TU WIEN VieVS

Vienna VLBI and Satellite Software

A simulator to generate VLBI baseband data in Matlab

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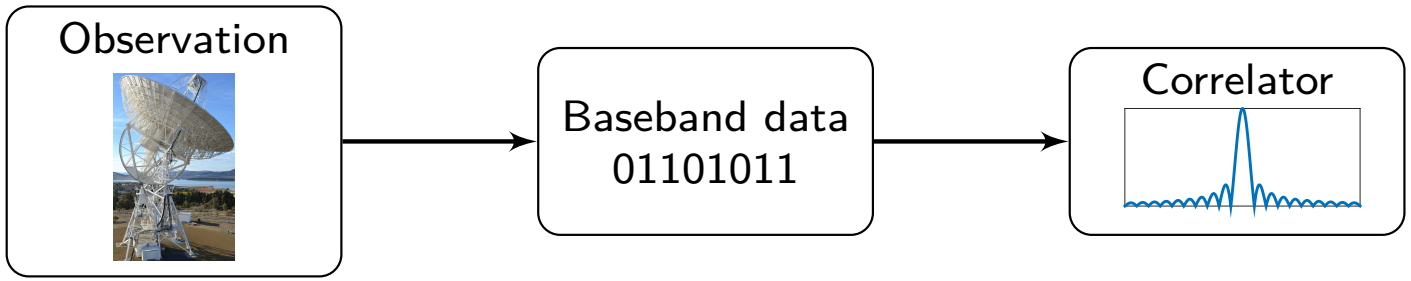
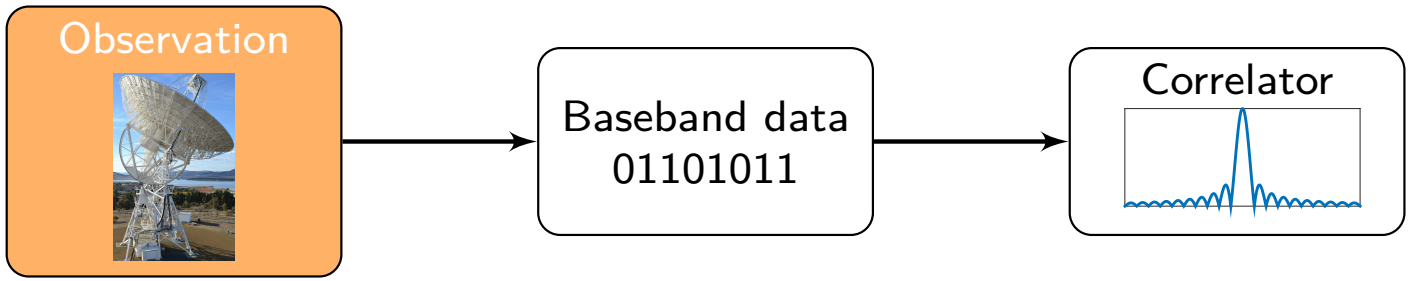
Baseband data

- "Baseband" data is referred to as the filtered, down-converted, sampled, and quantised electric field strength measurements generated at each station
- Output product of the station
- Input data for the correlator



Baseband data simulator

- Simulation of baseband data is a simulation of the observation process
- Model parameters to characterize the observation process
- Formatter to store the simulated baseband data



Motivation:

- Simulation of *new* VLBI observation scenarios (e.g. new satellite observations, new recording modes)
- Proof of concept (technical feasibility) and evaluation of the performance with respect to the correlation of the simulated data
- Correlation studies (scheduled vs. correlated, correlation parameterization, ...)

Model parameters (1/2)

Discretization of the observation process with its main drivers

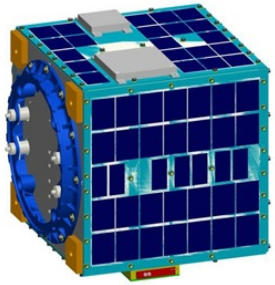
Source:

- Signal type of source:
  - white noise from quasars
  - artificial signals from satellites
- Received signal strength (flux density, antenna temperature)

Antenna:

- Sensitivity (SEFD, Tsys)
- Sky frequency
- System delays: cable, channel dependent delays
- Passband filter design
- Phase calibration signal
- Phase distortion
- Polarization

Courtesy of Beijing Aerospace Control Center



Model parameters (2/2)

Further noise components:

- Cosmic microwave background
- Ionosphere
- RFI
- ...

