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Handling of satellite observations with VieVS

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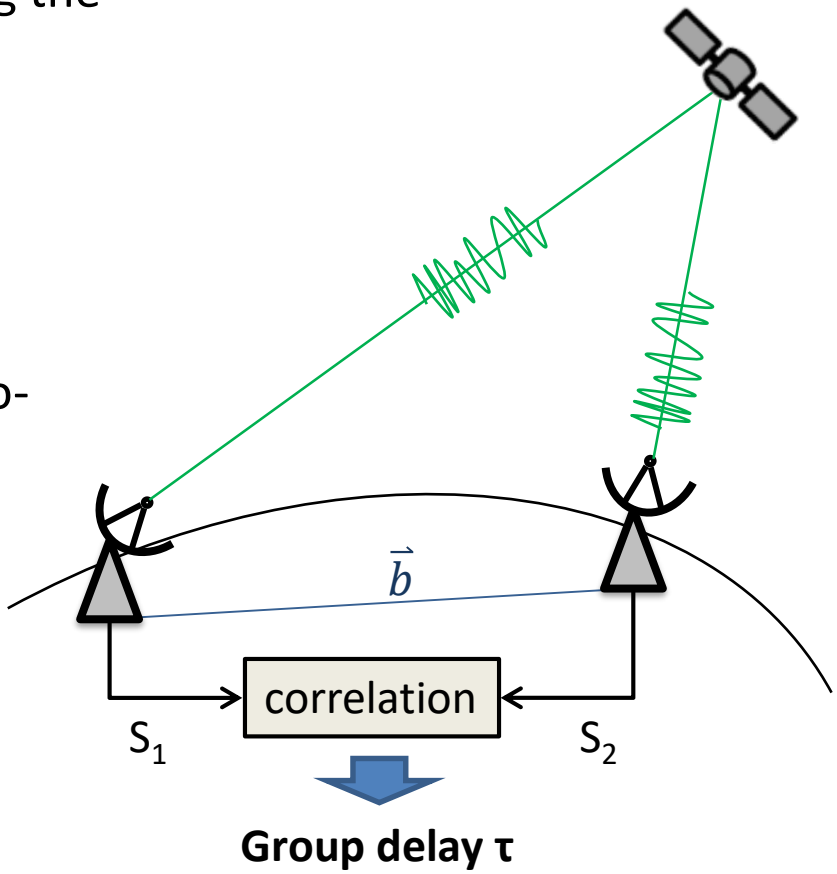
Satellite Observations with VLBI

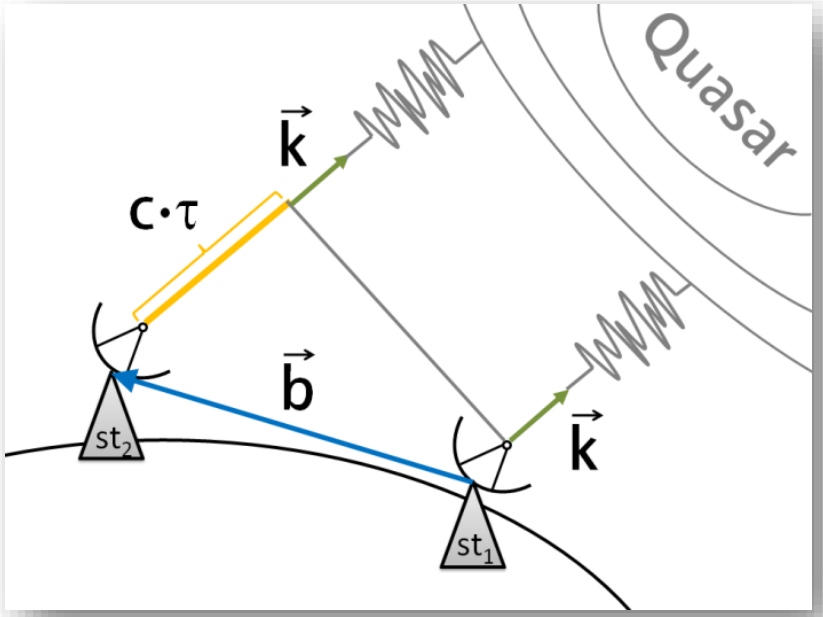
- **Direct observations of signals emittet by a Earth-satellite**
  - „Geodetric“ observation mode using the standard VLBI signal chain
  - ➢ Computation of **baseline-delays**

- **Long term goals**:
  - Esablish inter-technique ties via a co-location in space
  - etc...

