TECHNISCHE UNIVERSITÄT WIEN
Vienna University of Technology

SPACECRAFT TRACKING

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VieVS User Workshop

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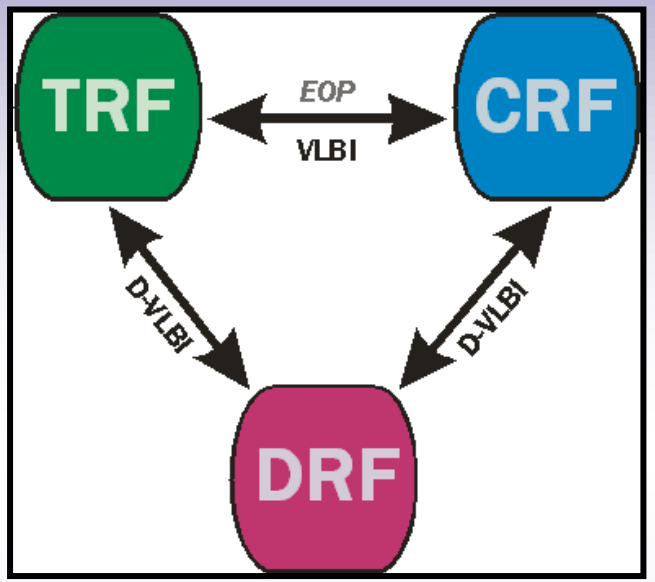
Vienna

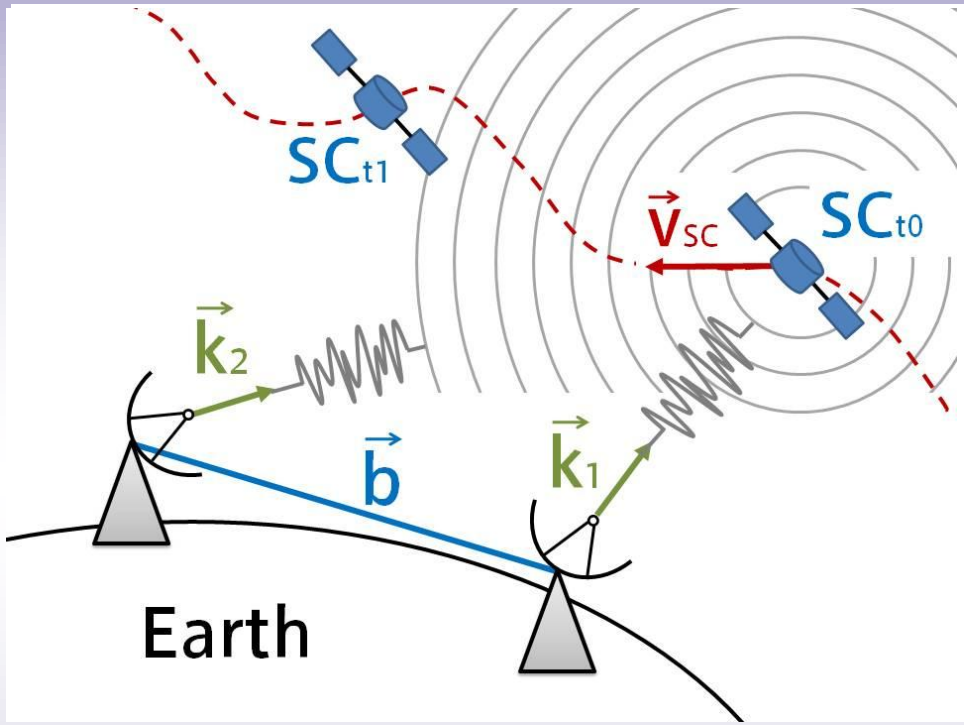
VLBI for space applications (1)

- Navigation
  - Deep space navigation
    - Routinely done (NASA, ESA)
    - Sensitive perpendicular to line of sight
  - Lunar missions
    - SELENE, Chang‘e
- Frame ties
  - Optical ↔ radio frequencies
  - Kinematic ↔ dynamic (ephemerides)
- Local ties
  - Co-location in space
    - GNSS, GRASP, MicroGEM,…



VLBI for space applications (2)

- **Differential VLBI (D-VLBI)**
  - Quasar – spacecraft (SC)
    - Deep space navigation
    - DSN, ΔDOR
    - NASA, ESA
  - SC – SC
    - multi-frequency method
    - same beam method
    - e.g. SELENE (JAXA)



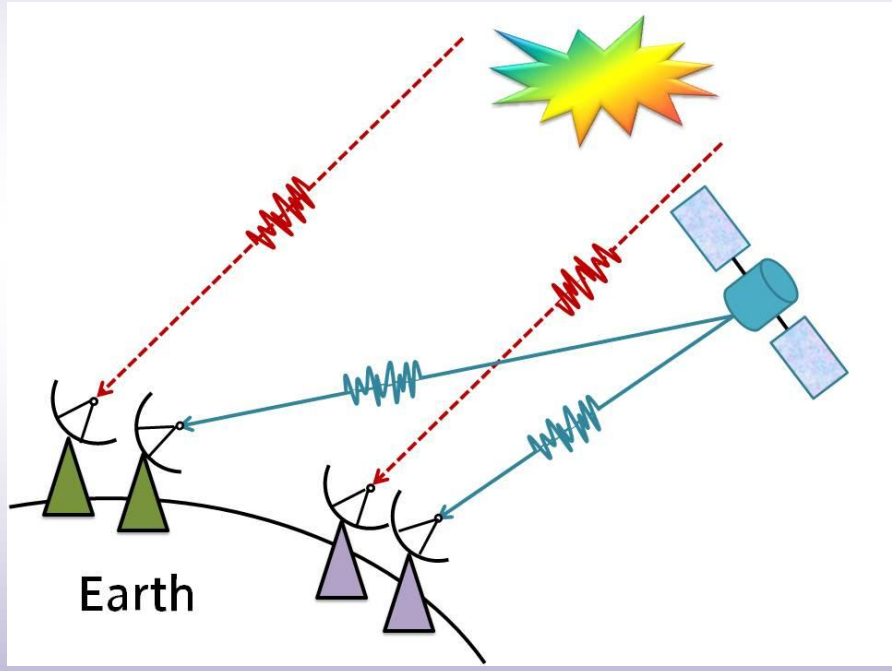
- **Satellite VLBI**
  - Chang‘e-1
  - Tracking of GNSS satellites
  - Tracking of other satellites

