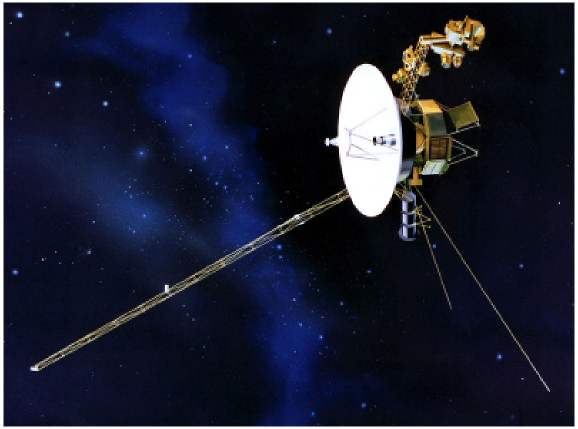
Reception of Voyager 1

the best DX ever!



Achim Vollhardt, DH2VA/HB9DUN

Amsat-UK Colloquium 2006

July 29th, 2006

Overview

- Some basics
- Teaming up
- Data Mining
- Calculations+Simulations
- Hardware
- Let's go!
- Results and Outlook

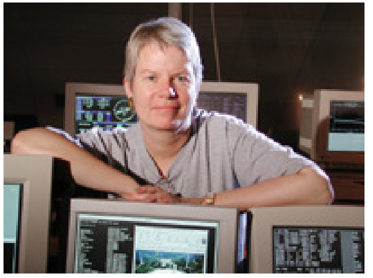
Some basics

- Deep space probes transmit in X-band: 8400-8450 MHz
- Biphase PSK modulation
- Deep Space Network uses 34&70 m dishes
  → beyond our capabilities

- +- 90 deg modulation would result in complete carrier suppression
- Probes use 60 or 70 deg: residual carrier (enhances tracking loop robustness in receiver)
- Typical carrier suppressions: -6 or -10 dB
- Amateurs CAN receive this constant carrier with small RX bandwidths and small antennas

First ideas

- Sept '04: Attended lecture of Paul Horowitz at physics conference : "SETI uses Voyager as beacon"
- Asked Jill Tarter for information (director SETI Institute)
- Response by SETI institute member just 24h later !
- James Miller, G3RUH confirmed possibility of detection with Bochum's 20m dish

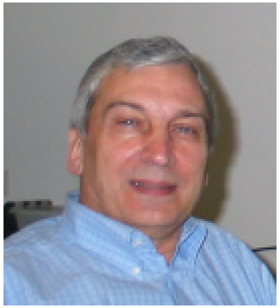


- Target date:
  30 year anniversary Amsat-DL at Sept 24, 2004
  → No success
- Reactivated idea on beginning of March 2006

Pull together the team

- James Miller, G3RUH
- Freddy de Guchteneire, ON6UG
- Hartmut Paesler, DL1YDD
- Achim Vollhardt, DH2VA

And many more..!



Ask the experts !

- Write email to Voyager mission PI : Prof. Edward C. Stone
- Got forwarded via Mission Manager to Mission Telecommunications Analyst Roger Ludwig
- Provided us with valuable and steady flow of information

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From: Ed Stone <. .>
Date: March 2, 2006 8:20:26 AM PST
To: Ed Massey <. .>
Subject: Fwd: Technical Question to Voyager radio downlink

Ed- I doubt they can detect VGR with an 18 m dish and amateur receivers, but could some one respond to this? Thanks, Ed

Nevertheless .. thank you all!

Data mining

DEep
Space
Communications
And
Navigation
Systems
Office

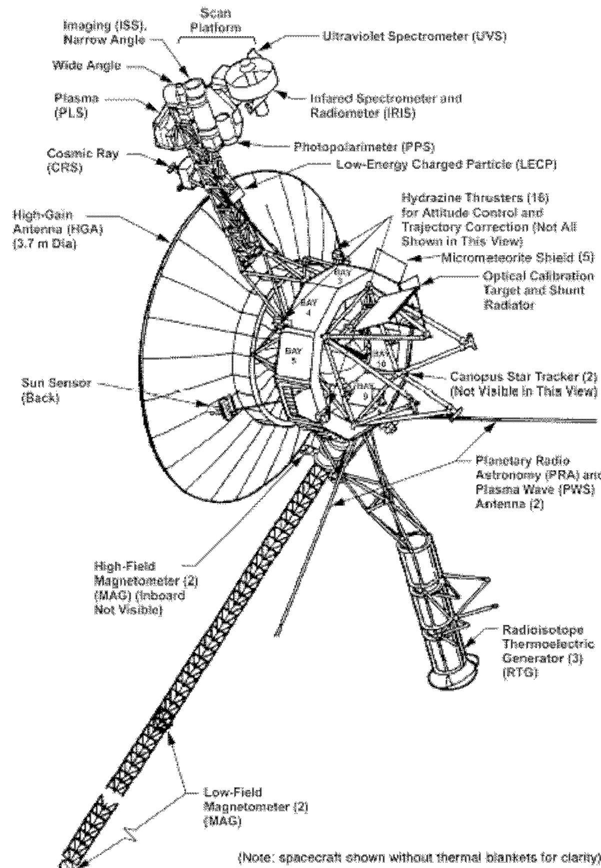
} DESCANSO

(descanso.jpl.nasa.gov)