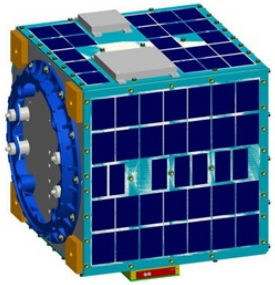
Observing mode:

- Observation duration
- Sampling frequency or bandwidth
- Number of bits
- Number of channels

Observing geometry:

- Group delay and delay rate
- Relative velocity between source platform and antenna platforms (Doppler shift)
- Date of observation

Courtesy of Beijing Aerospace Control Center

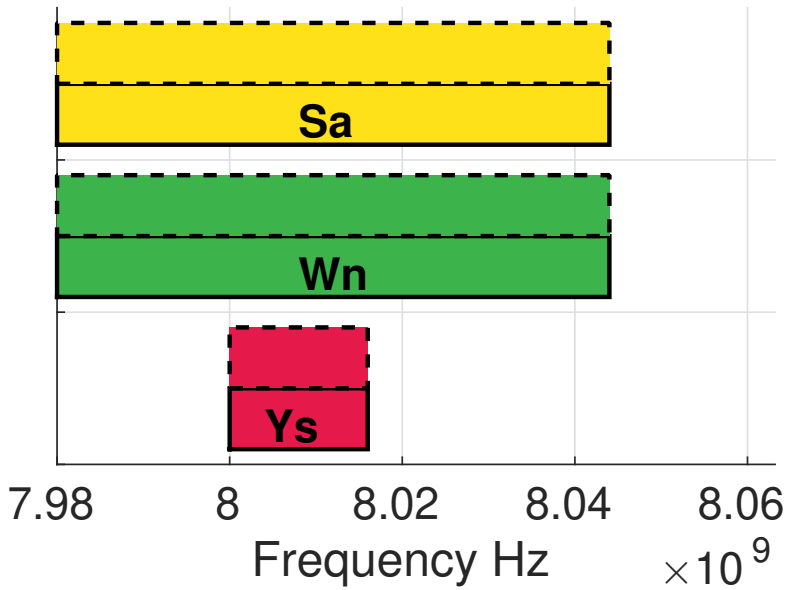


Example - different frequency setup

Simulation of mixed mode scans

- Source:
  - white noise from quasar
  - source flux: 4 Jy
- Ys:
  - sampling rate: 32 MHz
  - SEFD: 3000 Jy
  - f0: 8.00 GHz
- Sa and Wn:
  - sampling rate: 128 MHz
  - SEFD: 1900 Jy
  - f0: 7.98 GHz

