Open Source Satellite Tracking

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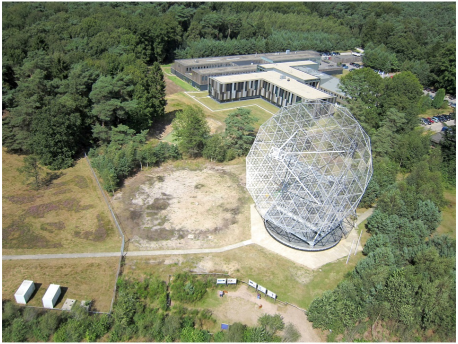
Background

- Radio astronomer (PhD) at ASTRON, the *Netherlands Institute for Radio Astronomy*. Using the LOFAR radio telescope to study pulsars
- Volunteer developer at *Libre Space Foundation* (SatNOGS stations #39, #40)
- Volunteer at the 25 m Dwingeloo radio telescope (SatNOGS station #384)
- Amateur satellite tracker



Catalogs of orbital elements

Where to get orbital elements:

- US military (CSpOC) publishes orbital elements for ∼18250 satellites
  Two-line elements (TLEs) publicly available at www.space-track.org
- Access to elements of national security satellites from US & allies (FR, DE, IL, JP. . .) is restricted
- Small world-wide group of amateur observers track ∼300 classified satellites
- Positional measurements from different methods
- Most measurements shared via SeeSat-L mailing list (www.satobs.org/seesat)
- Regular orbit updates computed by Mike McCants (www.prismnet.com/~mmccants/tles)

Open source satellite tracking software

sattools: github.com/cbassa/sattools

- Optical tracking using video and photographic cameras
- Capture and calibrate observations (time & astrometry)
- Predict, identify and measure satellite tracks
- Tools for planning, orbit determination, visualization

stvid: github.com/cbassa/stvid

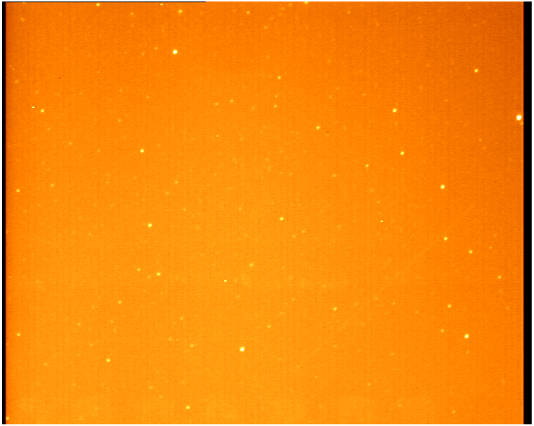
- `python` port of video tracking functionality from `sattools`
- Automatic track detection and position measuring

strf: github.com/cbassa/strf

- Radio tracking using software defined radios
- Record timestamped waterfalls (radio frequency vs time)
- Predict, detect, identify and measure Doppler curves
- Tools for orbit determination, visualization

Optical tracking: sattools/stvid acquisition

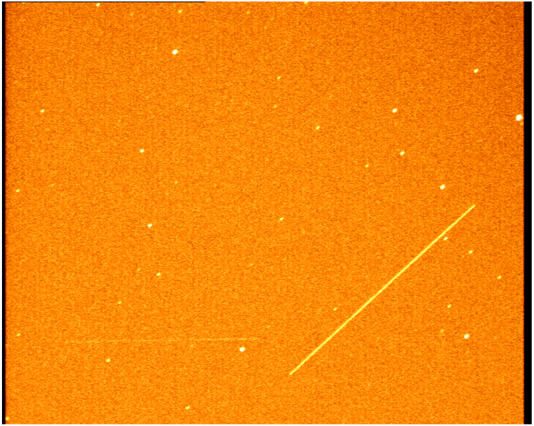
Data compression using **maximum temporal pixel** method (Gural & Segon 2009)