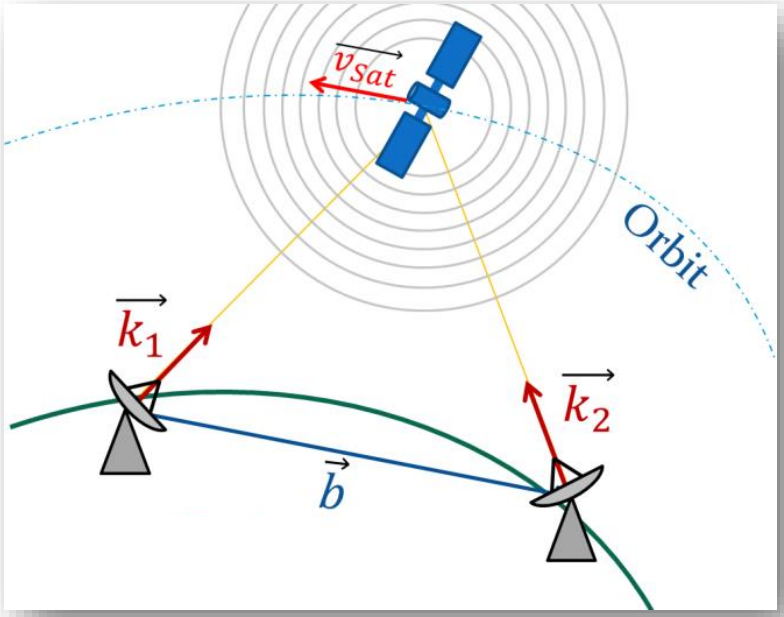


Framework Conditions

Standard VLBI



Satellite observations



Natural radio sources (quasars)

- At an infinite distance
- Parallel view directions $\vec{k}$
- Fixed points in the sky
- S/X-band

Artificial signal sources

- In the Earth's near field
- Different view directions ($\overrightarrow{k_1} \neq \overrightarrow{k_2}$)
- Moving fast
- e.g. L-band for GNSS

Features for VLBI Obervations of Satellites

- **Since VieVS 3.0**
  - Dedicated **scheduling tool** for observations of satellites
  - **Near-field delays model** in VIE_MOD
  - **Estimation of VLBI standard parameters** based on satellite observations (VIE_LSM)
  - **New observation file format (VSO)** that allows to include near-field observations

Scheduling tool for VLBI satellite observations (1)

