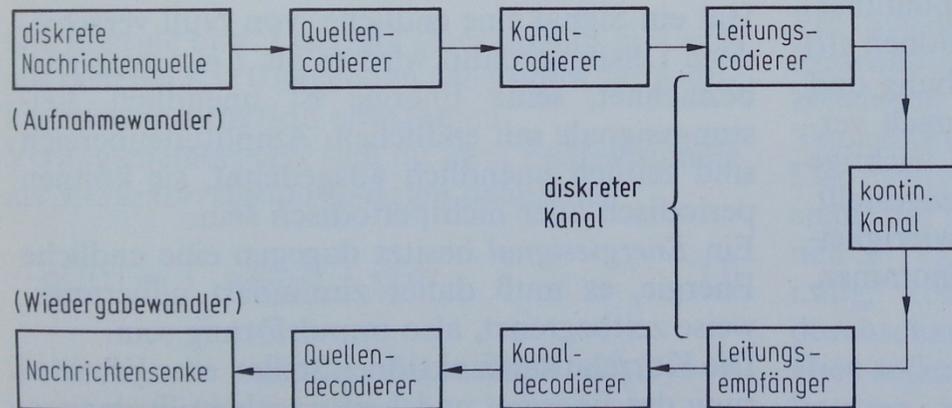
- Freiraumdämpfung
- Antennengewinn
- Signal-/Rauschverhältnis
- Bitfehler vs. Signal-/Rauschverhältnis
- Empfängerrauschen

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

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



**Bild 1.** Allgemeines Schema einer Nachrichtenübertragung



**Bild 2.** Schema eines digitalen Übertragungssystems

1) Empfangsleistung  
(isotrop)

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

$P_{ri}$  .. Empfangsleistung isotrop [W]  
 $S$  .. Strahlungsleistungsdichte [W/m<sup>2</sup>]  
 $A_w$  .. wirksame Antennenfläche  
 $P_{ti}$  .. Sendeleistung isotrop [W]  
 $r$  .. Entfernung Sender > Empfänger [m]  
 $\lambda$  .. Wellenlänge [m]

2) Freiraumdämpfung  
*Space Loss*  
(isotrope Antennen)

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

$F_i$  .. Freiraumdämpfung [1]  
 $P_{ti}$  .. Sendeleistung isotrop [W]  
 $P_{ri}$  .. Empfangsleistung isotrop [W]  
 $r$  .. Entfernung Sender > Empfänger [m]  
 $f$  .. Sendefrequenz [Hz]  
 $c$  .. Lichtgeschwindigkeit [m/s]

$$F_{i,dB} = 10 \log(F_i)$$

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

Verbindung	Frequenz	Entfernung	Freiraumdämpfung isotrop
TV-Satellit	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-Übertragungsgleichung

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

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

$P_t$  .. Sendeleistung [W]  
 $P_r$  .. Empfangsleistung [W]  
 $G_t$  .. Antennengewinn Sender  
 $G_r$  .. Antennengewinn Empfänger  
 $r$  .. Entfernung Sender > Empfänger [m]  
 $\lambda$  .. Wellenlänge [m]

4) Antennengewinn Parabolantenne

$$G = \frac{4\pi}{\lambda^2} \cdot A \cdot \eta_{eff}$$
$$G = \left( \pi \frac{d}{\lambda} \right)^2 \cdot \eta_{eff}$$

$G$  .. Antennengewinn  
 $\lambda$  .. Wellenlänge [m]  
 $A$  .. Antennenfläche [m<sup>2</sup>]  
 $d$  .. Antennendurchmesser [m]  
 $\eta_{eff}$  .. Wirkungsgrad 0,8..0,99 [1]

5) Empfangsleistung

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

6) Empfangsleistungabstand zur Leistungsdichte des Empfängerrauschens  $N_0$

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

... Maß für „Brauchbarkeit“ des Empfangssignals

## 7) Übertragungsrate (Shannon-Hartley)

$$C = B \cdot \log_2 \left( 1 + \frac{S}{N} \right)$$

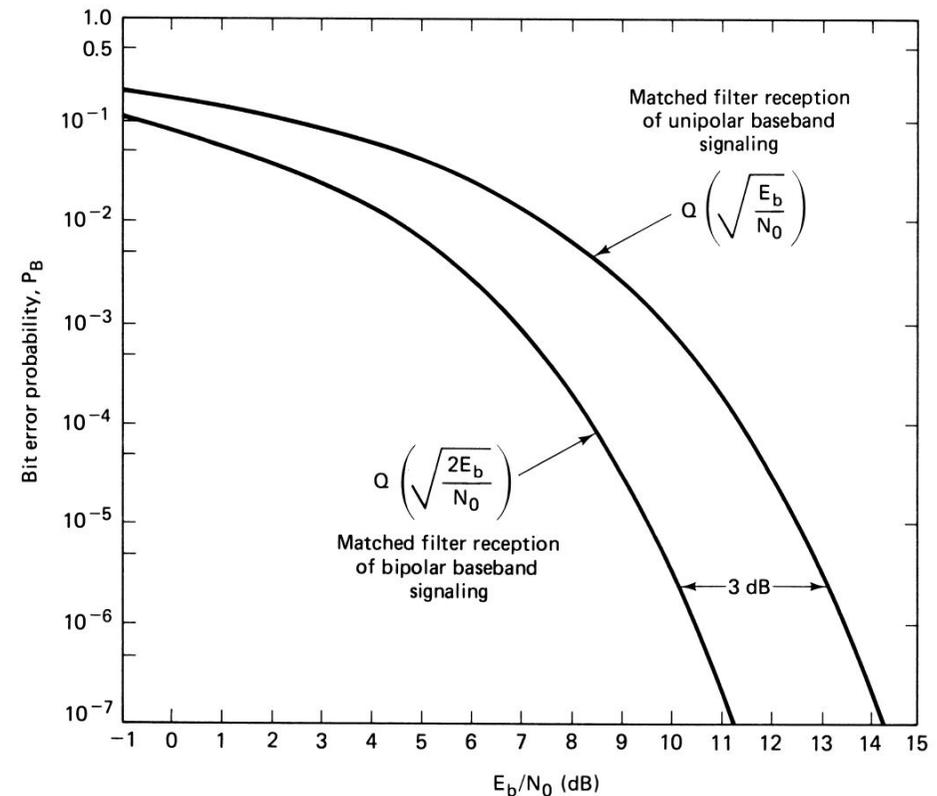
C .. Ideale Übertragungsrate [bps]  
 B .. Bandbreite [Hz]  
 S .. Singnalleistung [W] od.  $[\sqrt{V}]$   
 N .. Rauschleistung [W] od.  $[\sqrt{V}]$   
 S/N .. Signal-/Rauschverhältnis [1]