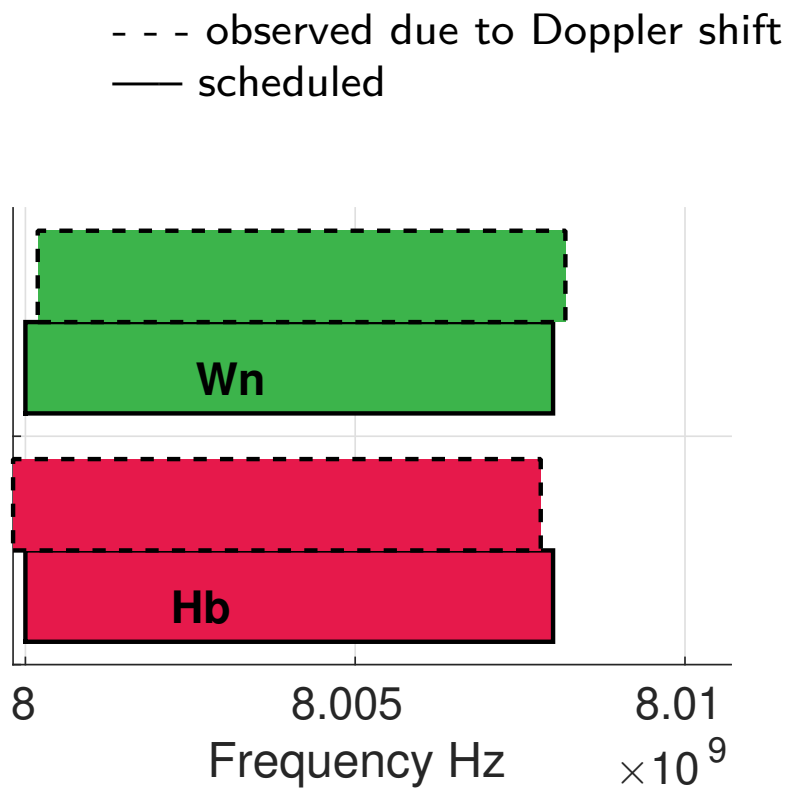
observed frequency bands



Example - Doppler shift

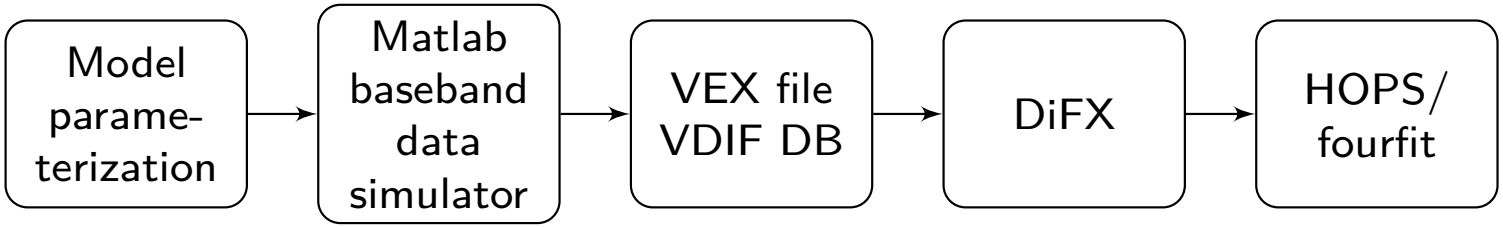
Simulation of moving targets

- Source:
  - LEO velocity: 7.8 km/s
- Wn:
  - bandwidth: 8 MHz
  - f0: 8.00 GHz
- Hb:
  - bandwidth: 8 MHz
  - f0: 8.00 GHz
- Loss of bandwidth: 2.3%



Simulation pipeline

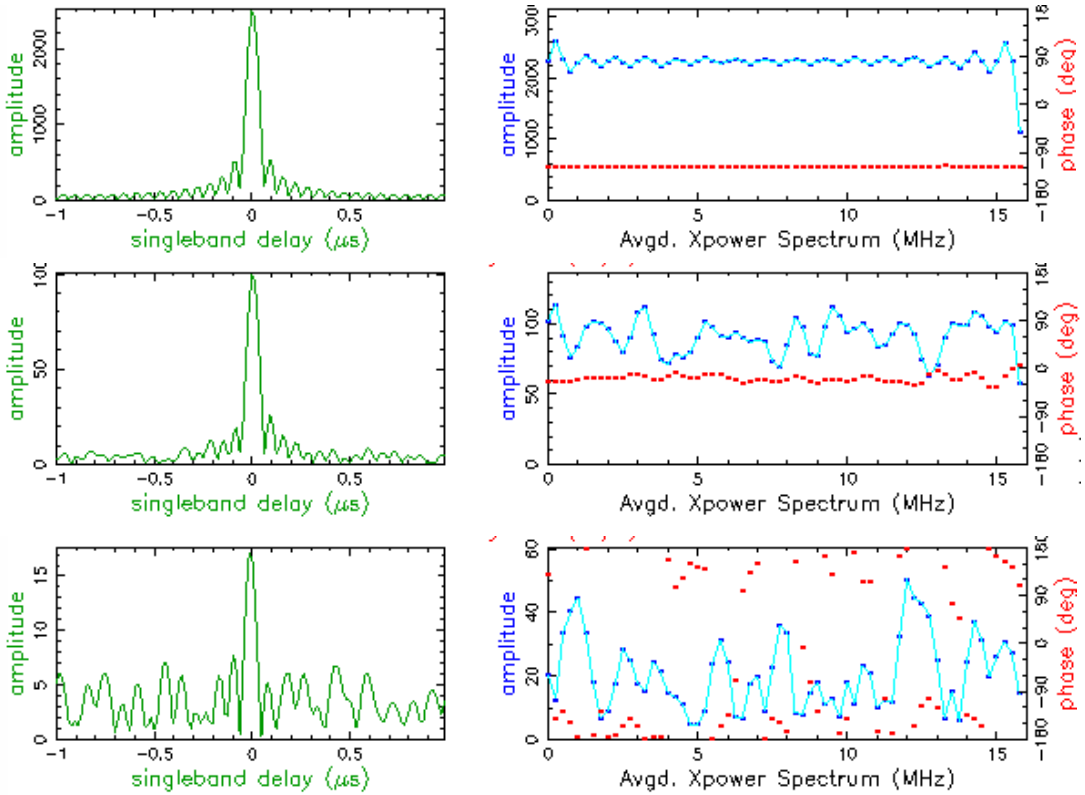
- Model parameterization, e.g. SEFD, date of observation represents input
- Simulated baseband data streams are stored in VDIF format
- VEX file creation included (required for correlation)
- VEX file and VDIF DB completely consistent → no correlation issues



