Spacecraft Doppler tracking software (SDtracker)

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Arising from software developed for the 2005 Huygens probe landing, the first official version of the **SDtracker** software was used for the 2008 initial detection test of the ESA's Venus Express (VEX) space mission.

In the **13 years since**, SDtracker has been regularly updated to accommodate different radio **telescope configurations**, newer VLBI **data formats**, different **hardware architectures**, and more.

Recently, a **major upgrade** was released to address several **performance and usability** issues. This newer version has a **simplified installation process**, **removed or updated dependencies**, and does the same job in **significantly fewer lines of code**.

Planetary Spacecraft Missions

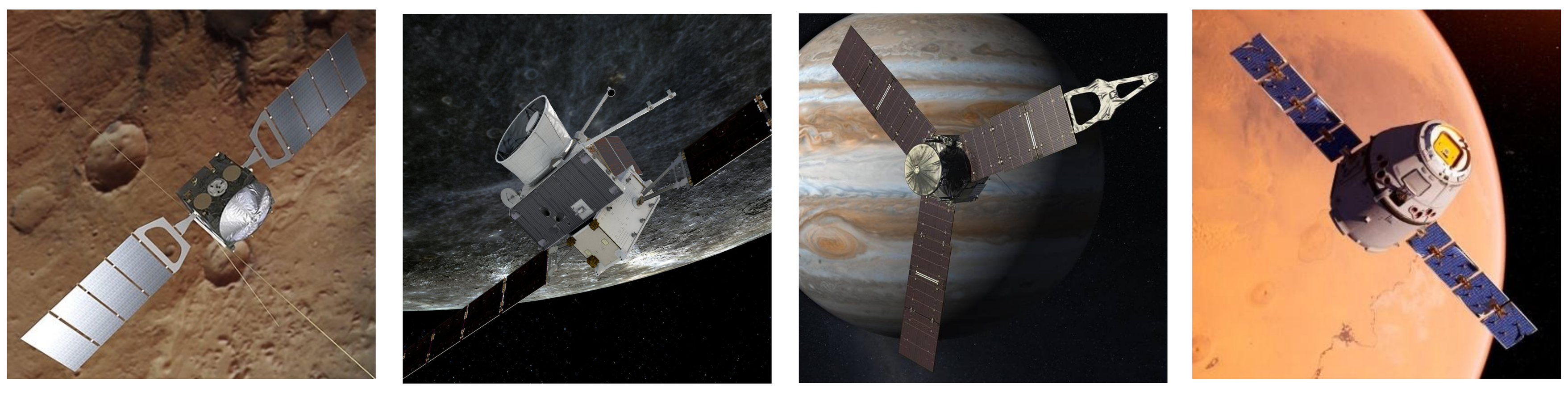

Figure 1. Key spacecraft that SDtracker has been used to track (Mars Express, BepiColombo, Juno, and Tianwen).[1]

SDtracker has been used to track planetary spacecraft **throughout the Solar system**. This is the primary task the software was designed for, so it can be used to obtain topocentric Doppler detections that isolate spacecraft signals to **within ~50m** over multiple AU, and the reconstructed and residual phases of the spacecraft carrier [1].

Asteroid Tracking

SDtracker has been used to track **dozens of asteroids**, from data captured by radio telescopes as small as **12 metres in diameter**. The NASA Dep Space Network in Canberra is used to transmit at 7159 MHz and the VLBI antennas are used to capture the 'echo' reflected to Earth [2].

