Decoding Mars spacecraft

Bits and pieces you can learn from spacecraft telemetry

Dr. Daniel Estévez EA4GPZ / M0HXM

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AMSAT-UK Online Colloquium

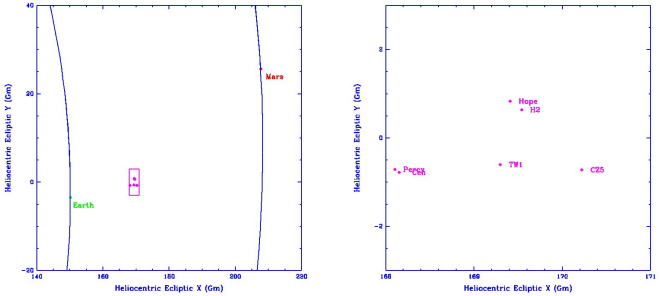
Meet the team

- Paul Marsh M0EYT
- Jakub (r00t.cz)
- AMSAT-DL / Bochum:
  - Achim Vollhardt DH2VA
  - Mario Lorenz DL5MLO
  - James Miller G3RUH
  - Michael Lengrüsser DD5ER
  - Thilo Elsner DJ5YM
  - Peter Gülzow DB2OS
- Edgar Kaiser DF2MZ
- Fer IW1DTU
- Graham Leighton G8FXB

Also special thanks to Jon Giorgini (JPL) for maintaining the ephemeris data at NASA HORIZONS, and to Bill Gray (ProjectPluto) for his analysis of optical observations

Meet the spacecraft

- In July, three spacecraft were launched to Mars:
  - Emirates Mars Mission (Hope), UAE, 19 July
  - Tianwen-1, China, 23 July
  - Mars 2020, USA, 30 July
- Not a coincidence! Launch windows to Mars are every 2 years and 2 months



*Plots by Jonathan McDowell (21 Sept)

Emirates Mars Mission (Hope)

- Orbiter to study Mars atmosphere
- 8402.7 MHz, LHCP (RHCP is the usual norm!)

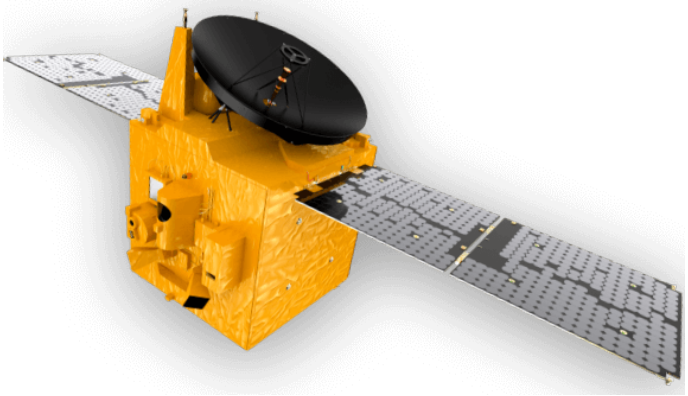


*Image from emiratesmarsmission.ae

Tianwen-1

- Orbiter and rover
- Very little information published: no frequencies published in ITU, no orbital information...
- Found by Paul, Edgar and others at 8431 MHz

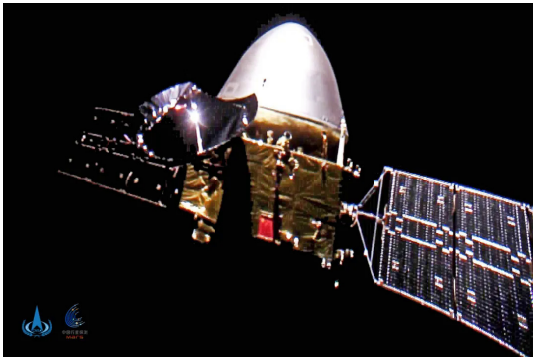


*Image from Chinese National Space Agency

Mars 2020

- Rover (Perseverance) and helicopter drone (Ingenuity)!
- 8414.9 MHz
- Very little in the spacecraft — only support for the journey to Mars