Average of N video frames

Optical tracking: sattools/stvid acquisition

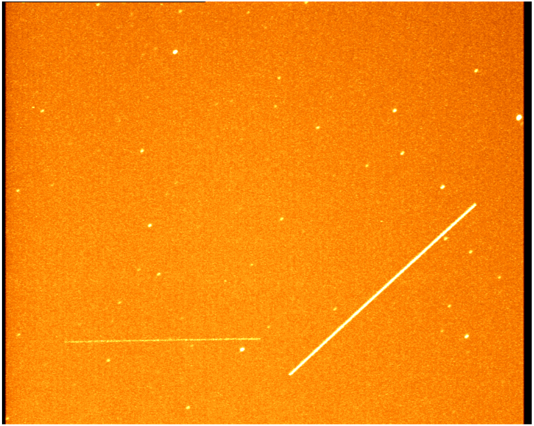
Data compression using **maximum temporal pixel** method (Gural & Segon 2009)



Standard deviation of *N* video frames

Optical tracking: sattools/stvid acquisition

Data compression using **maximum temporal pixel** method (Gural & Segon 2009)



Maximum of N video frames

Optical tracking: sattools/stvid acquisition

Data compression using **maximum temporal pixel** method (Gural & Segon 2009)

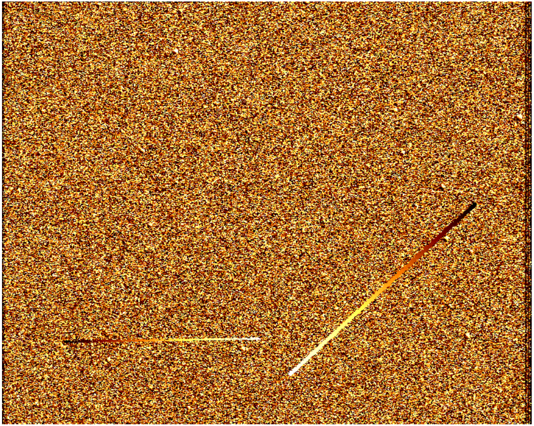


Image index of maximum (`argmax`) of *N* video frames

Optical tracking: sattools/stvid workflow

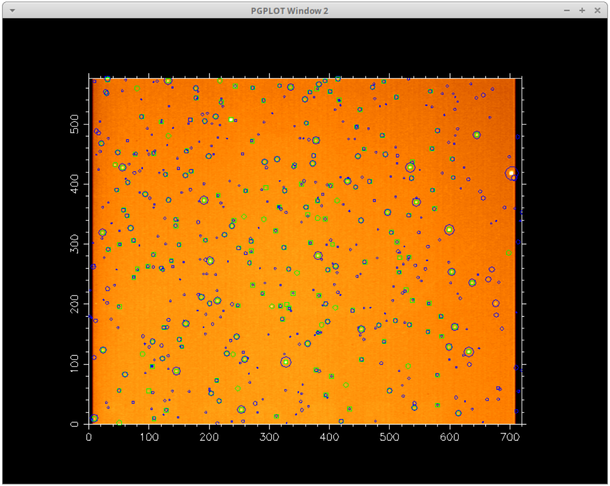
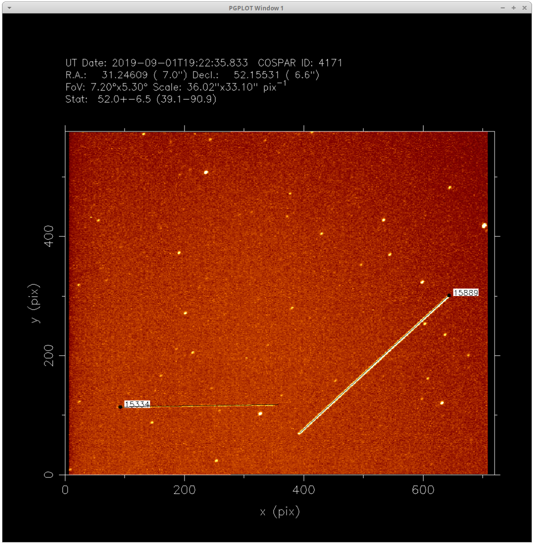