## 8) Bitfehlerhäufigkeit = Maß für Qualität der Übertragung in einem Kanal (Anzahl Fehler pro Zeiteinheit) - Messung

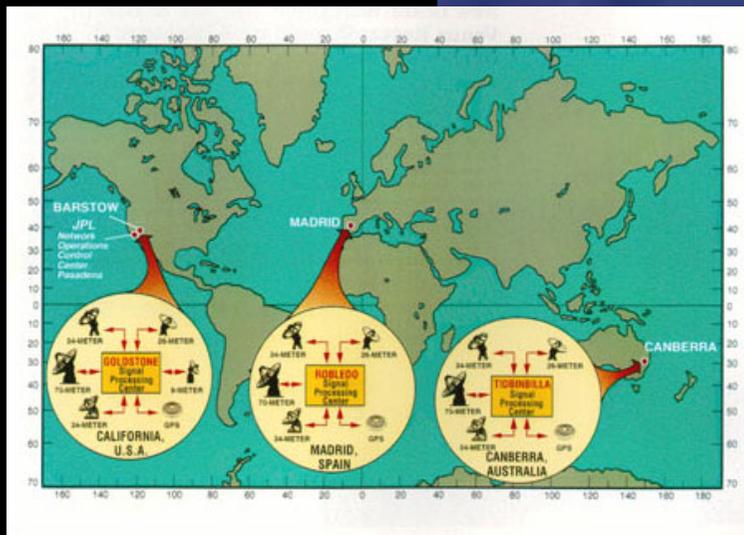
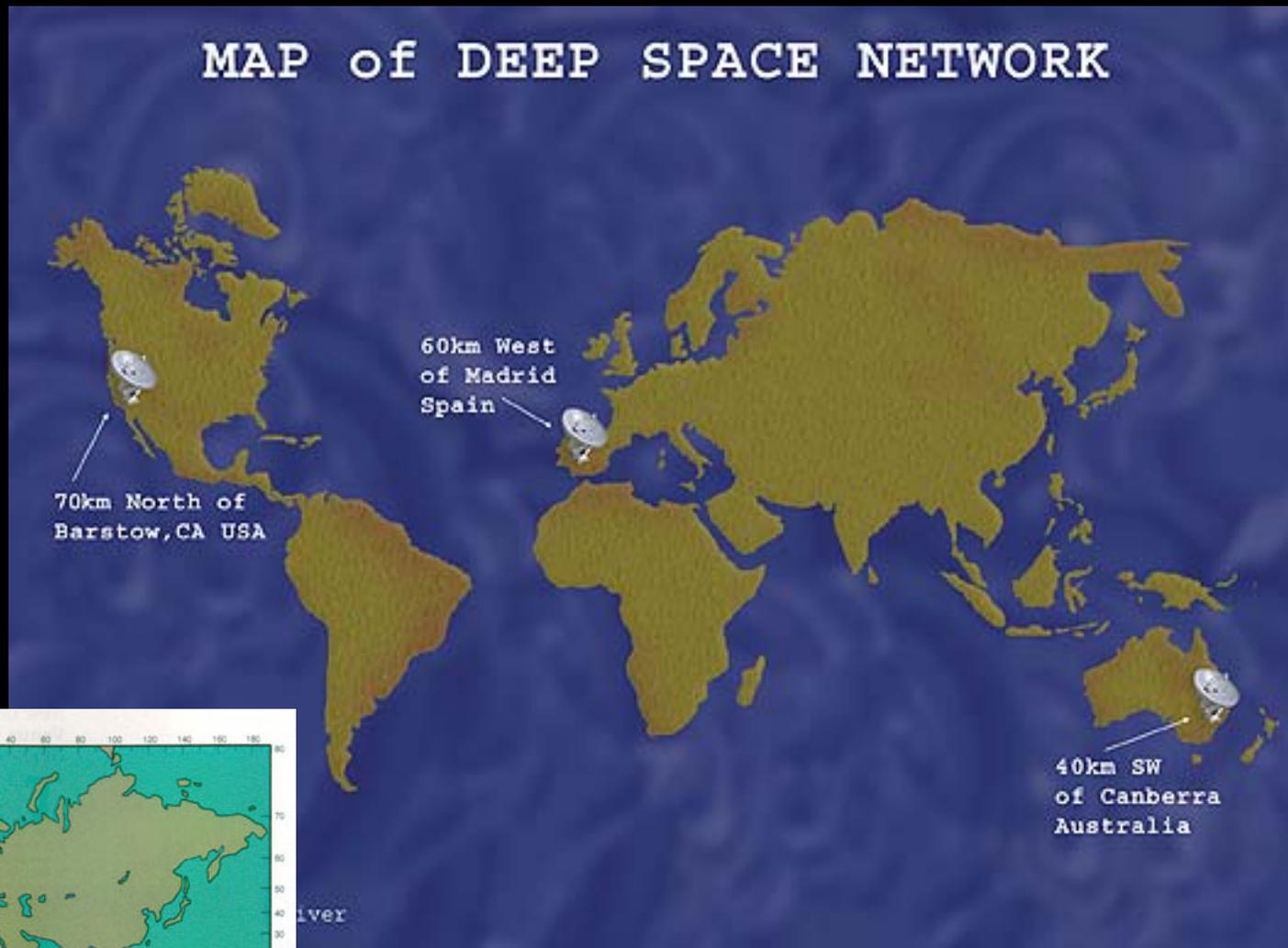
## 9) Bitfehlerwahrscheinlichkeit (Wahrscheinlichkeit für Auftreten eines Bitfehlers) - Rechnung

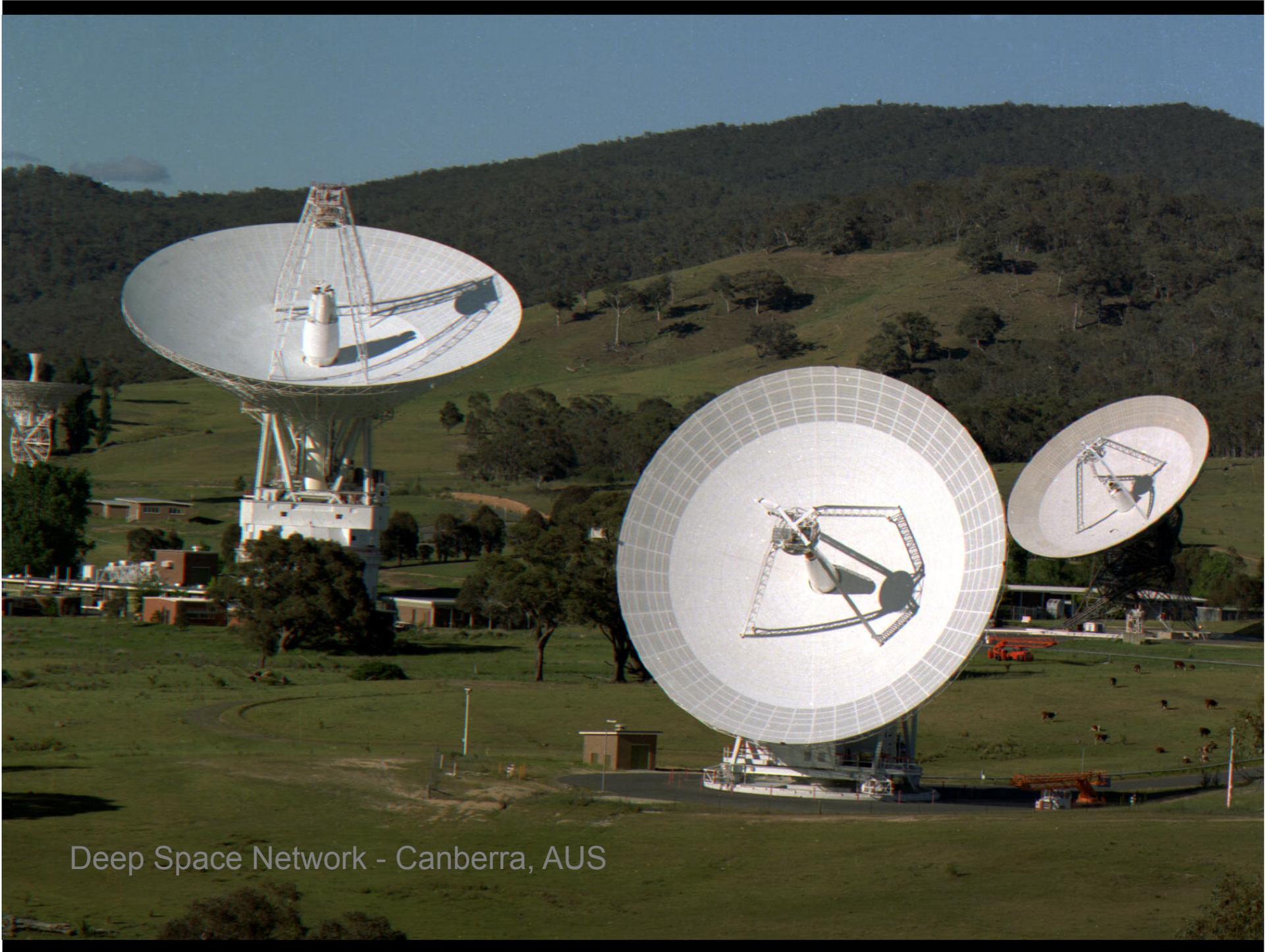
$P_B$  .. Bit erro probability  
 $E_b$  .. Energie für Informationsbit  
 $N_0$  .. Spektrale Rauschleistungsdichte

... Hinweis darauf, dass mit zunehmendem Empfangsleistungsabstand zum Empfängerrauschen die Bitfehlerwahrscheinlichkeit abnimmt.