- Usage of **short integration time but strong source flux method** to achieve desired SNR

Validation of the baseband data simulator

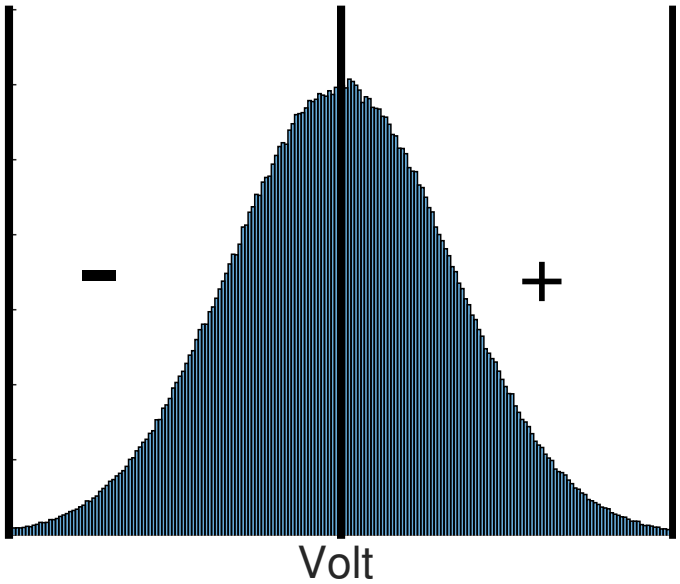
Results of correlated and fringe-fitted baseband data simulation:
→ Xpower spectrum shows flat phase and amplitude response with ringing artifacts at the bandpass edges
→ phase and amplitude stability decreases with decreasing SNR

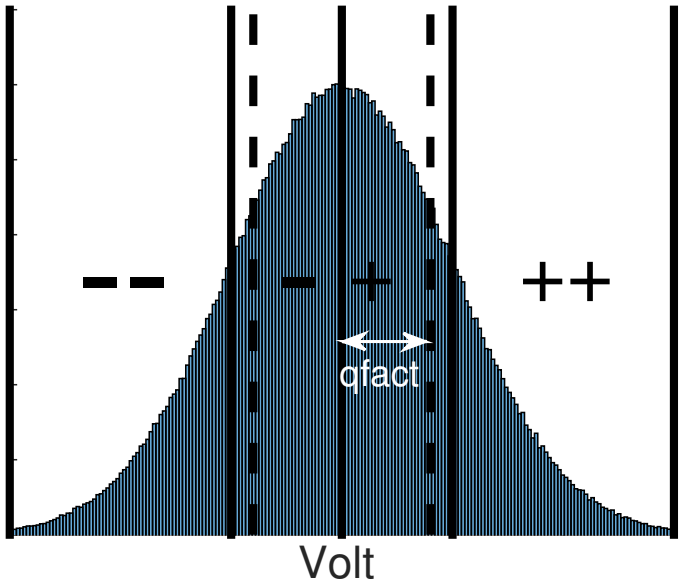


1 bit and 2 bit quantization

- Scheduled vs. correlated SNR
- Study the impact of 2 bit distribution
- **qfact:** sets the proportion to one sigma of the Gaussian noise distribution to define the limit of the inner quantization box
- Real VLBI antennas show qfact value of around 0.8

qfact	- -	-	+	+ +
0.6	27%	23%	23%	27%
0.7	24%	26%	26%	24%
0.8	21%	29%	29%	21%
0.9	18%	32%	32%	18%
1.0	16%	34%	34%	16%