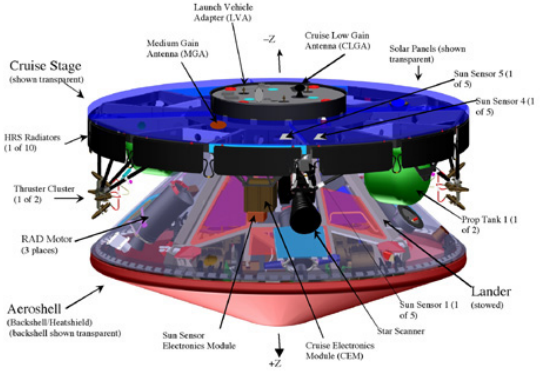


*Image from NASA

How to receive these spacecraft?

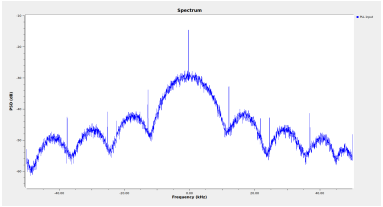
- They transmit in X-band, 8.4 - 8.45 GHz $\Rightarrow$ self-made microwave feed, LNA, downconverter, etc.
- Put up a dish in your backyard...

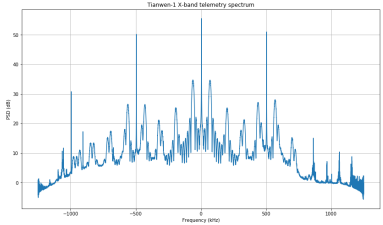
*Dish at Paul's M0EYT

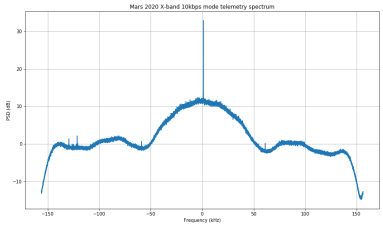
- ...or use Bochum's 20m antenna

- RX: 2.2 - 2.45 GHz, 8.4 GHz, 10 GHz; TX: 2.45 GHz
- Managed by AMSAT-DL, it's a real treasure for the Amateur radio community

Hopefully you'll be able to see a signal

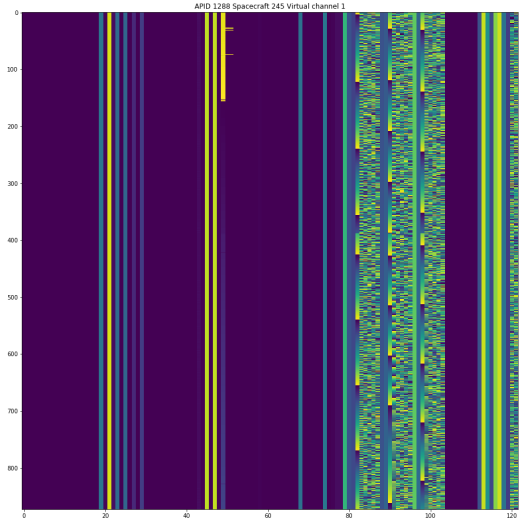






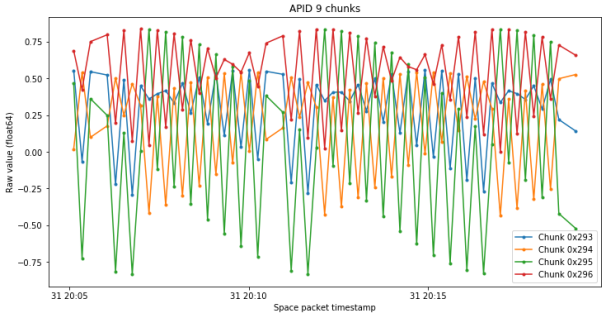
- If the signal is weak, you'll just see the CW carrier in the middle
- But if the signal is strong, you'll see the data sidebands and you can decode the data
- We use GNU Radio to decode the data, in real-time or from recordings, and store the received frames in a file

But what do all these bits mean?