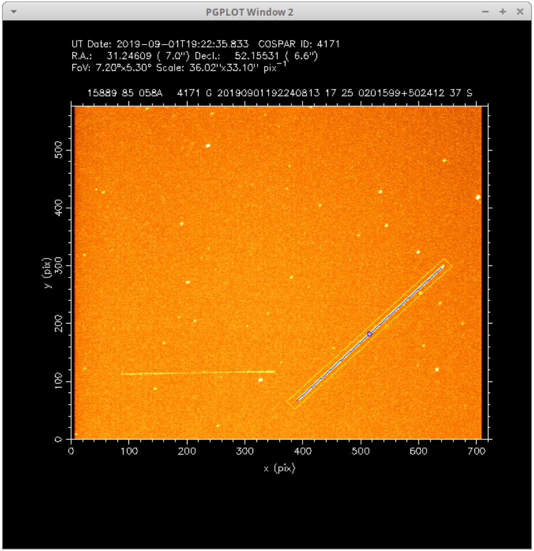
Image calibration against known stars

Optical tracking: sattools/stvid workflow



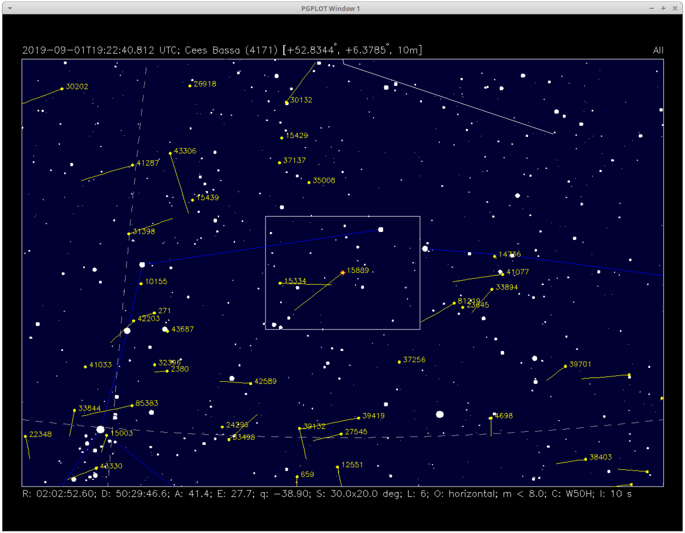
Satellite predictions using SGP4/SDP4

Optical tracking: sattools/stvid workflow



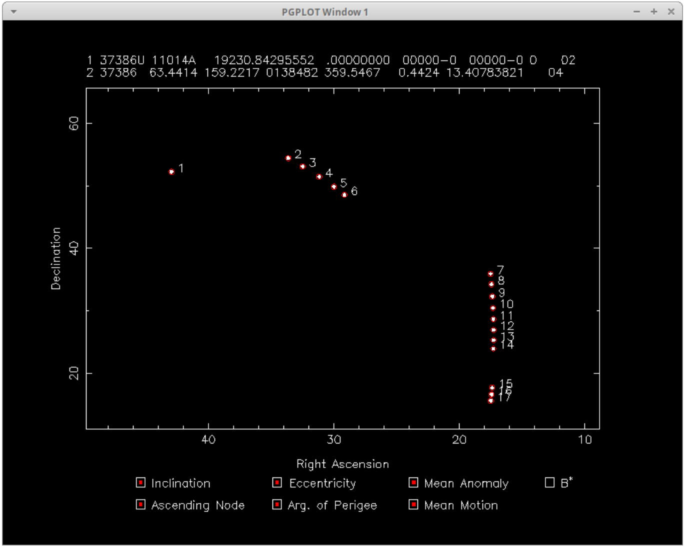
Determine positions from satellite tracks

Optical tracking: sattools/stvid workflow



Compare positions against predictions

Optical tracking: sattools/stvid workflow



Use positions for orbit determination against SGP4/SDP4

Optical tracking: hardware

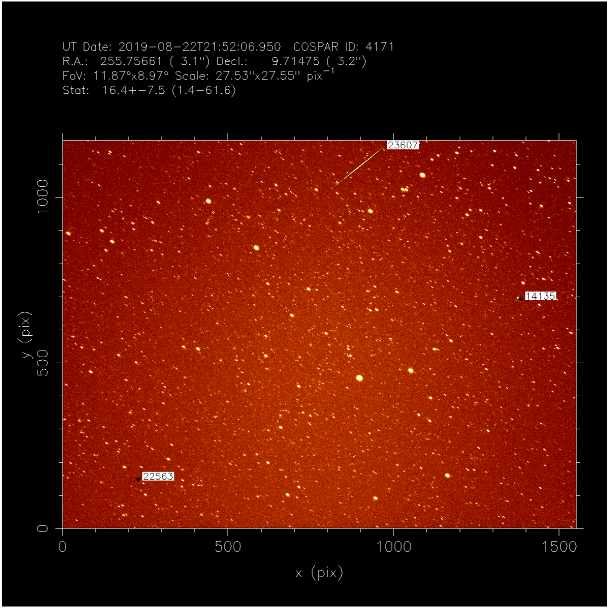
Watec 902H2 + 50 mm F/1.8:

- EasyCAP adapter for digitization
- 0.4 Mpix, $7\overset{\circ}{.}20 \times 5\overset{\circ}{.}30$ FOV
- 25 Hz frame rate

ZWO ASI1600MM Pro + 55 mm F/1.2:

- 16 Mpix, binned to 2 Mpix, $18\overset{\circ}{.}1 \times 13\overset{\circ}{.}7$ FOV
- 10 Hz frame rate

ZWO ASI1600MM Pro results



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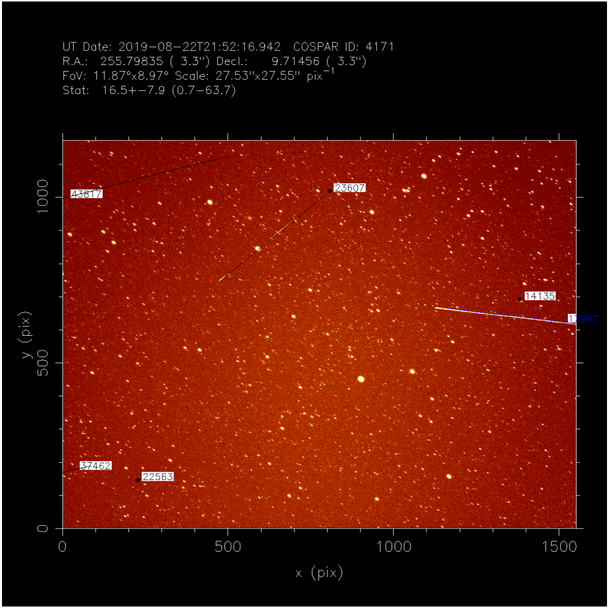

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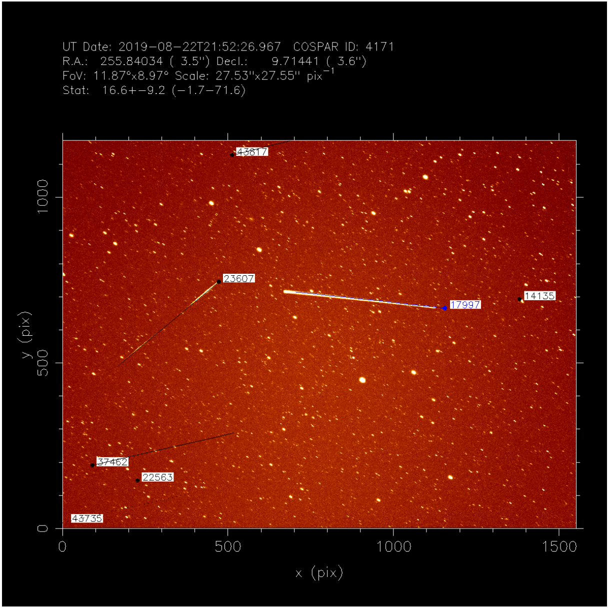

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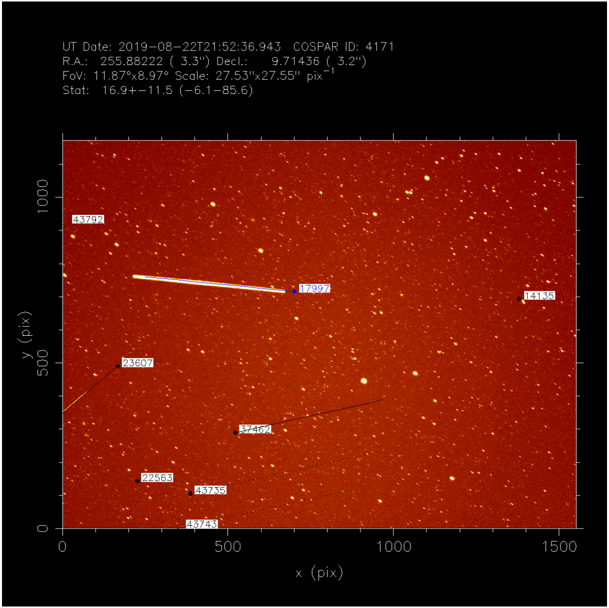