- Has detailed (!) communications link information for multiple deep space missions
- Provided us with almost everything…

Voyager Spacecraft

- Three-axis stabilized s/c
- 3.74 m diameter HGA
- Radioisotopic Thermoelectric Generator (RTG)
- Mission life determined by
  - Hydrazine fuel (2040)
  - RTG power (2020)
  - Funding (4 Mill. USD per year)
- Magnetometer on 13 m long boom
  - Needs to be calibrated about 6 times per year (MAGROL)

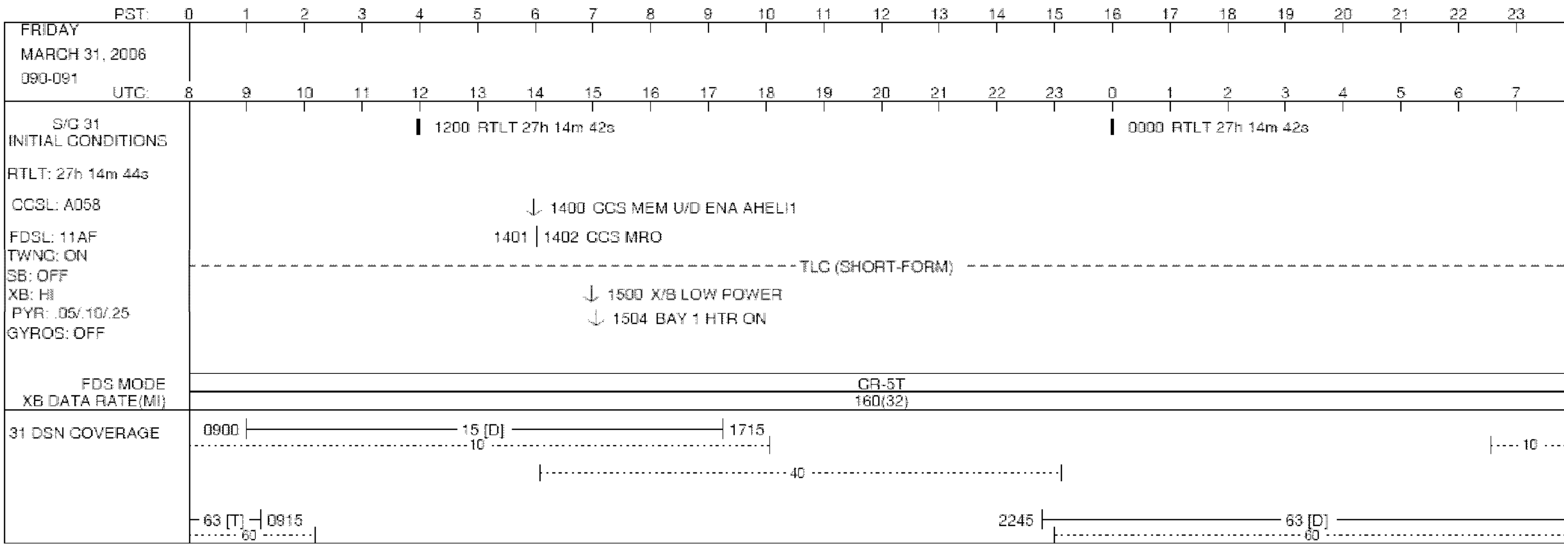


Voyager link parameters

- Frequency: 8415.000000 MHz (non-coherent)
  8420.432097 MHz (coherent)
- Polarisation: LHCP (not RHCP!) since failure of TWTA-2 in 1987
- Transmit power: 12/18 W in low/high power mode
- Carrier suppression: -6 dB
- Data rate: 160/1400 bps
- UltraStableOscillator (USO) failed in Sept. 1992,
  Voyager 1 relies now on crystal AUXOSC