- We often plot the bytes in the frames to identify different fields and see how/when they change
- But it's usally difficult to guess what these number really mean
- They might be voltages, temperatures, angles, or really any measurement of whatever is going on in the spacecraft

Plotting the data can help



- These are 4 telemetry channels from Mars 2020 which show the same kind of oscillations
- What do they mean? No clue...
- We would have to know if something in the spacecraft is “oscillating” in this way

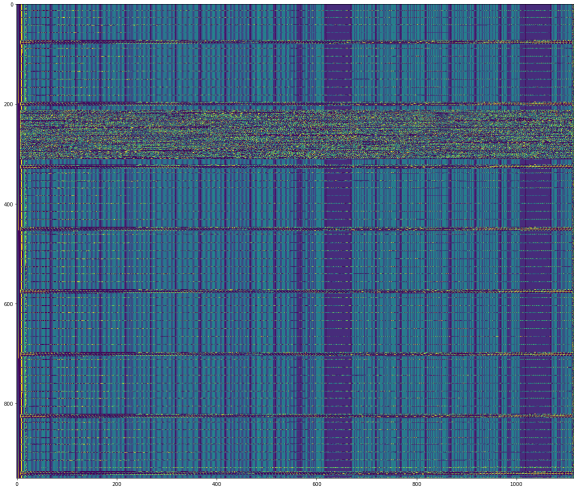
And sometimes we see something obvious

Such as this ASCII text used as padding for Mars 2020 idle frames

```
N.Abcouwer P.Basa M.Belete E.Benowitz S.Brooks
J.Biesiadecki L.Burke D.Byrne S.Chen S.Scandore
J.Carsten K.Edelberg D.Gaines D.Leang R.Joshi
R.Haleski A.Harris L.Galdamez S.Lewis T.Litwin
D.Lam Q.Ho M.Maimone M.McHenry D.Morgan S.Myint
B.Martin P.Partikian G.Rabideau P.Romano R.Tsao
M.Schoppers A.Shearer R.Srisamang C.Williams
L.Stewart O.Toupet I.Trettel I.Uchenik V.Verma
P.Vieira E.Wang B.Wright G.Yang B.Cichy C.Pong
G.Reeves M.Tuszynski J.Casoliva P.Brugarolas
Z.Rahman G.Griffin T.Fouser M.Wang P.Kwan
A.Baez Harry *** The MSL FSW development team.

 There is beauty in space, it is orderly. There
 is no weather, and there is regularity. It is
 predictable. Just look at our little Explorer;
 you can set your clock by it. Everything in
 space obeys the laws of physics. If you know
 these laws, and obey them, space will treat
 you kindly.      -- Wernher von Braun

 Deep Purple '72 - Let's go Space Truckin'
```



Why is Tianwen-1 our “favourite” spacecraft?

- It’s no secret that among the 3 Mars spacecraft, we pay much more attention to Tianwen-1. But why?
- It has a huge signal: even with a 60cm dish, Scott Tilley VE7TIL is able to make out the data sidebands at 25 million km
- It transmits more varied and interesting telemetry than the others. It also seems somewhat easier to understand
- The lack of information maybe makes it a more attractive challenge

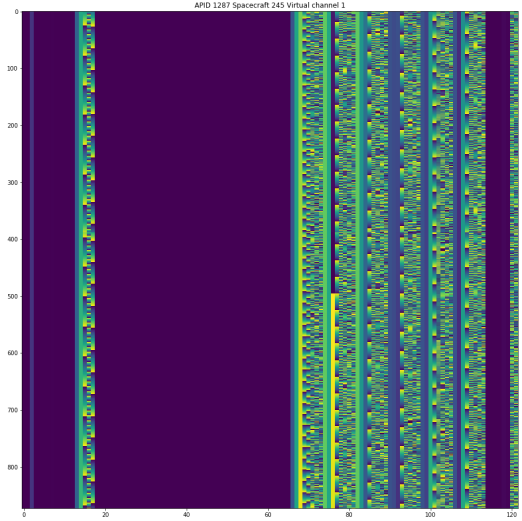
Finding Tianwen-1's orbit

- Everything started with Paul showing me these numbers r00t.cz had found in the telemetry and asking if they could be star tracker data

```
  start at 20200723 064007z
77395324.623705 -120028596.942956 -52029631.885987 31.179136 15.128088 7.490056
77396322.143351 -120028112.790527 -52029392.206920 31.164092 15.130745 7.489563
77397319.187608 -120027628.552638 -52029152.543120 31.149230 15.133334 7.489055
77398315.752926 -120027144.235999 -52028912.897277 31.134548 15.135857 7.488534
```