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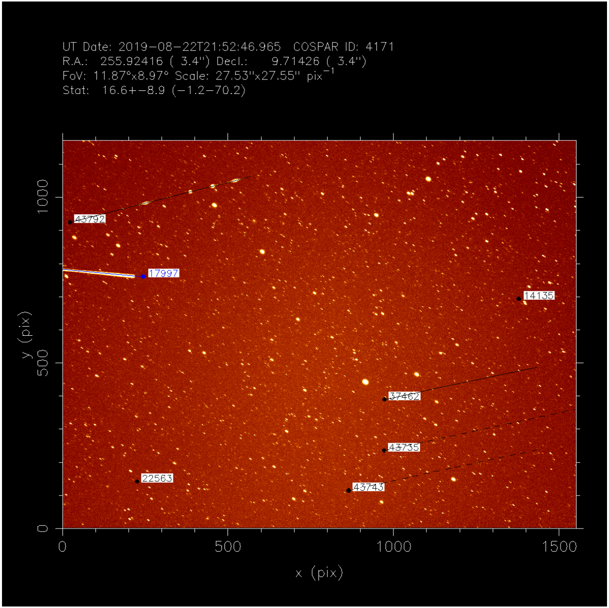

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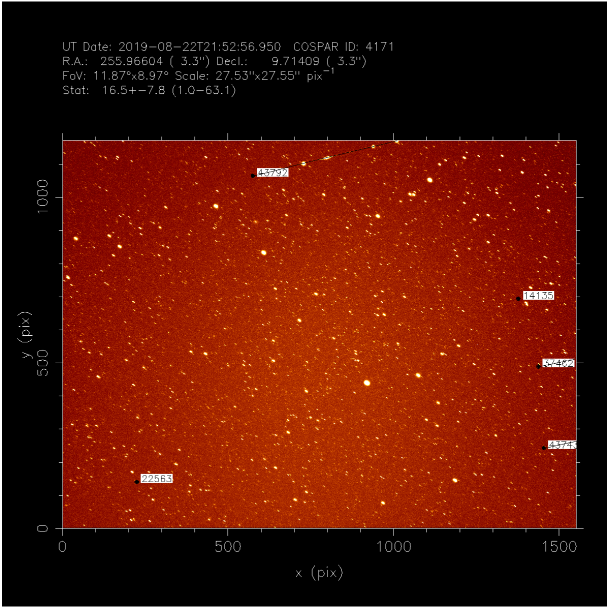
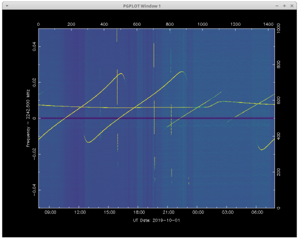
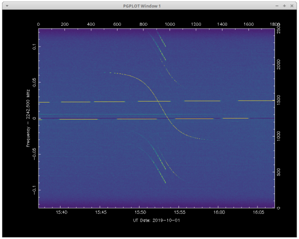


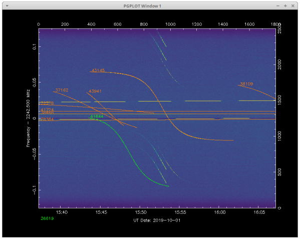
Radio tracking: strf

Monitor radio spectrum to identify satellites through their Doppler curves

- Monitor radio spectrum (e.g. VHF, UHF, S-band) with SDRs
- IQ data is channelized, integrated and time tagged
- Extract Doppler curves and match against known orbits
- Determine SGP4/SDP4 orbits from Doppler curves
- Working on implementing time tagged waterfalls in SatNOGS