# MAP of DEEP SPACE NETWORK





Deep Space Network - Canberra, AUS

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

# LEISTUNGSBILANZ

(„Descanso“-Dokument)

- Erde → Sonde  
2,1 GHz

Voy 2 (JSX), 70m/18 kW/12 Hz, 0 dB Rng, 0 dB Cmd, Cir 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				
	Design	Fav Tol	Adv Tol	Mean	Variance	
<b>Transmitter Parameters</b>						
	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
Durchmesser 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		
<b>Path Parameters</b>						
	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
<b>Receiver Parameters</b>						
	6) Polarization Loss, dB	-0.12	0.12	-0.18		
Durchmesser 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
Empfängerrauschen	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		
Nötiger Abstand für Bitfehlersicherheit	11) Carr Thr Noise, BW, dB-Hz	12.72	-0.24	0.23	12.7	0.01
<b>Power Summary</b>						
	12) Rcvd Power, $P_r$ , dBm				-127.4	0.16
	(1+2+3+4+5+6+7+8+9)					
	13) Rcvd $P_r/N_0$ , 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
Verbleibender Sicherheitsabstand	18) Carr SNR in 2BLO, dB (17-10-11)				26.5	0.17
					2.0 $\sigma$	= 0.80

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

# LEISTUNGSBILANZ

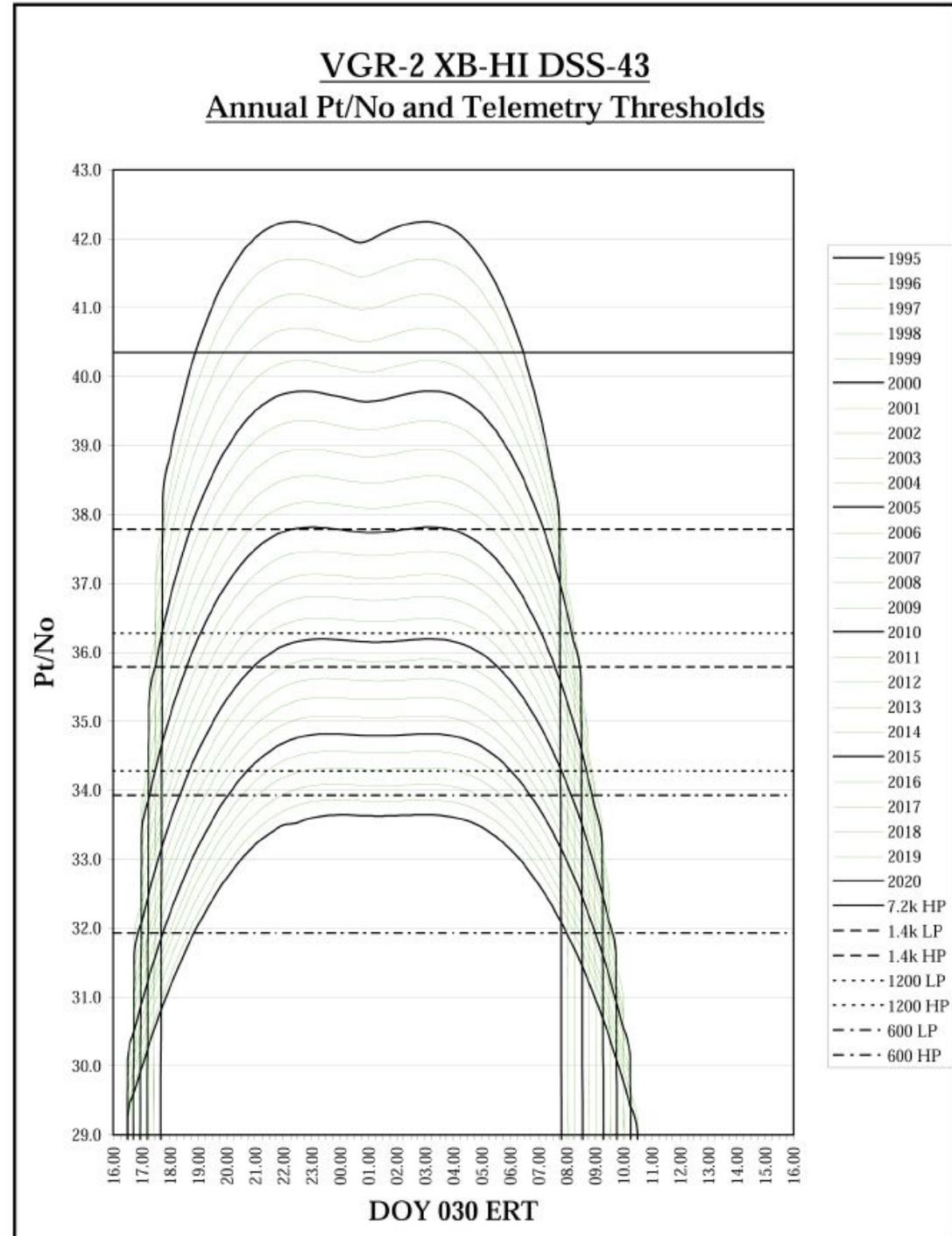
(„Descanso“-Dokument)