- I realized they were actually coordinates for the spacecraft's position and velocity
- Clues:
  - 3 numbers of one "type", 3 numbers of another "type"
  - Subtract two rows: we get 32 times the 3 last columns $\Rightarrow$ measurements every 32 seconds and velocity in 3 last columns
  - Distance to the origin: close to 1AU (Sun-Earth distance)
  - Plot the position: is it close to Earth?

No tricks up our sleeve: these do come from the telemetry



- On the right we see the 6 numbers
- On the left we see something that looks like timestamps

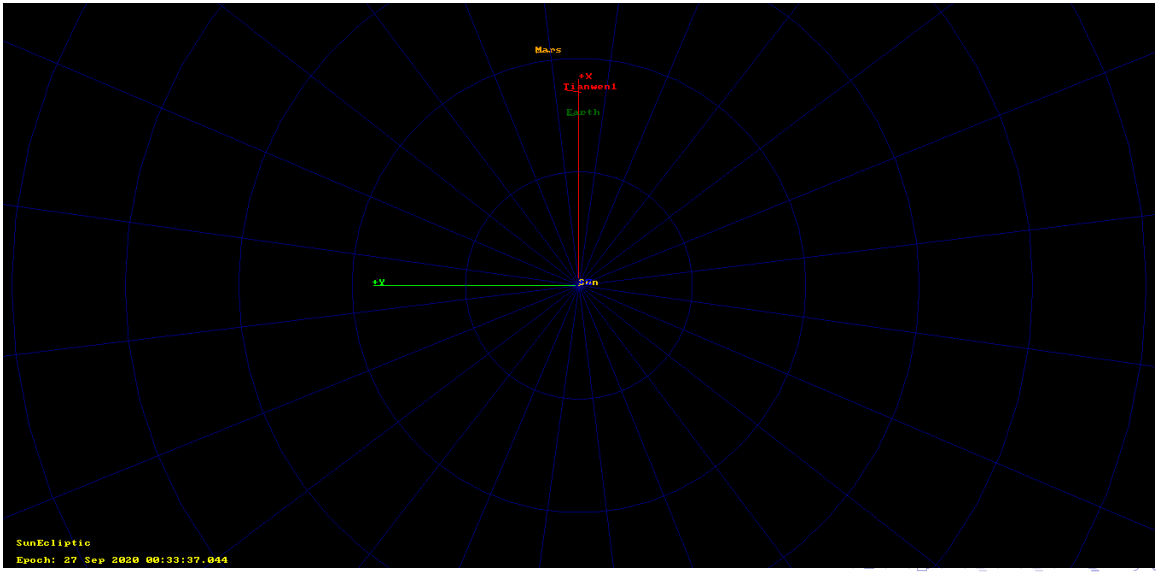
A matter of timestamps

- Without accurate timestamps, the position data is not very useful: everything moves in space
- Timestamps look like these: `779751d0`, `779c33d6`, `77a115e2`
- Subtract timestamps (should give you 32 seconds) $\Rightarrow$ it is a counter in units of 0.1ms
- But when does the counter start? What is the epoch? And why?
- We could estimate an epoch of 2020-07-22 23:03:19.8 UTC, which doesn't make any sense
- A few days later we saw the `014f` bytes before the timestamp change to `0150` and realized that they were also part of the timestamp
- Now our epoch estimate was pretty close to 2015-12-31 16:00:00 UTC
- This is Beijing time 2016-01-01 00:00:00, so it totally makes sense!