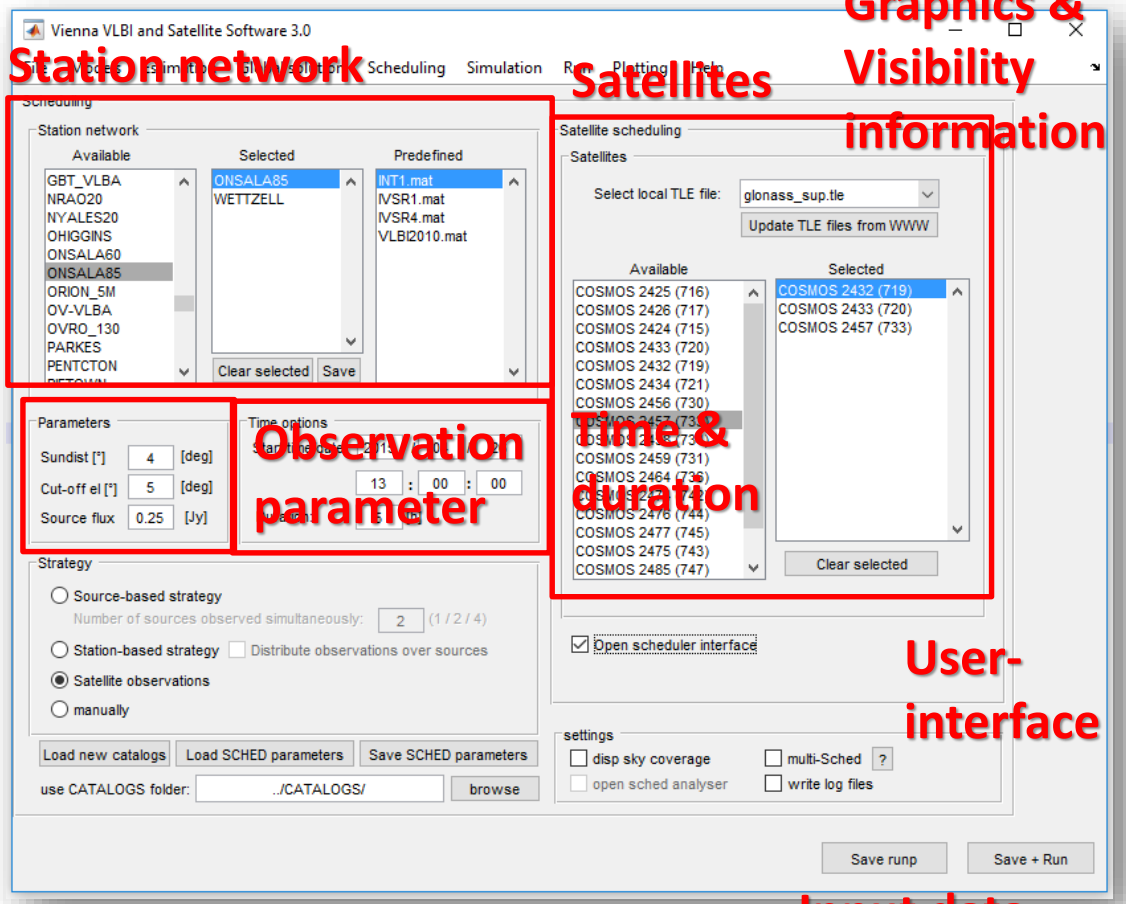
- Expension of the standard scheduling module VIE_SCHED (Sun et al., 2014)
- **Combination of quasar and satellte scans** in one schedule
- Different scheduling modes
  - Manual
  - Automatic (sky-coverage optimization)

➢ **Create all control files that enable actual observation experiments**

- ➢ VEX schedules
- ➢ Tracking files (AzEl tracking points)

➔ *See Hellerschmied et al., 2017*

Scheduling tool for VLBI satellite observations (2)