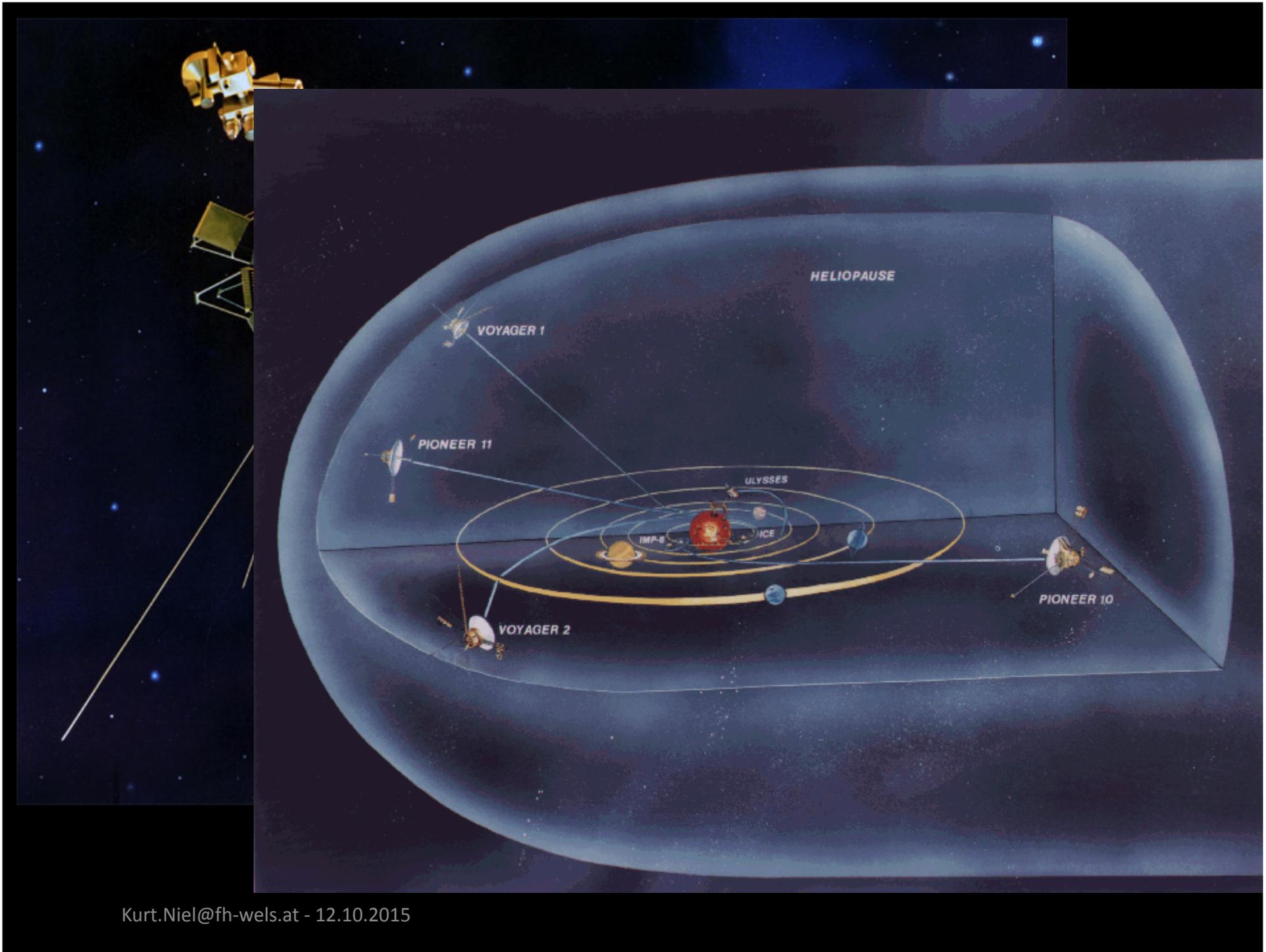
- Sonde → Erde  
8,4 GHz

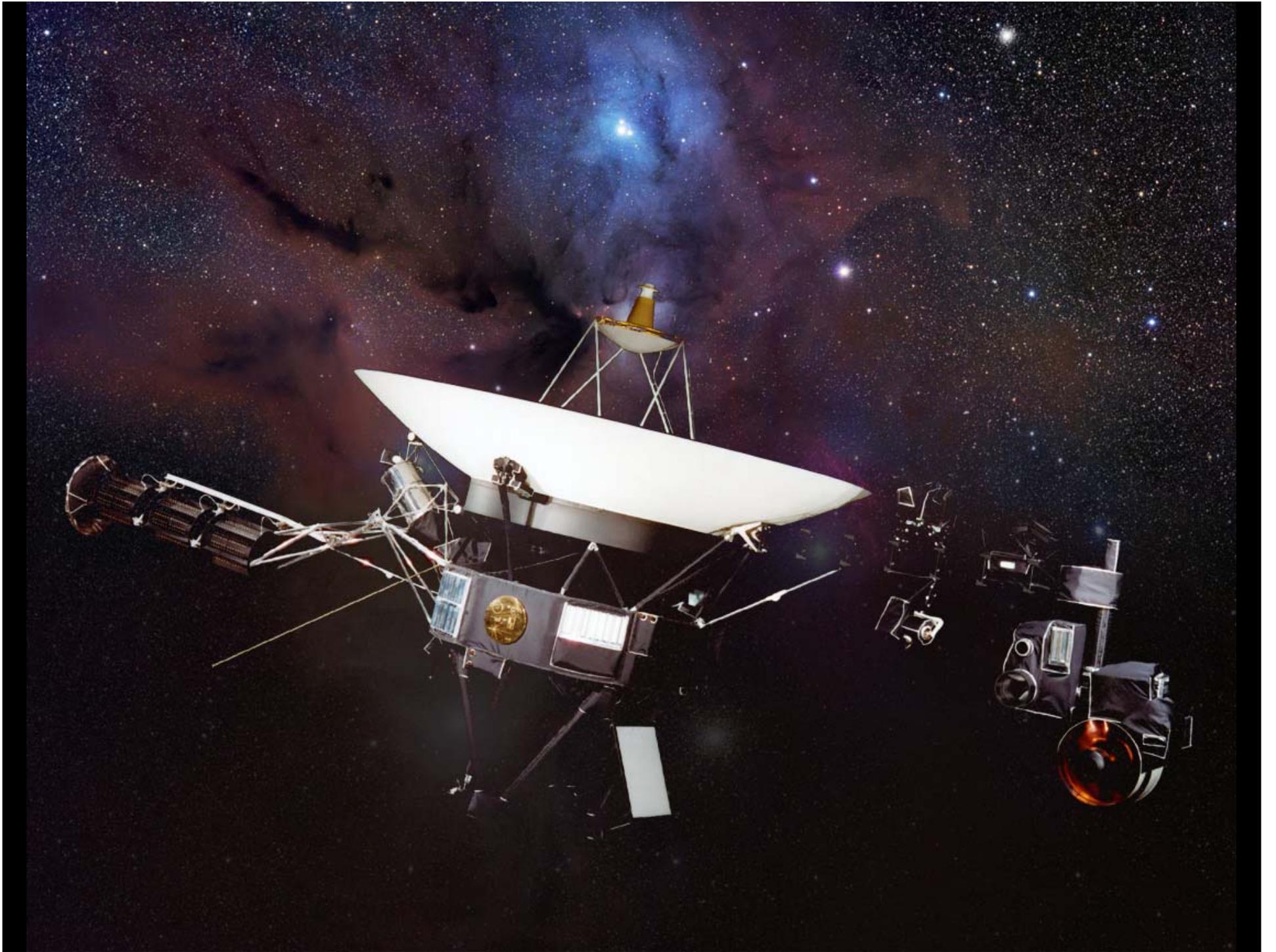
Voy 2 (JSX), 70m/18 kW/12 Hz, 0 dB Rng, 0 dB Cmd, Clr Wthr X-Band TWT LP, HGA/NLC, 160 bps Coded, 2-Way Radio Losses						
Spacecraft 2		Station 43				
Time in Mission 96/001/00/00		Time from Epoch 35065 00:00				
	Design	Fav Tol	Adv Tol	Mean	Variance	
<b>Transmitter Parameters</b>						
1) RF Power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

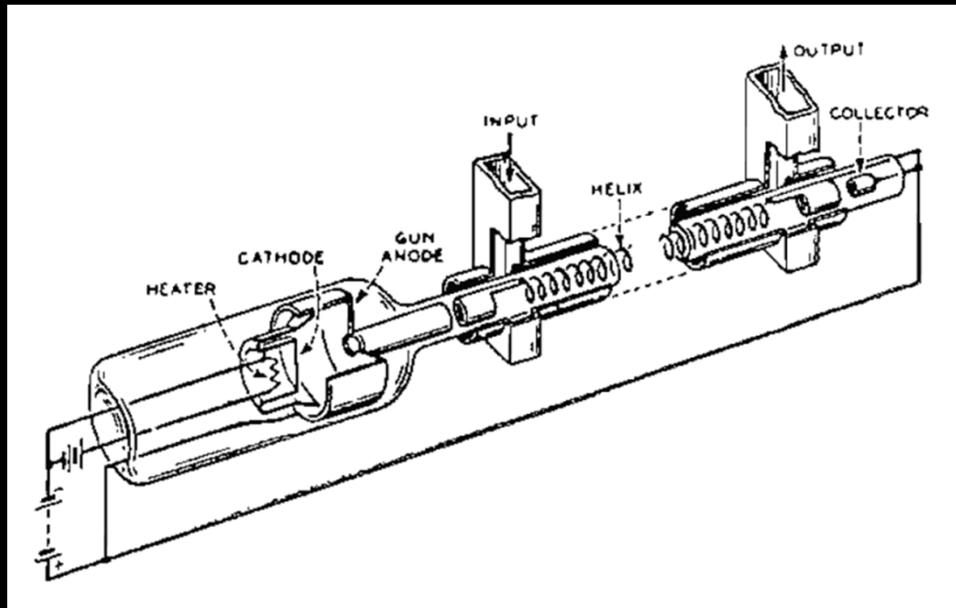
## LANGZEITPROGNOSE 1995 bis 2020

- Downlink
- Signal wird mit zunehmender Entfernung schwächer
- Übertragungssicherheit für immer geringere Übertragungsraten gegeben









Wanderfeldröhre TWTA  
*Travelling Wave Tube Amplifier*  
Endverstärker für Sendesignal  
S-/X-Band