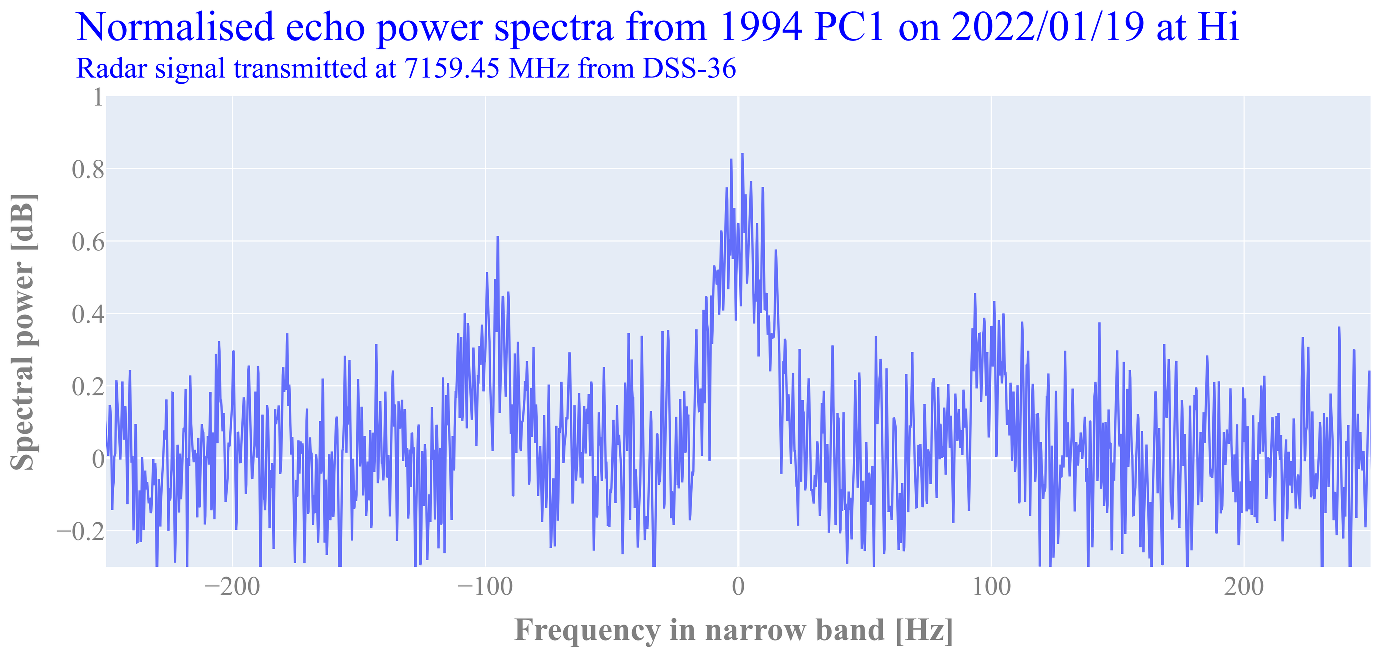

Figure 2. Reflected echo from 1994 PC1 asteroid at 2 million km.

Spectral Line Observations

With an inbuilt software spectrometer, SDtracker is suitable for single-dish spectroscopy for astronomical applications.