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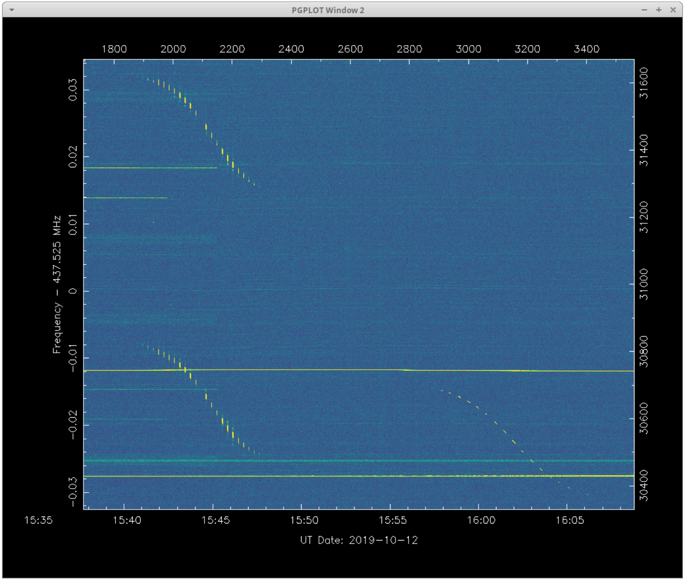

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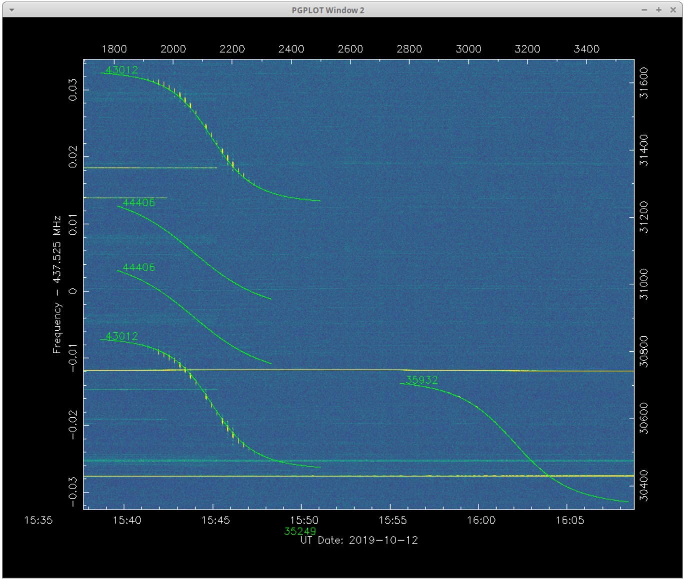

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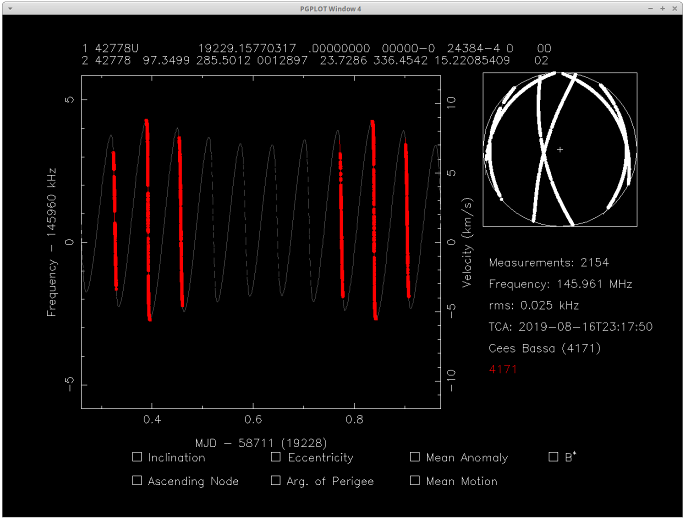

Conclusions

Implications for cubesats:

- Optical and radio tracking of satellites is feasible for low budgets ($\lesssim$2k€)
- Optical tracking requires good weather and sunlit satellite during twilight
- Optical variability useful for determining stability
- Cubesats are optically faint due to small size, but detectable at favorable circumstances (range and phase angle)
- Radio tracking only when transmitter is active
- During *TLE bingo* radio tracking is crucial for identification, linking TLE to satellite TX frequency

Dream goal: Create an open source orbital catalog from optical and radio measurements

Thank you!

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Optical tracking: sattools/stvid dependencies

sattools dependencies:

- Timestamps from computer synchronized with ntp
- Star finding with source extractor
- FITS library for storing images
- WCSLIB library for astrometric calibration
- INDI library for computerized mount control

stvid: ongoing port of sattools video tracking functionality to python

- Use popular libraries numpy, astropy, scipy, matplotlib
- opencv for video capture, ZWO ASI SDK for ASI cameras
- Automatic astrometric calibration using astrometry.net
- Automatic satellite track detection and position measurements