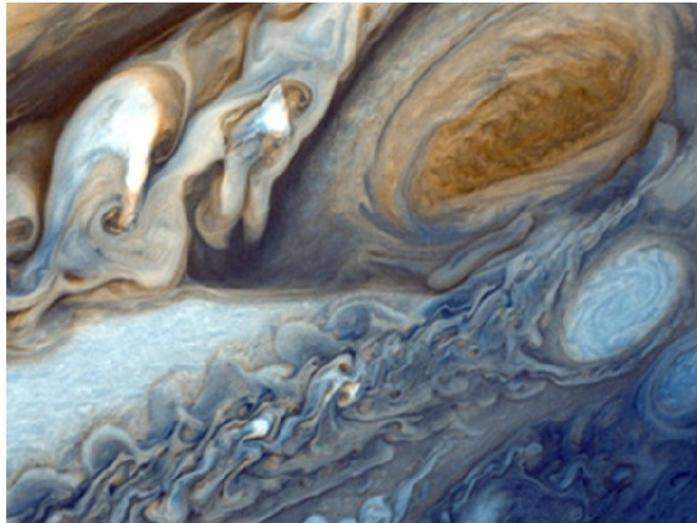


**MARINER (11-12) JUPITER /SATURN  
VOYAGER 1 & 2**

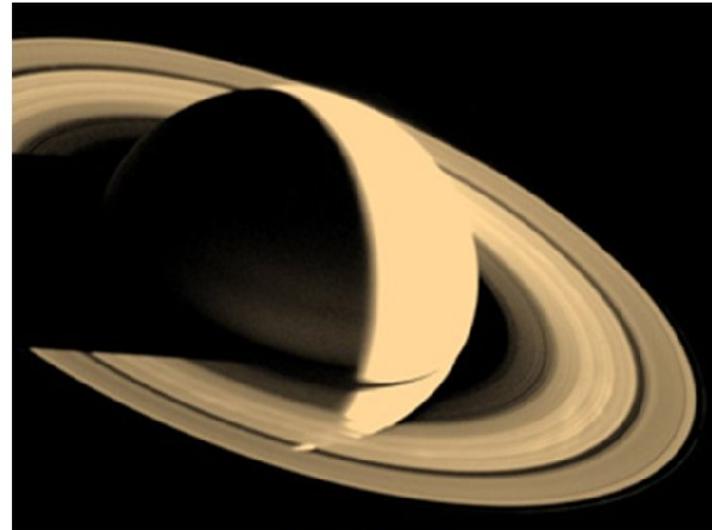


**VOYAGER VIDICON (1977)**

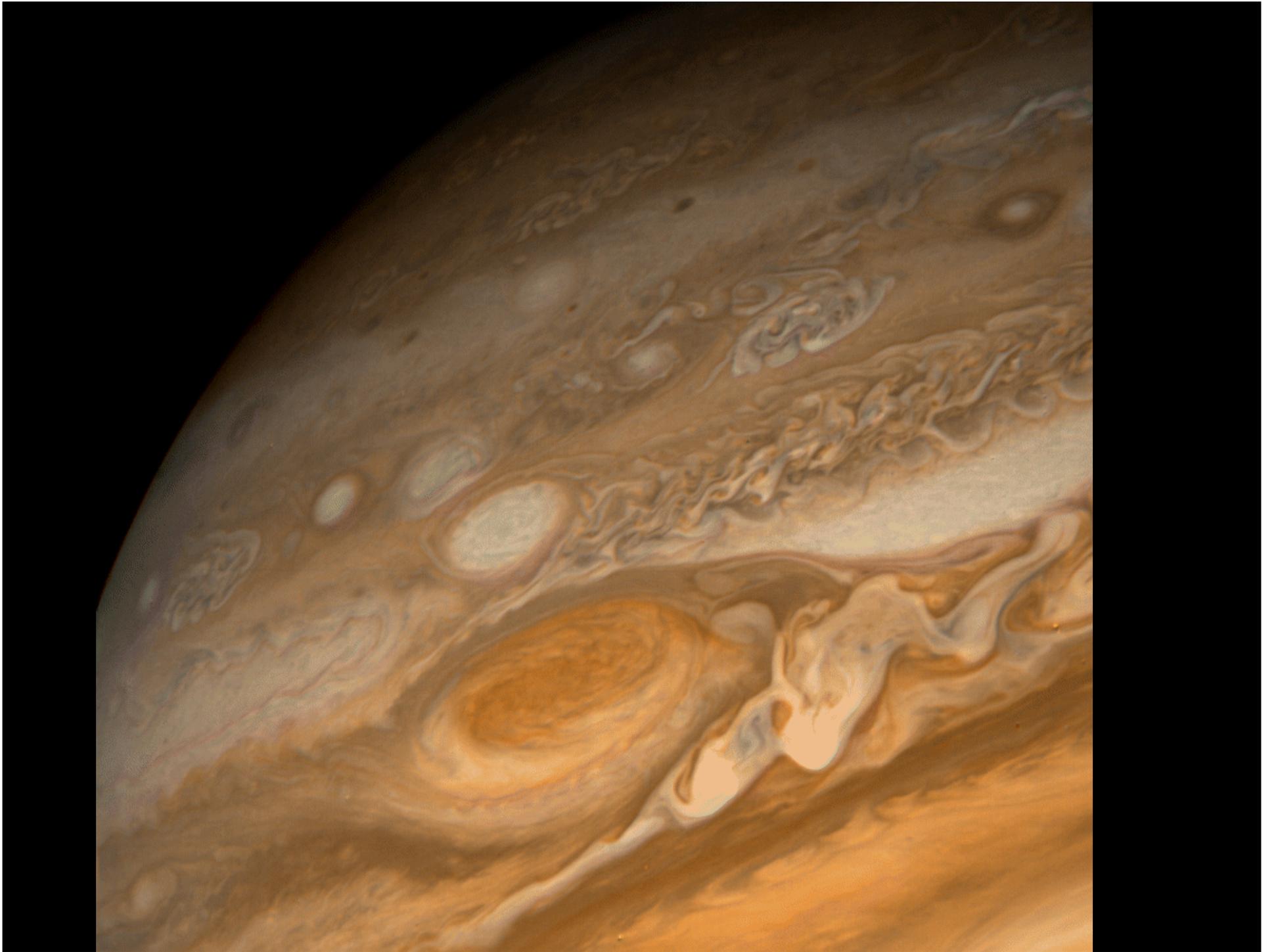
**Exploring Jupiter, Saturn, Uranus, Neptune and Interstellar space.**