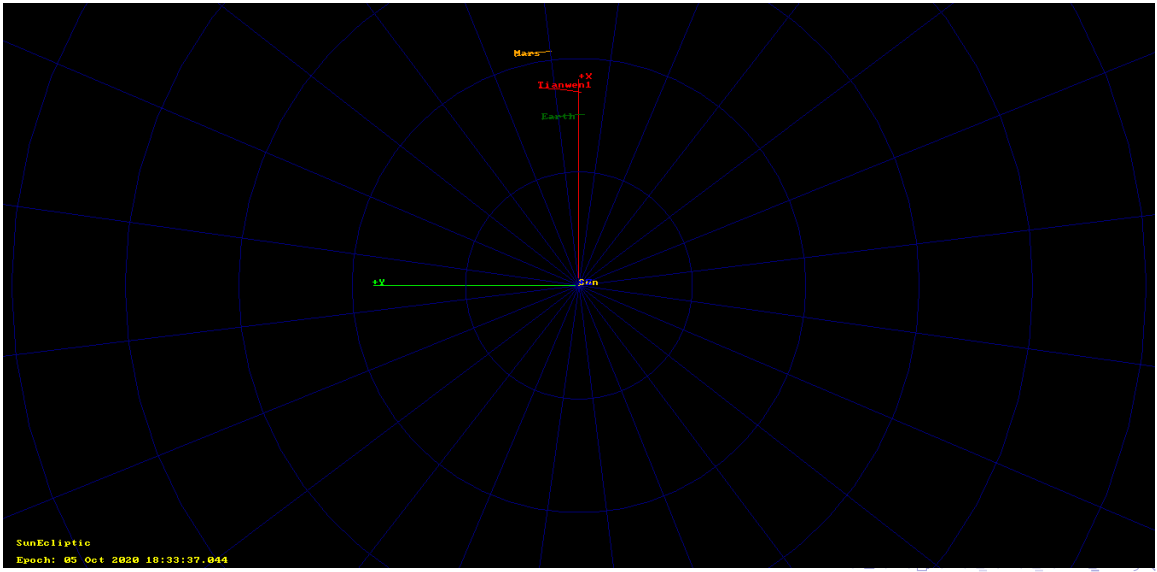
Using the orbit data

- Using the position and velocity data, we can propagate the trajectory into the future or past
- This doesn't consider trajectory correction burns, which we don't know in advance
- But we can keep receiving the telemetry to observe correction burns:
  - Bochum runs a fully automated receiver and collects data every day
  - We pass the new information to JPL if there are trajectory changes
- We use GMAT to calculate the trajectory