Station network

Satellites

Graphics & Visibility information

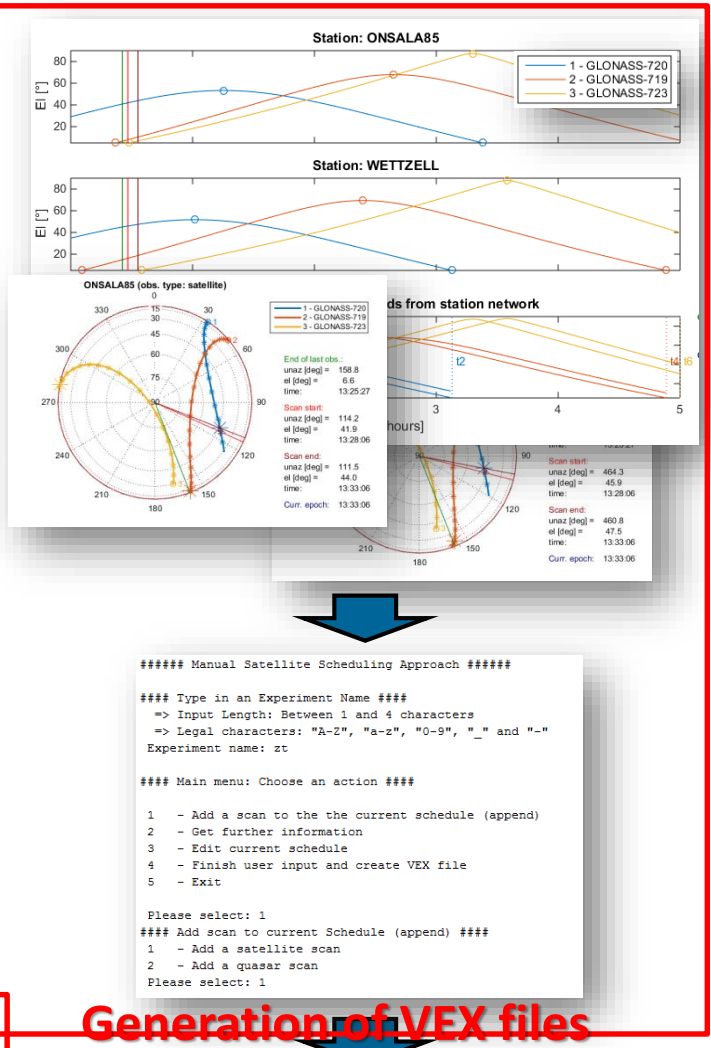
Observation parameter

Time & duration

User-interface

Input data

GUI of the VieVS satellite scheduling module

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###### Manual Satellite Scheduling Approach ######

#### Type in an Experiment Name ####
  => Input Length: Between 1 and 4 characters
  => Legal characters: "A-Z", "a-z", "0-9", "_" and "-"
 Experiment name: zt

#### Main menu: Choose an action ####

 1   - Add a scan to the the current schedule (append)
 2   - Get further information
 3   - Edit current schedule
 4   - Finish user input and create VEX file
 5   - Exit