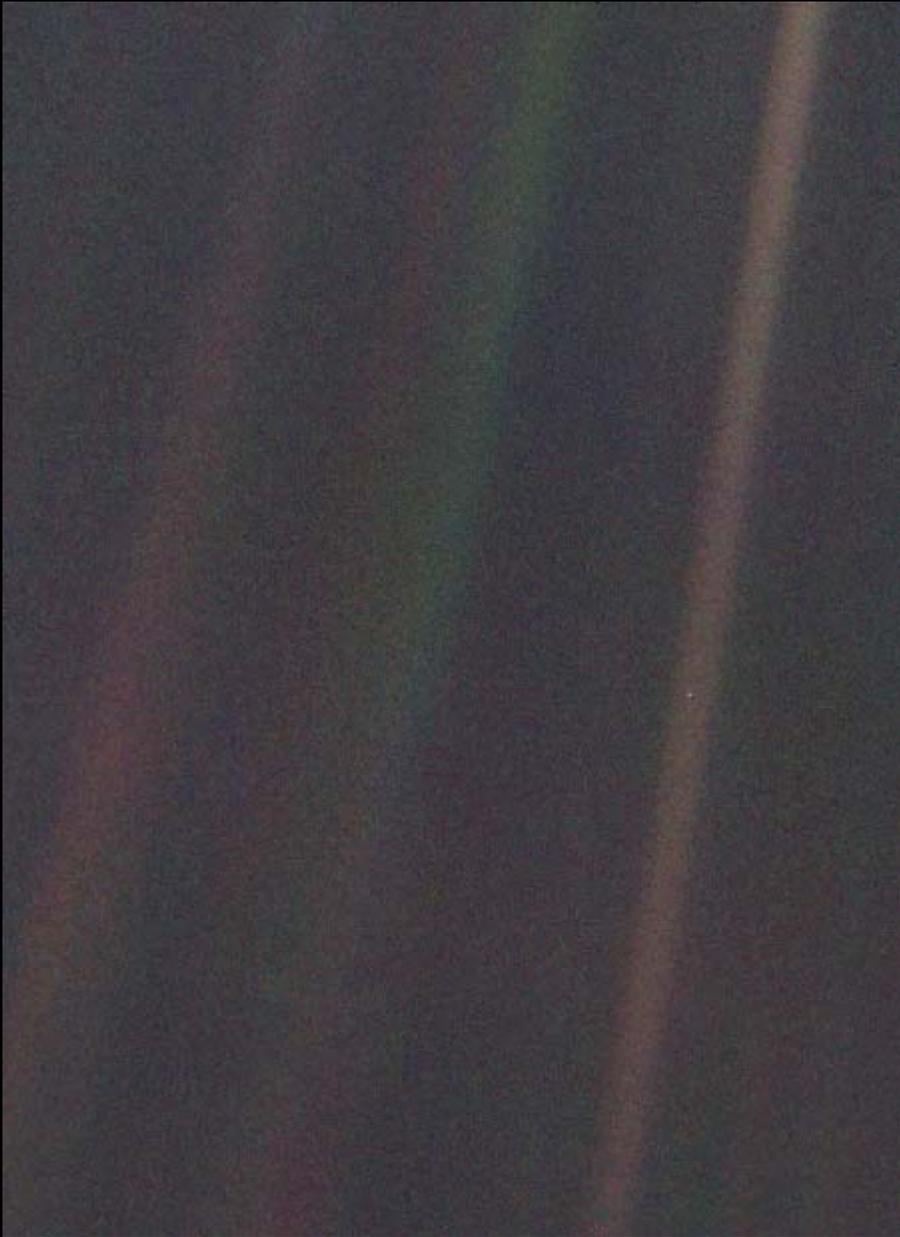


**JUPITER**



**SATURN**



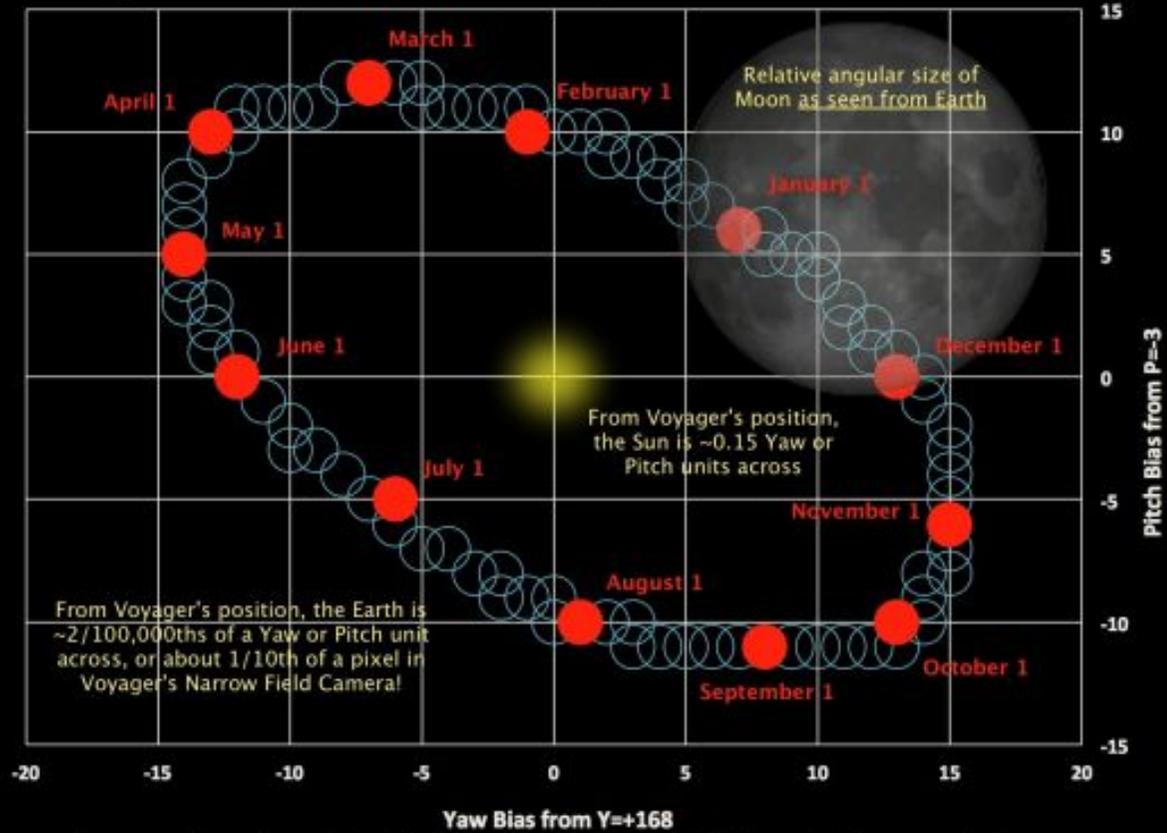


14. Februar 1990 - Rückblick auf Erde



Radioteleskopaufnahme von Voyager

### Voyager 2 Sun Sensor Bias and X-band 1/2-Beam width at Earth for 2010

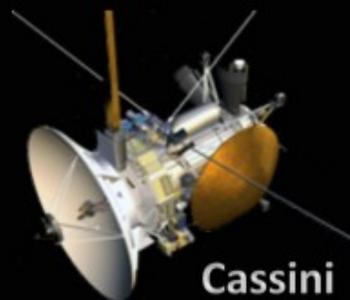


Voyager adjusts the position of its X-band beam to follow the Earth as it orbits about the Sun

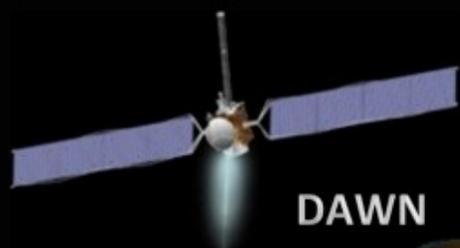
## Kalibrierprozedur zur Ausrichtung der High-Gain-Antenne auf Erde



# Missions Currently Tracked at Goldstone



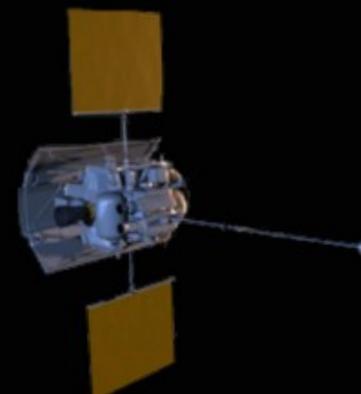
Cassini



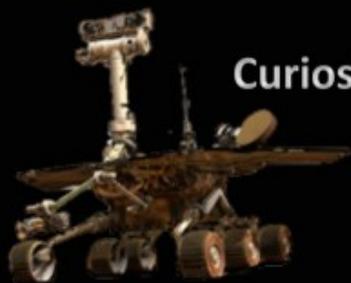
DAWN



Kepler



MESSENGER



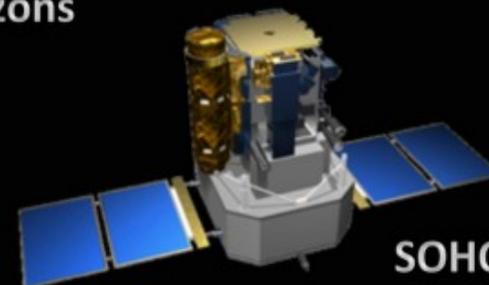
Curiosity



New Horizons



Mars Express



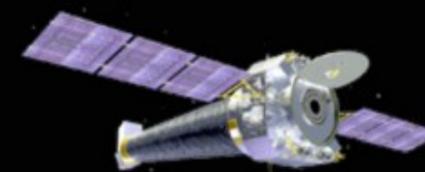
SOHO



Mars Reconnaissance Orbiter



ROSETTA



Chandra



# SCaN Current Network



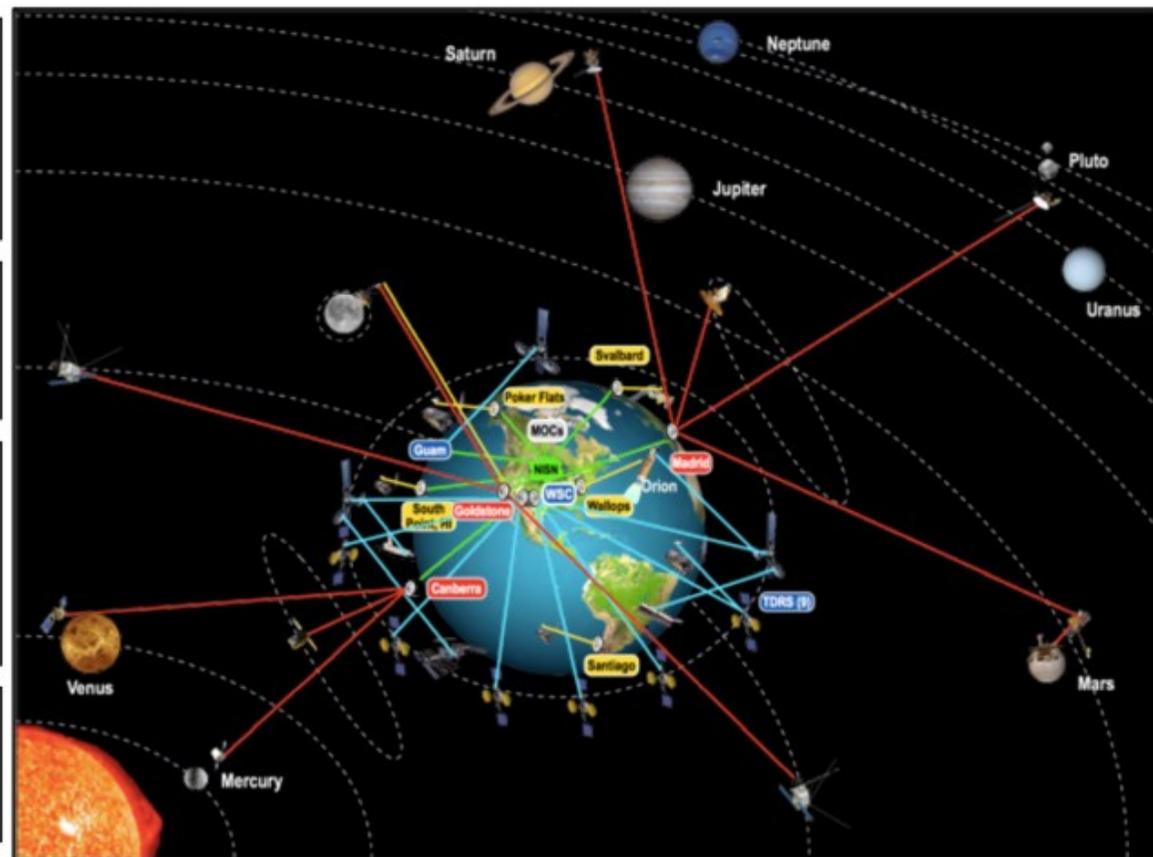
The current NASA space communications architecture embraces three operational networks that collectively provide communications services to supported missions using space-based and ground-based assets