Impact of quantization on fringe SNR

Results:

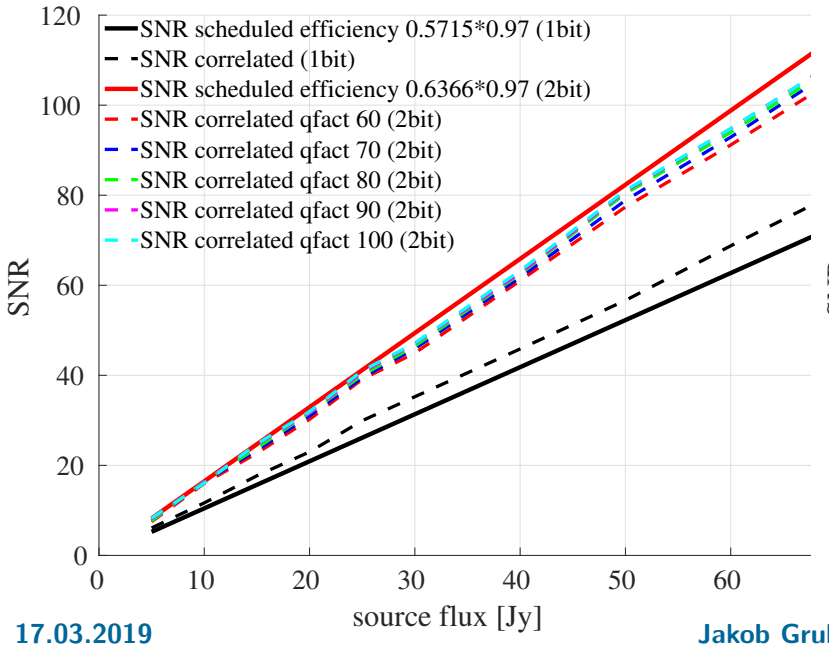
→ General good agreement between scheduled and correlated SNR values

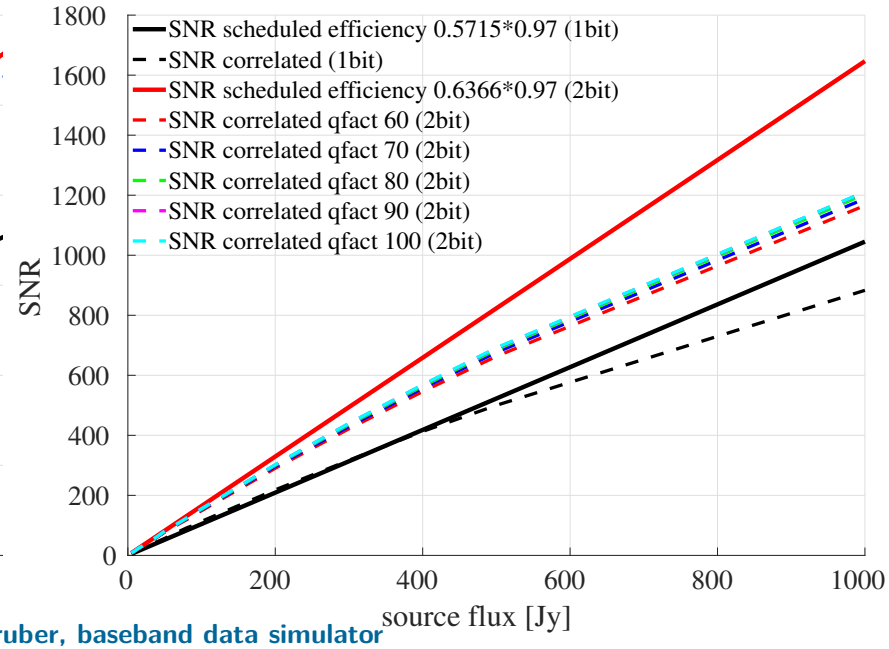
→ 1 bit sampling seems to be slightly pessimistic

→ 2 bit sampling seems to be slightly optimistic

→ Small difference in SNR values using different qfact (best result with a qfact values of 1)

