UNIVERSITY of TASMANIA

Developments in Doppler tracking software (SDtracker)

GUIFRÉ MOLERA CALVÉS & MARS BUTTFIELD-ADDISON, UNIVERSITY OF TASMANIA, AUSTRALIA

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**.

Here we discuss the **scientific achievements** and **novel applications** of the improved software.

Planetary Spacecraft Missions

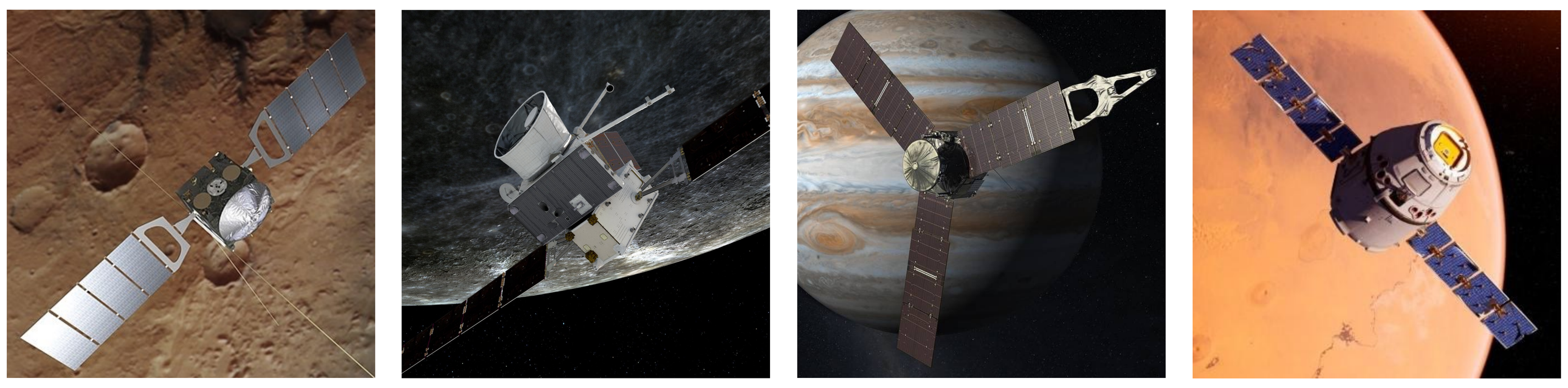


Figure 1. Key spacecraft that SDtracker has been used to track (Mars Express, BepiColombo, Juno, and Tianwen).[1]

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, as well as 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**

Bistatic radar experiments have been done using transmitters from the NASA Deep Space Network in Canberra to transmit tones, and VLBI receivers around Australia to capture the 'echo' returned to Earth [2].