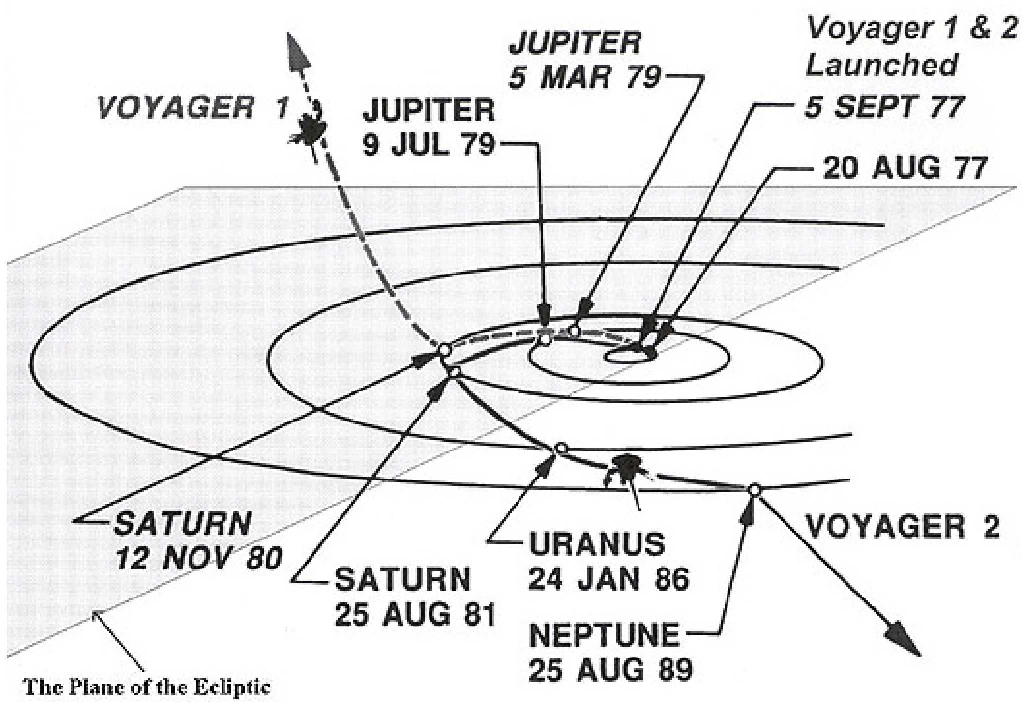
SFOS: space flight operations schedule

Available on Voyager Mission Homepage: http://voyager.jpl.nasa.gov



Where are Voyagers today?

- Voyager 1:
  98 AU
  (northbound)
- Voyager 2:
  80 AU
  (southbound)



One-way 'Radar' equation

<u>Standard version:</u>

Path loss [dB] $= 20\log(fR) + 20\log(4\pi/c)$
$= 20\log(fR) + (-147.55\text{ dB})$ (f= [Hz], R=[m])

Set f= 8.4 GHz and express R in astronomical units →

<u>DH2VA version:</u>

Path loss [dB] $= 20\log(R) + 274.4\text{ dB}$ (R=[AU])

How to use?

- 1 AU distance → path loss = 274.4 dB
- 1.5 AU (Venus today) → path loss = 276.2 dB
- 2.5 AU (Mars Today) → path loss = 278.8 dB
- 100 AU distance → path loss = 314.4 dB

1. Find out EIRP of spacecraft carrier :
   Transmit power + antenna gain – carrier suppression
2. Subtract path loss
3. Add RX antenna gain
4. Compare to receiver noise in assumed bandwidth (1 Hz)
5. Result: Signal-to-Noise Ratio in 1 Hz Bandwidth

Transmit side

Find out EIRP of spacecraft (DESCANSO + Google):

- MRO:
  100 W (50 dBm) + 3m dish (45.5 dBi) = 95.5 dBm (3.5 MW !)
  carrier suppression -10 dB: 85.5 dBm
- VEX:
  65 W (48.1 dBm) + 1.3m dish (38.3 dBi) = 86.4 dBm (436 kW)
  carrier suppression -10 dB: 76.4 dBm
- Voyager 1:
  18 W (42.5 dBm) + 3.74 m (48.2 dBi) = 90.7 dBm (1 MW)
  carrier suppression -6 dB: 84.7 dBm

Receive side

- Antenna gain

$$G = 10 * {}_{10}\log(\eta * (\pi * D/\lambda)^2)$$

- System temperature (Noise figure) → Noise power in 1 Hz

$$P = k * Tsys * B$$

Results for Bochum

- Diameter : 20 m
- Efficiency : 55%
- Gain: G = 61.9 dBi
- Moon noise : 3.3 dB → Tsys = 189 K

P = k * T * B = -175.8 dBm

spacecraft	EIRP	Path loss	Gain	Noise	SNR (1 Hz)
VEX	76.4	276.2	61.9	-175.8	37.9
MRO	86.5	278.8	61.9	-175.8	45.4
Voyager 1	84.7	314.4	61.9	-175.8	8.0

Detection principle

- Depending on signal level:
  - 40 dBHz: can be easily heard in speaker
  - 20 dBHz: can be heard with headphones
  - <20 dBHz: requires DSP (soundcard)
  - <10 dBHz: requires integration >1 sec
- Display signal power vs. AF frequency (Fourier display)
- Waterfall display: color code signal strengths and plot one line per integration period
- Integration: average over multiple FFT's and plot only one line for x FFT's: noise evens out, while signal persists

Performance Simulation

- G3RUH generated sample WAV files with 3 dBHz (735 seconds) to test analysis techniques
- G3RUH used own analysis package, same algorithm implemented in SCILAB (DH2VA)
  - Record audio samples
  - Perform FFT
  - Add to previous FFT results (integrate)
  - Use 10 Hz convolution filter to compensate for finite VFO step size
- Same algorithm on two different machines and software packages perform equally well and within expectations