Deep space reception by AMSAT-DL

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Tianwen-1, the Chinese mission to Mars

On 23 July 2020, Tianwen-1 launched from Hainan (China)



Source: the-sun.com

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The mission has an orbiter...

- Studies Mars geophysical properties from polar orbit
- Serves as a communications relay



Source: dw.com

...and a rover called Zhurong

- Landed on Utopia Planitia (Mars) on 14 May 2021
- Studies geological properties, including the search for water ice



Source: wikipedia.com

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Amateur tracking of Tianwen-1

- The mission caused great interest, because the X-band (8.4 GHz) frequencies and trajectory information were not public
- Amateur observers in Europe managed to find the spacecraft a few hours after launch



UHF Satcom ∰ S im @uhf_satcom · Jul 23, 2020 ···· Another #hearsat successI Detection and acquisition of Tianwen-1 Chinese Mars mission! 8430.879MHz RX freq. Approximate RA/DEC RA = 23.02 h, Dec = -3.193° - that'll teach them not to give us tracking data or frequency info :-) How do you like them eggs !!



- r00t.cz was able to decode the X-band telemetry signal using Paul M0EYT's recordings
- r00t.cz noticed some floating point numbers in the telemetry. I could identify these as *state vectors* giving the real-time position and velocity of the spacecraft.
- Knowing the trajectory, we could now tell the AMSAT-DL folks where to point the 20 metre antenna at Bochum Observatory (Germany). This antenna has a beamwidth of 0.1 degrees!
- I built a GNU Radio decoder for the telemetry signals (see the workshop at GRCon20)

Bochum Observatory's 20m antenna



Source: amsat-dl.org

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- Tracked almost daily for ~10 months (end of July 2020 to beginning of June 2021, and now back again in September!)
- Used a real-time GNU Radio decoder flowgraph with a USRP N210
- Nearly 6 GB of data gathered at 7 kbps (230 hours of decoding)
- Decoded signals from 393 million km (and increasing). This is probably the farthest digital communication decoded in real-time with GNU Radio
- Done YouTube livestreams on the major mission events

- Low data rate (real-time telemetry):
 - Residual-carrier phase-modulation
 - Data subcarrier at 65536 Hz, BPSK-modulated at 16384 baud
 - Concatenated coding (k = 7, r = 1/2 convolutional code + (252, 220) Reed-Solomon)
 - CCSDS AOS frames and Space Packets
- High speed signal:
 - Suppressed carrier QPSK
 - 2.048 Mbaud near Earth; much less in Mars orbit
 - Concatenated coding (k = 7, r = 1/2 convolutional code + 4x (255, 223) Reed-Solomon)
 - CCSDS AOS frames and Space Packets / ad-hoc

Low data rate signal



Tianwen-1 X-band telemetry spectrum



I know what you're thinking:

But this is GRCon... Show us some GNU Radio flowgraphs!

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- GMAT is an open source space mission simulation tool from NASA
- It includes an orbit propagator with a complex force model
- We used it to visualize Tianwen-1's trajectory, predict and calculate future maneouvres, etc.

GMAT demo

- Our paper in GRCon21 proceedings
- My blog https://destevez.net/tag/tianwen/
- r00t.cz's page http://www.r00t.cz/Sats/Tianwen1
- Last year's GRCon workshop "Decoding interplanetary spacecraft" https:

//github.com/daniestevez/grcon2020-workshop/