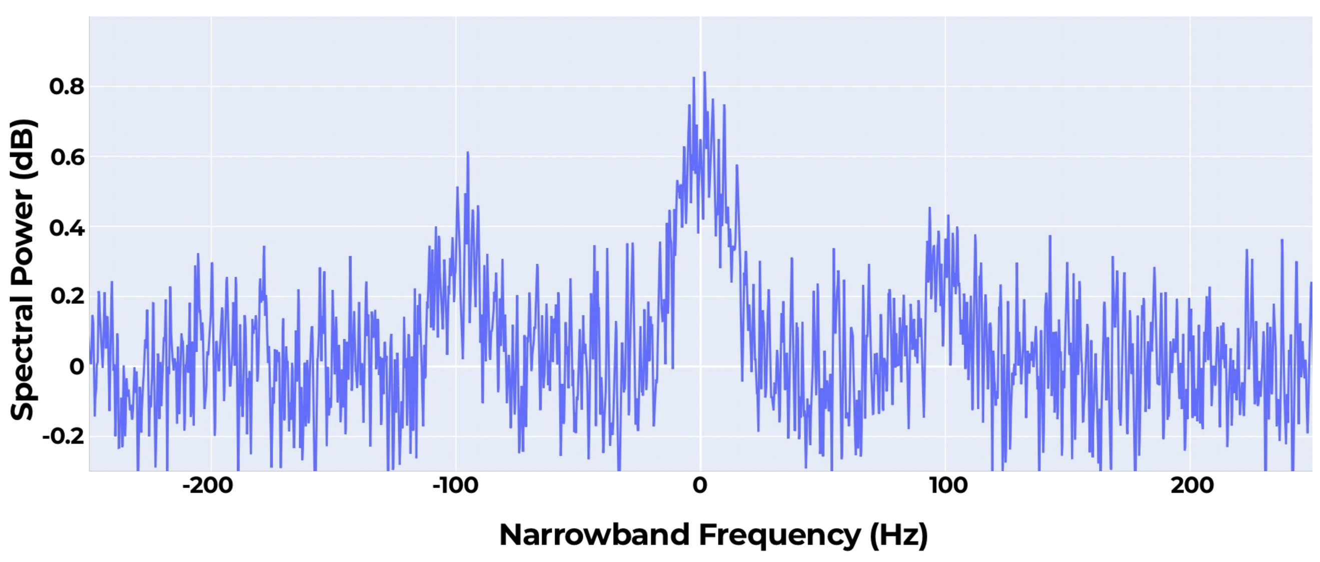
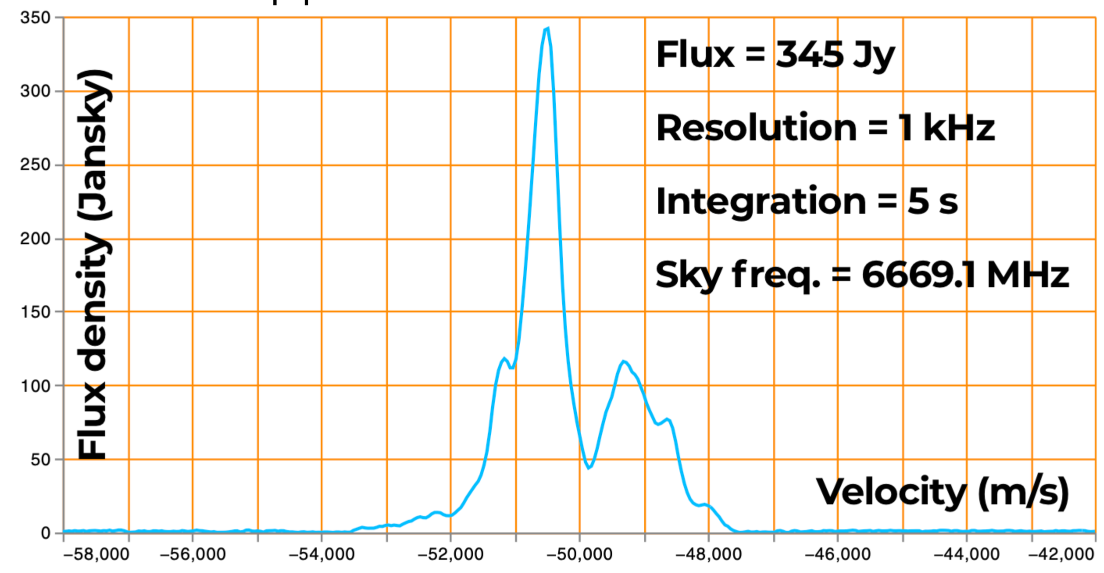


Figure 2. Normalised echo from asteroid 1994-PC1 at a range of 2 million km to a 12m dish.

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.