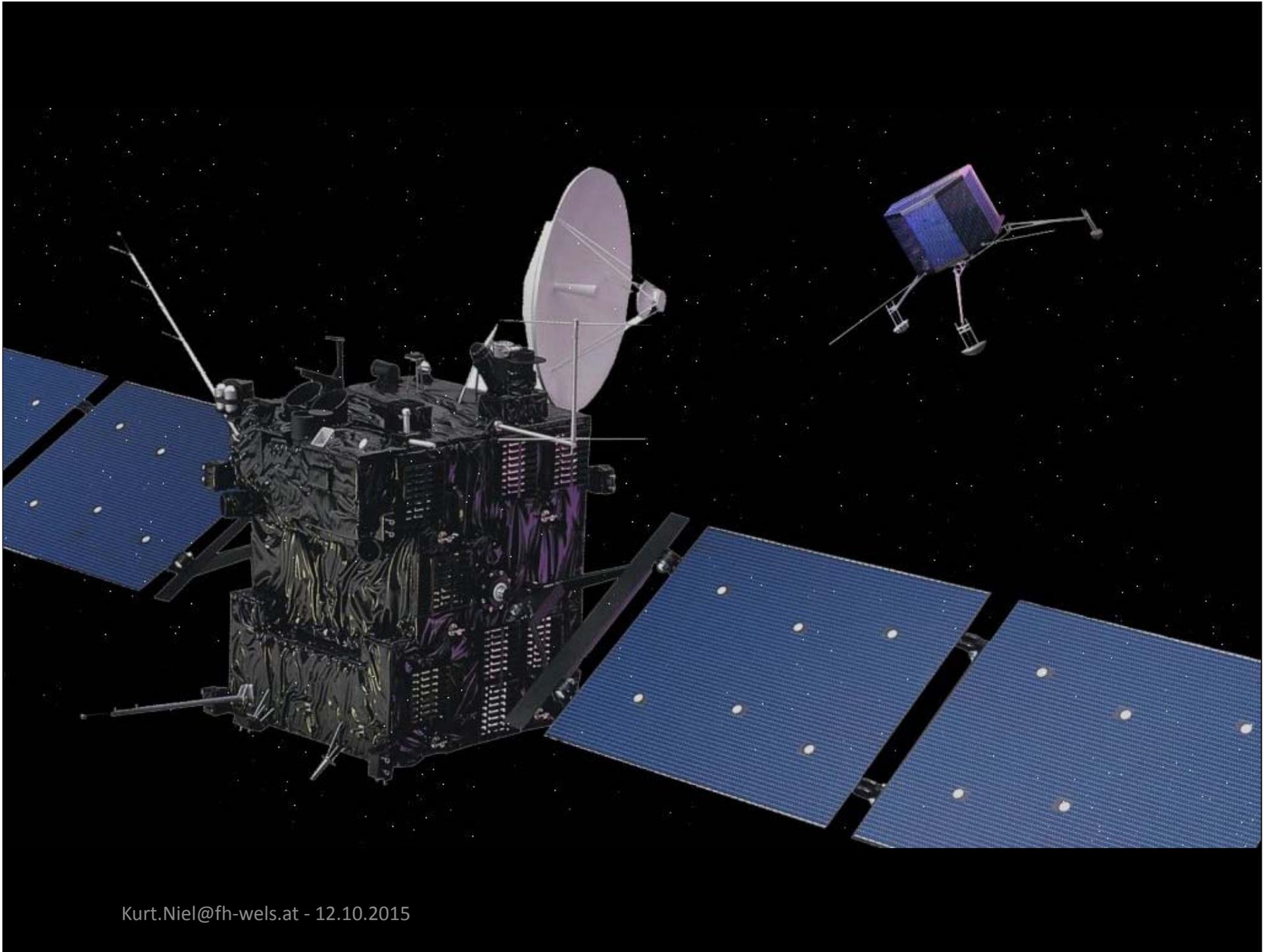
**Near Earth Network** - NASA, commercial, and partner ground stations and integration systems providing space communications and tracking services to orbital and suborbital missions

**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 - 12.10.2015

## ROSETTA

Start 2005; jetzt nach Perihel Richtung Mars (1,4 AU)

Technische Daten (Funk via Deep Space Network DSN + ESA/Perth)

- Gewicht 1.670 kg + Treibgas ca. 1.500 kg
- Energieversorgung Solar array (2 x 32 m<sup>2</sup>)  
850 W (3,4 AU) / 395 W (5,25 AU)
- Antennen 2,2 m High Gain Parabolspiegel +  
0,8 m Medium Gain Parabolspiegel +  
2 omnidirectional Low Gain
- Sendeleistung 28 W RF X-Band TWTA +  
2 x 5 W RF S/X-Band

Technische Daten Übertragungskanal 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

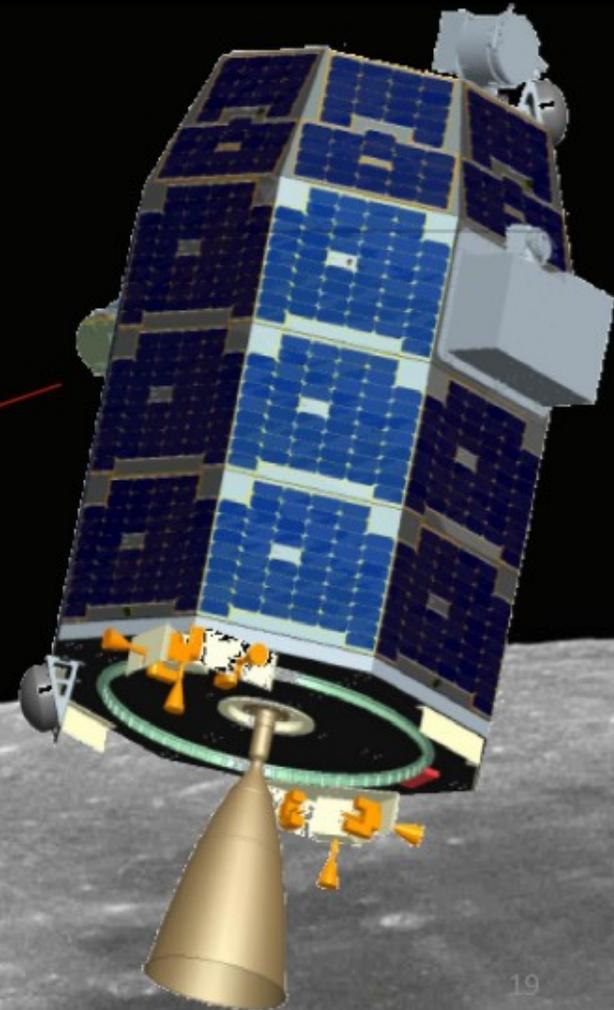
Abkopplung von Rosetta 12.11.2014; jetzt auf 67P ?

Technische Daten (Funk via Rosetta in max. 100 km Entfernung):

- Gewicht 100 kg
- Energieversorgung Solar array  
970 Whr + 110 Whr battery
- Antenne ??
- Sendeleistung 1 W RF S-Band transmitter