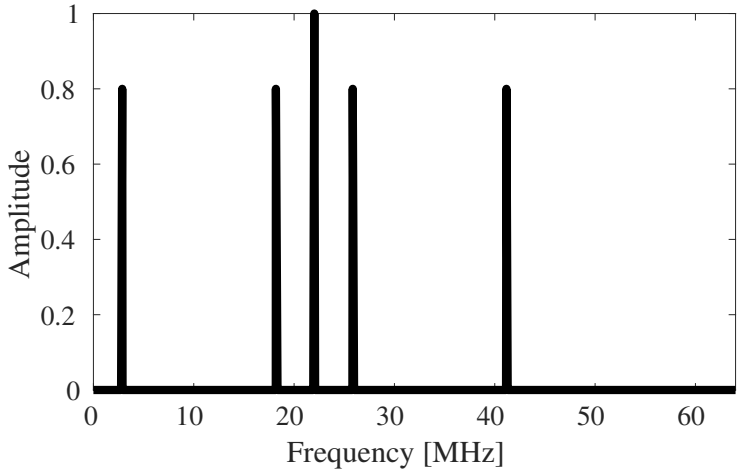
→ Large scale SNR values show non-linear trend and large differences between scheduled and correlated results (might be due to bad simulation configuration of the ratio of source flux and SEFD)



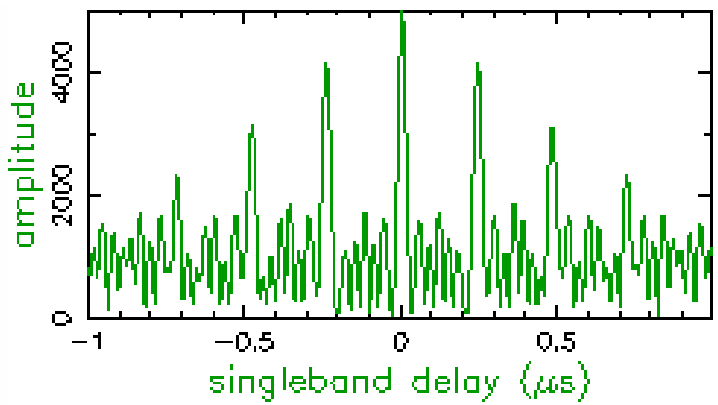


APOD DOR tones

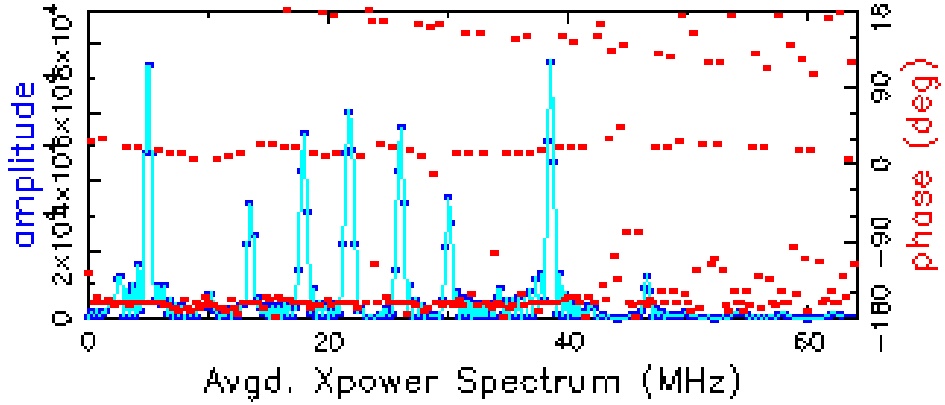
→ Proof of concept to generate artificial source signal with specific signal structure → Usage of very high sampling rate (128MHz)
→ Can be used to test the applicability of a certain signal structure of future satellite missions



frequency spectrum of APOD DOR tones used in the simulation



Xpower spectrum after correlation



Conclusion

- **Baseband data simulator in Matlab** with
  - source model
  - antenna model
  - recording and geometry model
- **VDIF formatter** to feed simulations into correlators
- Baseband data simulator can be used to
  - **study impact of antenna behaviour** on correlation results (e.g. phase stability)
  - **simulate artificial signals** and test their applicability in the analysis

- Usage of **supercomputing infrastructure (VSC3/4)** at TU Wien to generate large simulated baseband data files (http://vsc.ac.at/)
  $\rightarrow$ Evaluation of the difference of short integration in contrast to common integration times
- Will be put under the **VieVS** umbrella and will be open source