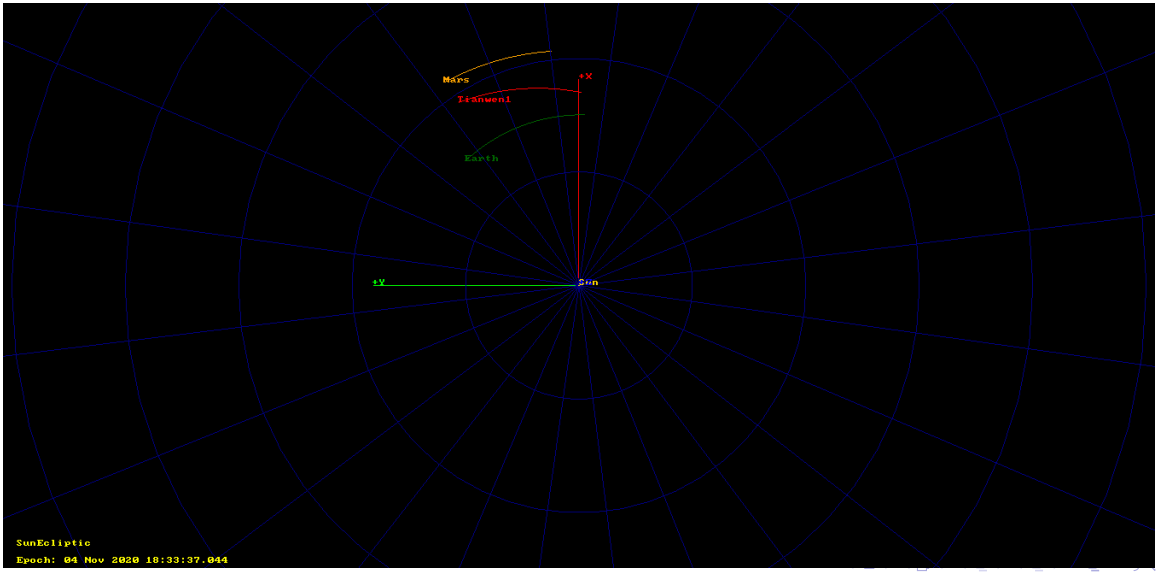
Trajectory in GMAT



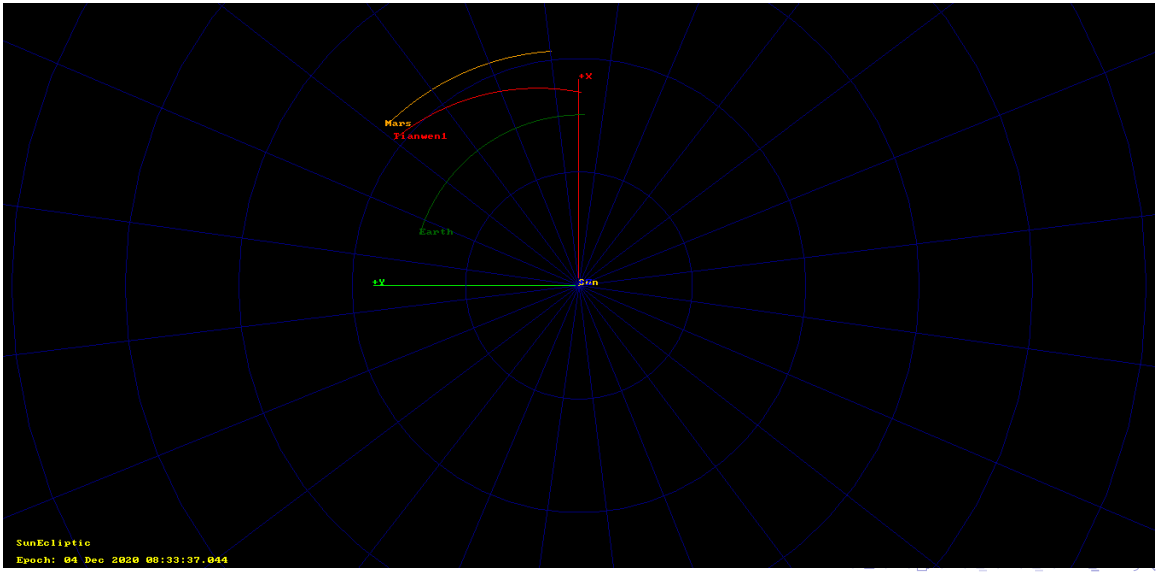
Trajectory in GMAT



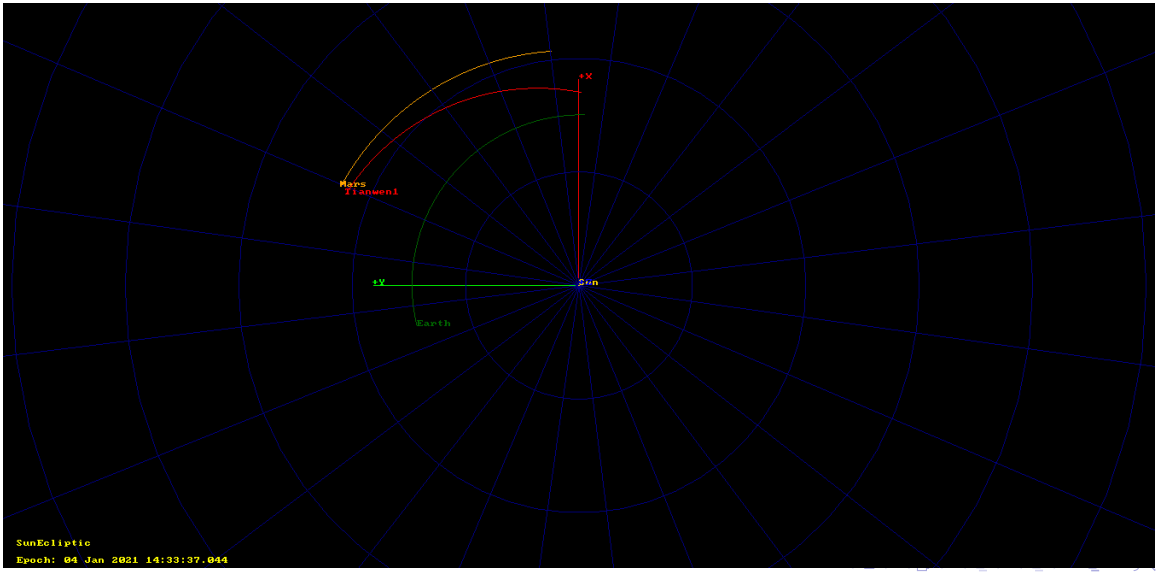
Trajectory in GMAT



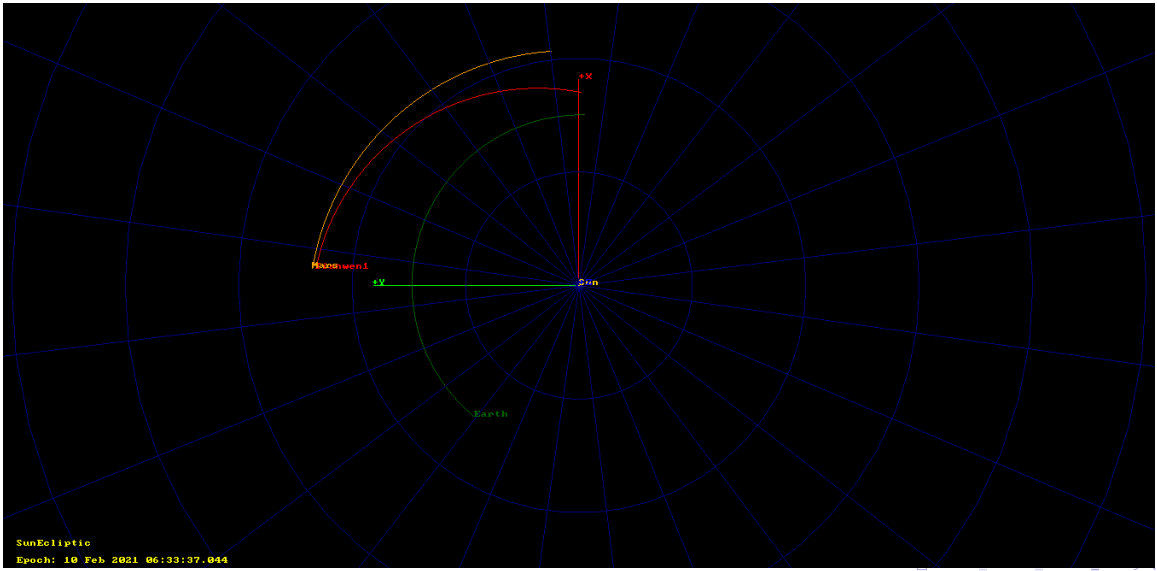
Trajectory in GMAT



Trajectory in GMAT



Trajectory in GMAT



Deep Space Manoeuvre

- We already saw small correction burns TCM-1 (1 August) and TCM-2 (20 September)
- The orbit that Tianwen-1 was launched in would only get within 3 million km of Mars
- We were expecting a large correction burn
- This happened last Friday at 15:00 UTC! (right after the end of the Chinese Mid-Autumn festival)
- Soon after the spacecraft started being tracked by Bochum and Paul at 19:00 UTC, we were able to get telemetry and check that the new trajectory gets within 22000 km of Mars

Tianwen-1 arriving at Mars