 Please select: 1
#### Add scan to current Schedule (append) ####
 1   - Add a satellite scan
 2   - Add a quasar scan
 Please select: 1
```

Generation of VEX files

Catalog files

Configuration files

TLE datasets

VEX files

VSO Format

- Observation file format that enables to define near-field observations
  - Text file, column mode
  - Equally usable to NGS and vgosDB
  - Content:
    - Observations (observed or modeled) + formal errors
    - Meterologic data (p, t, e)
    - Cable delay corrections

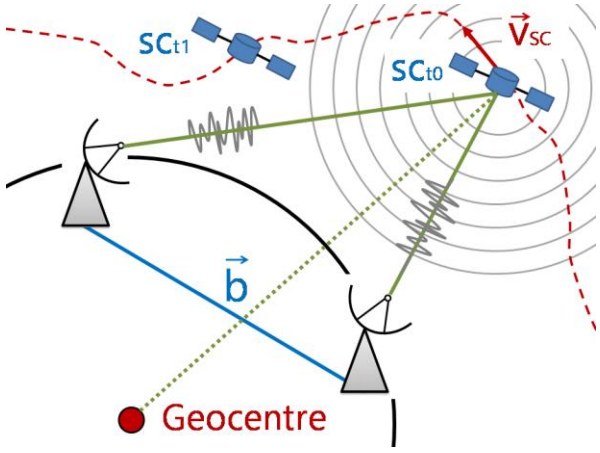
http://vievswiki.geo.tuwien.ac.at/doku.php?id=public:vievs_manual:data#vso_files

Near-field Delay Model

- **Consensus model** (IERS conventions, 2010; std. in VieVS)
  - Error > 1ps for source distances < 200 kpc due to curved wavefront
  - Plane wave assumption not valid in the Earth‘s near-field

- **Near-field model** according to Klioner (1991) implemented in VIE_MOD
  - Iterative solution of the light-time equation in the GCRS (suitable for Earth satellites!)
  - Valid for source distances < 10^6 km

➢ Required for
  - Correlator input model
  - Calculation of O-C residuals ➔ LSM
  - Simulations

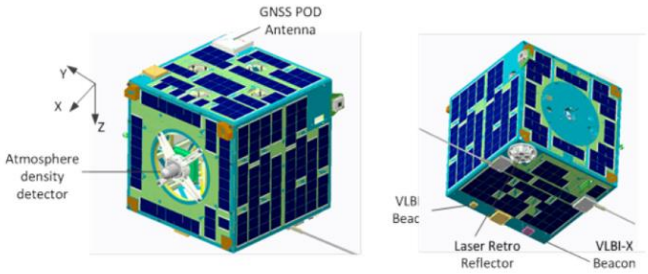


Further Useful Features...

- Calculation of **Ionosphere corrections based on TEC maps**
  - Important for single band observations!
  - See *Tierno Ros et al., 2011*
- Estimation of satellite orbits in terms of PWLO w.r.t. a priori orbits
  - „kinematic orbit solution“
- Full support of all plotting and data inspecton features
  - Plottin Residuals and Estimates
- Full support of tools for problem handling