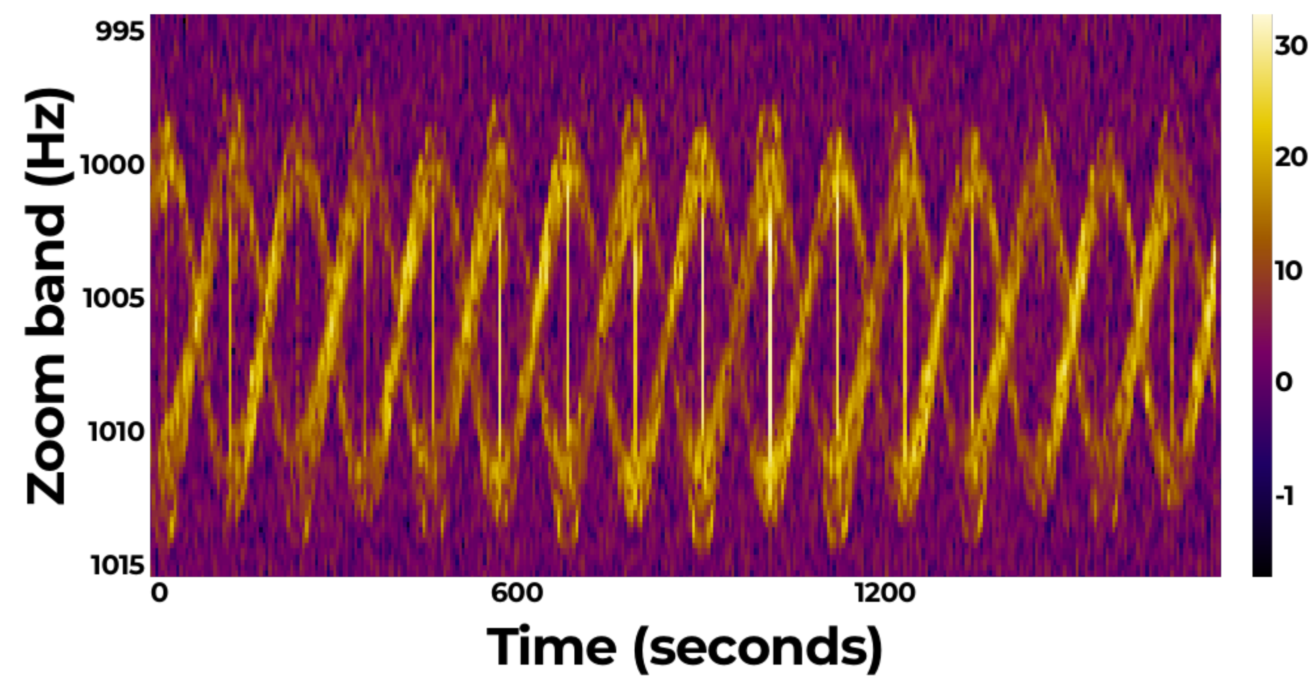


Figure 4. The observed micro-Doppler signature of rocket body 2015-056B, showing the rotation of the debris object every ~220 seconds [4].

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** (ICMEs) [5].

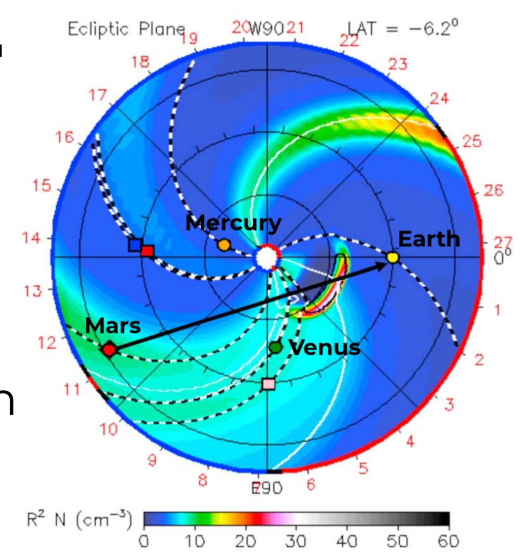


Figure 5. The R^2 times electron density at the time of a detected ICME. The path of the transmission used is shown by the black arrow (Source: iSWA).

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

Author contact: guifre.moleracalves@utas.edu.au