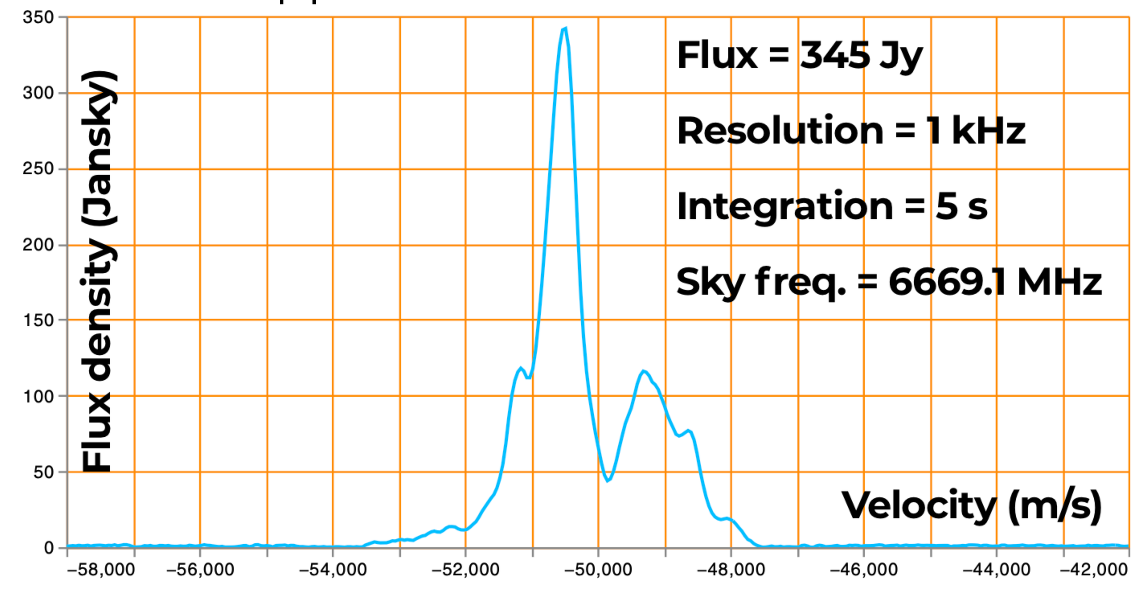

Figure 3. Observation of the G323.740 **methanol maser**, as part of the university's long-term investigation into early detection of **maser flares** in high-mass star forming regions [3].

Satellite and Debris Monitoring

SDtracker has been effectively used for a wide range of near-Earth **spacecraft tracking** and **space domain awareness** tasks, including:

- object tracking, spin state evolution, and pattern-of-life assessment;
- RF characterization;
- receiver targeting (for spacecraft communications); and
- debris detection.