  - Outlier elimination, „OPT-file options“

Case Study: APOD (1)

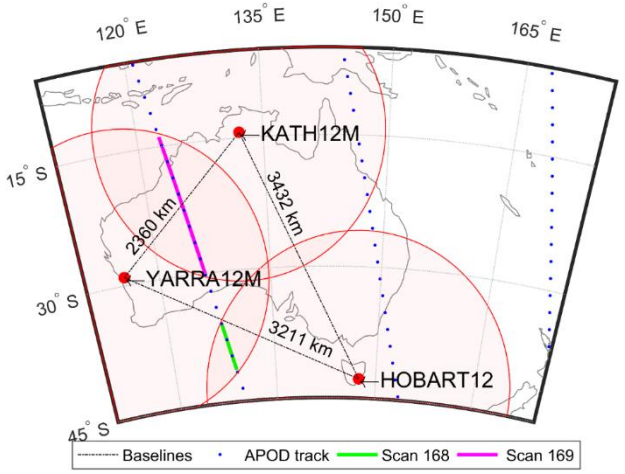
- Chinese Cube satellite mission by BACC launched in Sept. 2015
- LEO orbit (~450 km, i ≈ 97°)
- Geodetic payload:
  - GNSS receiver (GPS & BD)
  - SLR retroreflector
  - **VLBI S/X beacon (DOR tones)**



Physical layout of APOD-A (Sun et al., 2017)

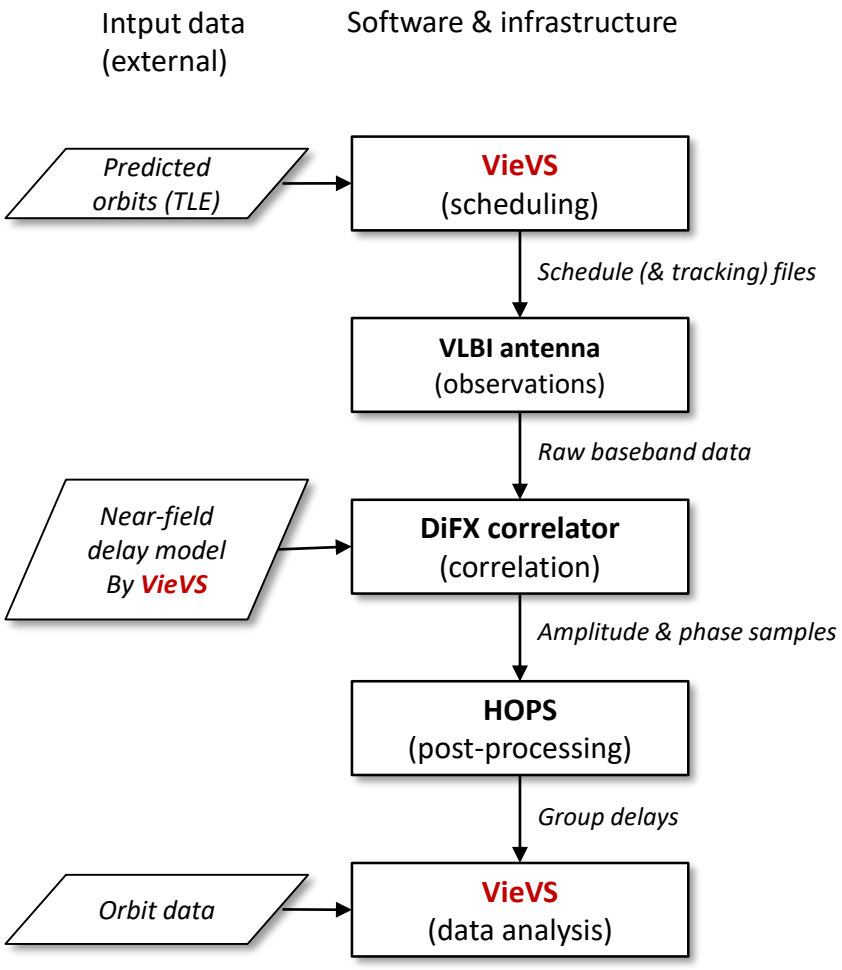
- Tracked by **AuScope** VLBI array in Nov. 2016

➢ **Eight sessions recorded**



Observation geometry in session a332. The antenna's projected field of views are indicated as red circles (Hellerschmied et al., 2018)

Process Chain for VLBI satellite observations



- Starting and finishing with **VieVS**, we have developed a complete process chain
- Whenever possible, we used **standard procedures**

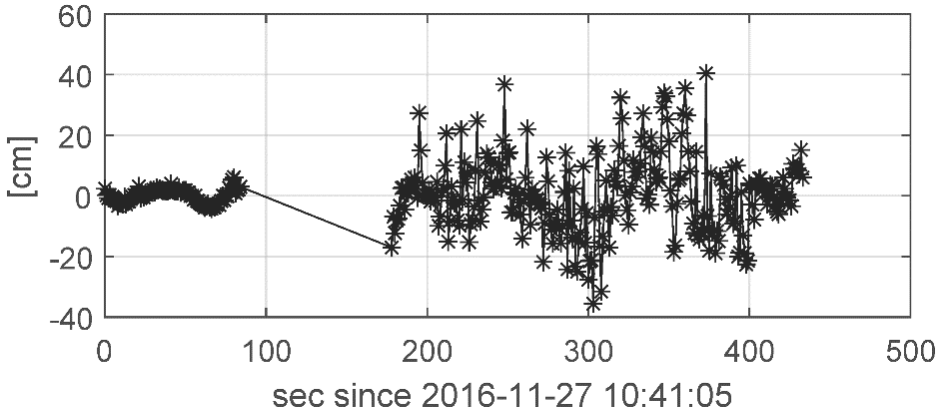
Case Study: APOD (2)

- **Data analysis in VieVS**
  - VIE_MOD: O-C on 10 ns level
- **Least-squares adjustmnent**
  - Based on APOD observations
  - Const. Offsets estimated

Parameter	Estimate	Formal error
Clock offset, Hb	$14.0m$	$2.3m$
Clock offset, Ke	$-1.1m$	$1.9m$
ZWD, Hb	$3.4cm$	$1.7cm$
ZWD, Ke	$14.3cm$	$2.1cm$
ZWD, Yg	$7.3cm$	$1.7cm$
Orbit, radial	$1.2m$	$0.3m$
Orbit, along-track	$-7.8m$	$0.3m$
Orbit, cross-track	$-1.9m$	$1.3m$

Parameter estimation results from scans 168 and 169 in experiment a332 (Hellerschmied et al., 2018)

Scan 168 (Yg-Hb) Scan 169 (Yg-Ke)



Post-fit residuals of scans 168 and 169 in session a332

WRMS = 9.5 cm

Thank you for your attention!

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References:

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