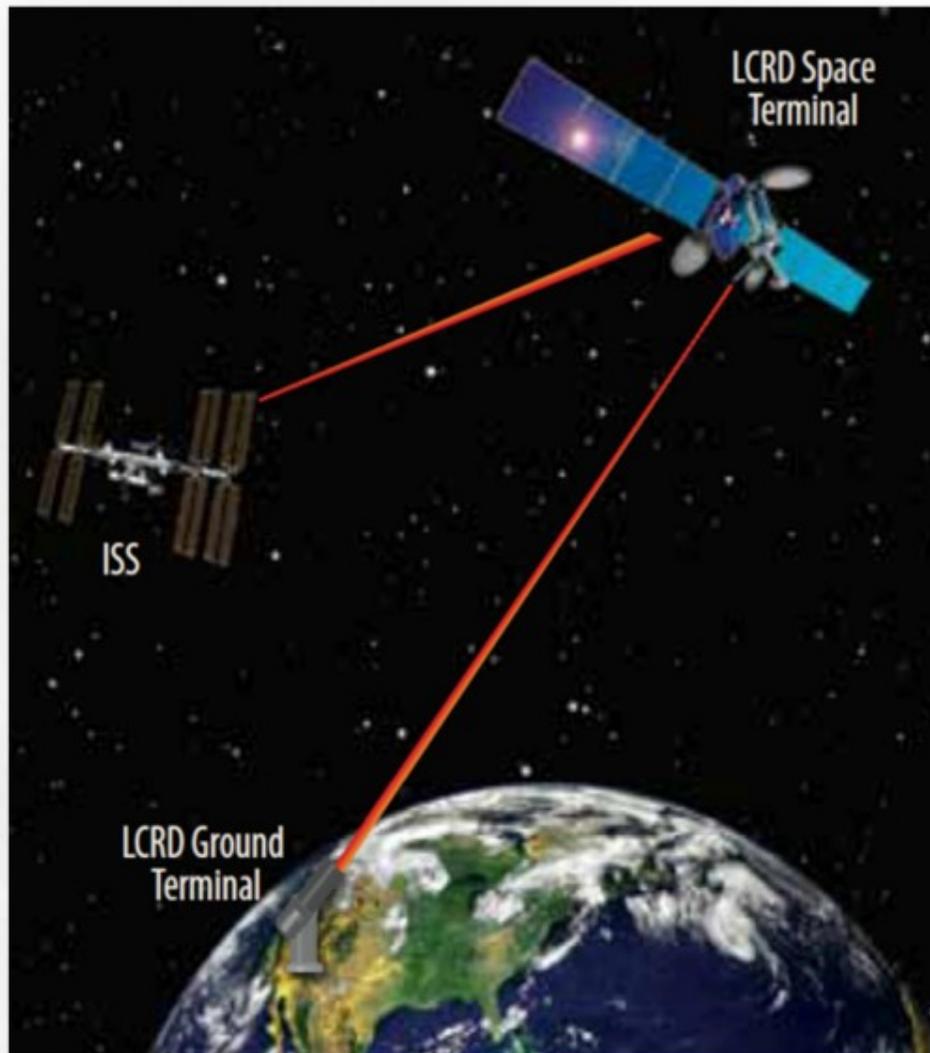
# Lunar Laser Communication Demo

- 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

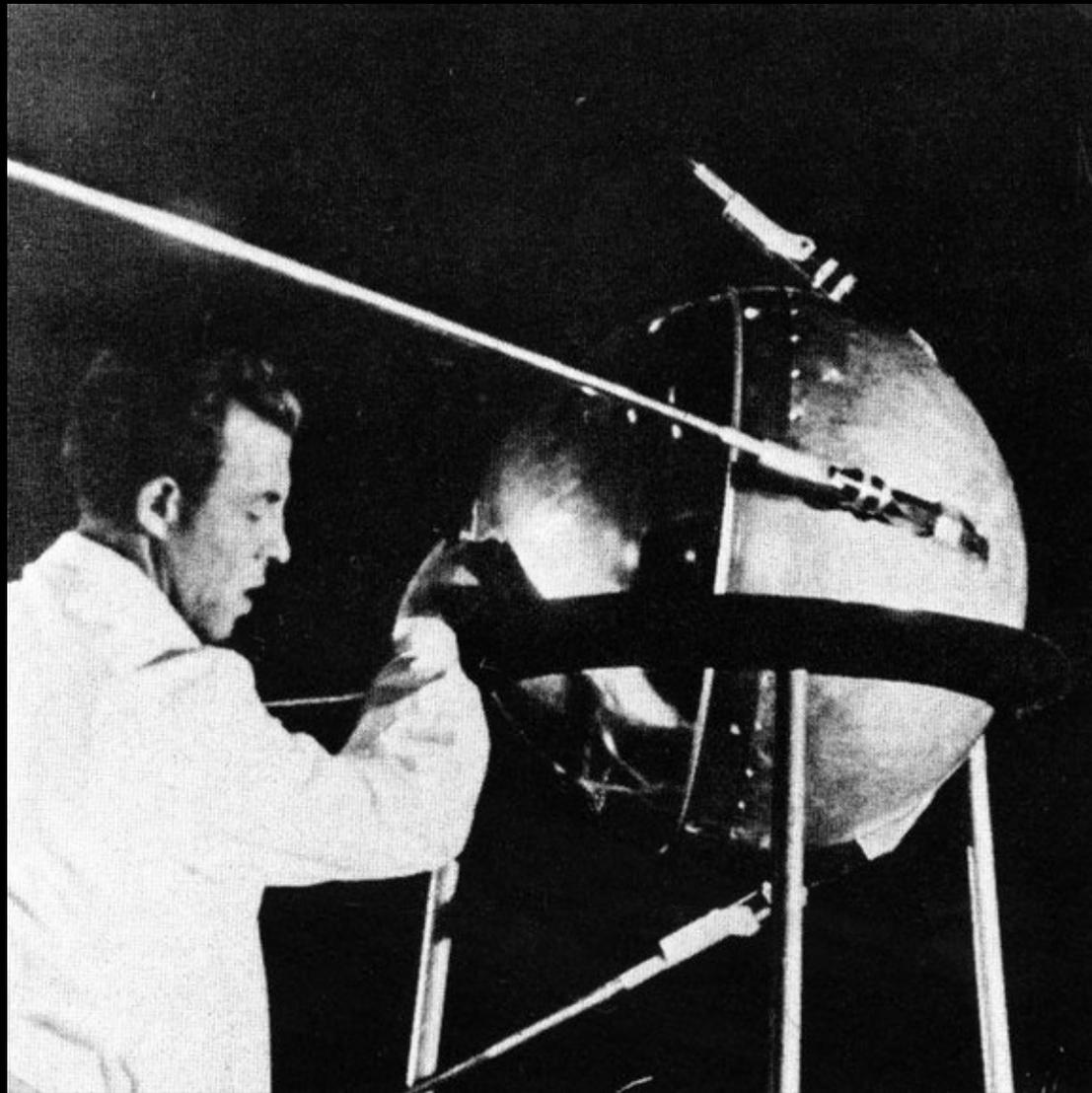




# Laser Communications Relay Demo (LCRD)



- 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 LLCDC 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.



Kurt.Niel@fh-wels.at - 12.10.2015

# HÖRPROBEN WELTRAUMGERÄUSCHE

1) Sputnik 1 (Okt. 1957) – Orbit 238 – 947 km; 20/40 MHz CW

<http://www.dd1us.de/sounds/DL3PD%20Alois%20-%202001%20-%20Sputnik%201%20first%20satellite%20reduced.mp3>

2) Sputnik 2 (Nov. 1957) – Orbit 320 – 1770 km; Herzschlag Hund 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) – Stimme Jurij Gagarin

<http://www.dd1us.de/sounds/DL3PD%20Alois%20-%202006%20-%20Juri%20Gagarin%20first%20man%20in%20Space%20reduced.mp3>

4) Mercury Atlas 6 (Feb. 1962) – Stimme John Glenn

[http://www.dd1us.de/sounds/Mercury-6\\_Zero-G.mp3](http://www.dd1us.de/sounds/Mercury-6_Zero-G.mp3)

5) Apollo 13 (Apr. 1970) – Weg zum Mond

<http://www.dd1us.de/sounds/apollo-13%20houston%20we%20have%20had%20a%20problem.mp3>

6) Voyager (Jul. 1979) – Plasma Wave Subsystem Nahe Jupiter

<https://www.youtube.com/watch?v=5j5lOblReqk>

7) EME Amateurfunk (1995) – OE2AXH über 6,4 m Parabolspiegel

[http://www.dd1us.de/sounds/EME\\_5GHZ6\\_OH2AUE\\_7\\_ssb.mp3](http://www.dd1us.de/sounds/EME_5GHZ6_OH2AUE_7_ssb.mp3)

8) Rosetta (2014?) – Magnetfeldoszillationen von 67P/Tschuryumov/Gerasimenko

[http://www.dd1us.de/sounds/manuel\\_senfft\\_-\\_a\\_singing\\_comet.mp3](http://www.dd1us.de/sounds/manuel_senfft_-_a_singing_comet.mp3)



Amateur Radio on the International Space Station

<http://www.ariss.org>

UK Amateur Radio Educational Satellite

<http://warehouse.funcube.org.uk>

## QUELLEN

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“-Dokument: Descanso4--Voyager\_new.pdf  
→ JPL „Voyager Telecommunications“, R. Ludwig, J. Taylor, March 2002

ARISS Amateur Radio on the International Space Station

- <http://www.ariss.org>

FUNCube UK Amateur Radio Education Satellite

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

Sounds from Space by Maththias Bopp/DD1US

- <http://www.dd1us.de>