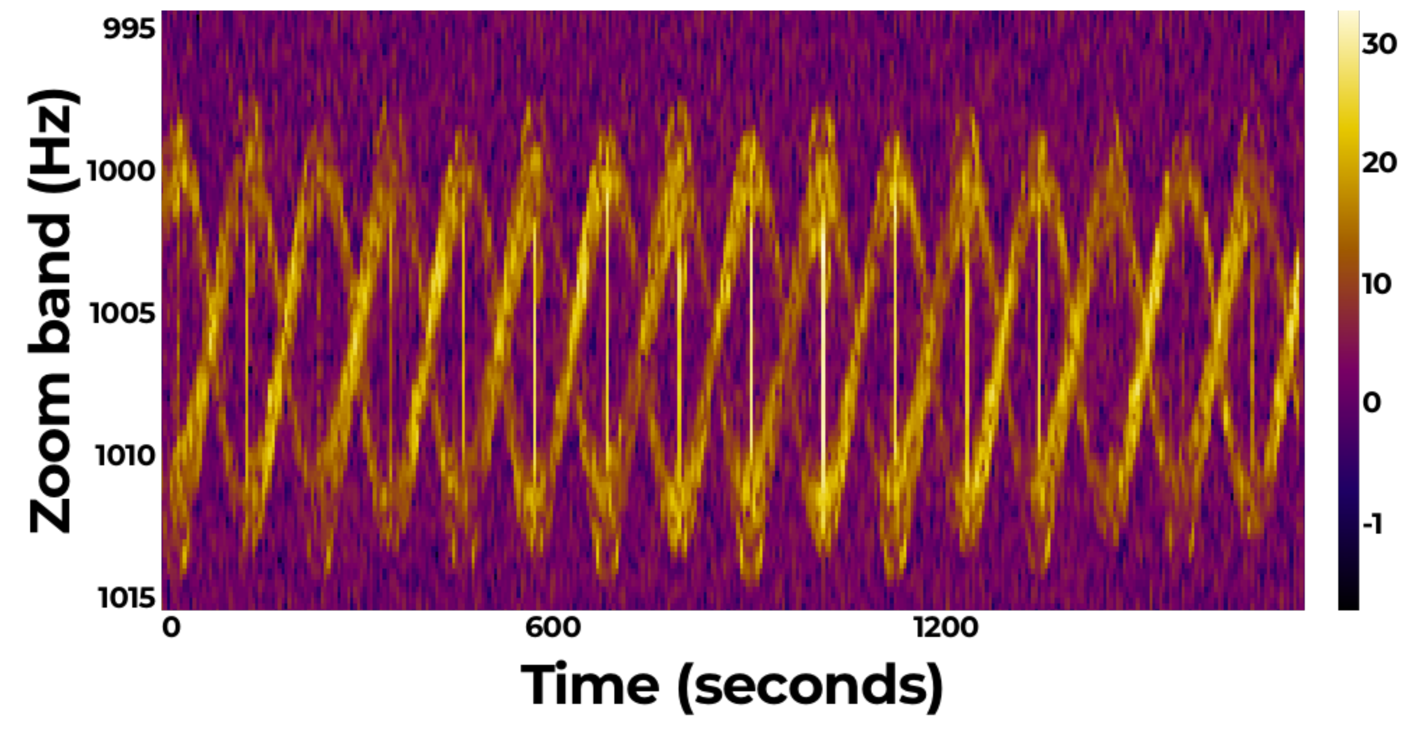

Figure 4. The observed micro-Doppler signature of rocket body 2015-056B, showing the rotation of the debris object every ~220 seconds [4].

Space Weather

The **phase scintillation** of planetary spacecraft signals have been analysed with SDtracker to detect and characterise phenomena such as Interplanetary **coronal mass ejections** [5].

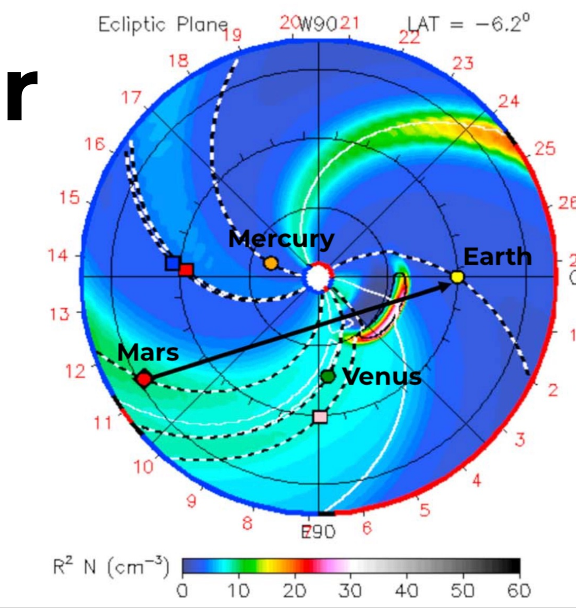

Figure 5. The R^2 times electron density at the time of a detected ICME. The path of the transmission used is shown by the black arrow (Source: iSWA).

gitlab.com/gofrito/sctracker

[1] **Credits:** ESA/ATG medialab and ESA/DLR/FU Berlin (Mars Express), ESA/ATG medialab (BepiColombo), NASA (Juno), Reuters (Tianwen-1).

References

[1] Duev, D. A. et al. (2016). **Planetary Radio Interferometry and Doppler Experiment (PRIDE) technique: A test case of the Mars Express Phobos fly-by.** *Astronomy & Astrophysics*, 593, A34. doi:10.1051/0004-6361/201628869

[2] *Horiuchi, S. et al. (2021).* **Bistatic radar observations of near-earth asteroid (163899) 2003 SD220 from the southern hemisphere** . Icarus 357 (2021) 114250. doi:10.1016/j.icarus.2020.114250

[3] Molera Calvés, G. et al. (2021). **High spectral resolution multi-tone Spacecraft Doppler tracking software: Algorithms and implementations.** *Publications of the Astronomical Society of Australia*, 38, E065. doi:10.1017/pasa.2021.56

[4] Molera Calvés, G. et al. (2022). **Micro-doppler signatures of space debris observed with radio telescopes.** Submitted to *IEEE Transactions on Aerospace and Electronic Systems.*

[5] Molera Calvés, G. et al. (2017). **Analysis of an Interplanetary Coronal Mass Ejection by a Spacecraft Radio Signal: A Case Study.** *Space Weather*, 15, 11. doi:10.1002/2017SW001701

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