VLBI for space applications (3)

- Technical realization is strongly mission-dependent.
  - Differential vs. Single
  - Signal structure
  - Phase vs. Group delay
  - Receiving system

But:

- Promising recent & future missions
  - Better accuracy, small antennas,…
- Technical development
  - VLBI transmitters as payload
  - twin-telescopes offer new observing modes
- Strong request for inter-technique ties
  - Co-location in space
  - GRASP, GNSS, Micro-GEM,…



Possible observing mode with 2 twin telescopes

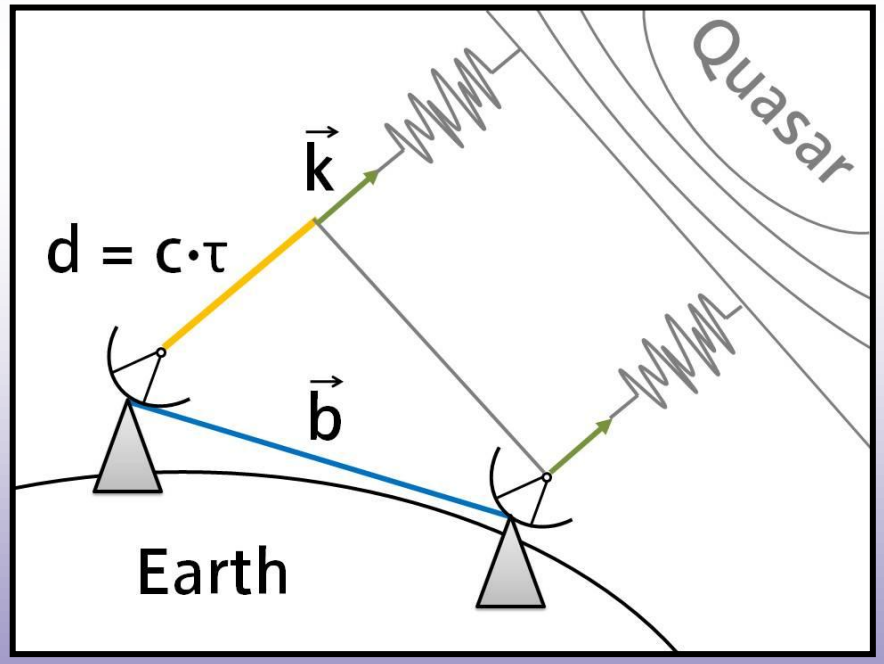
Spacecraft Tracking with VieVS (1)

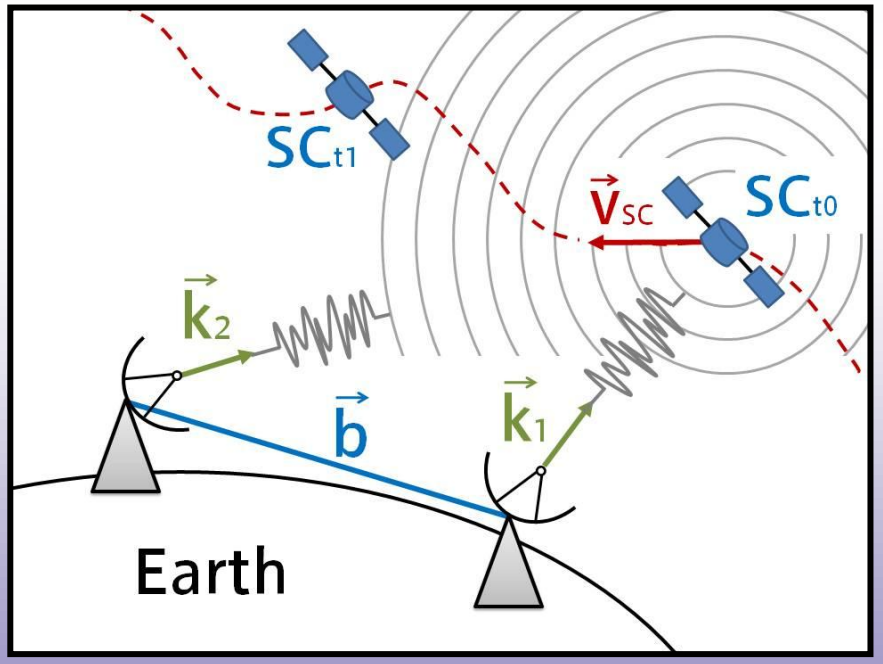
GEODETIC VLBI

- plane wave front
- stable sources

SPACECRAFT VLBI

- curved wave front
- fast moving sources
- time of emission t0





Spacecraft Tracking with VieVS (2)

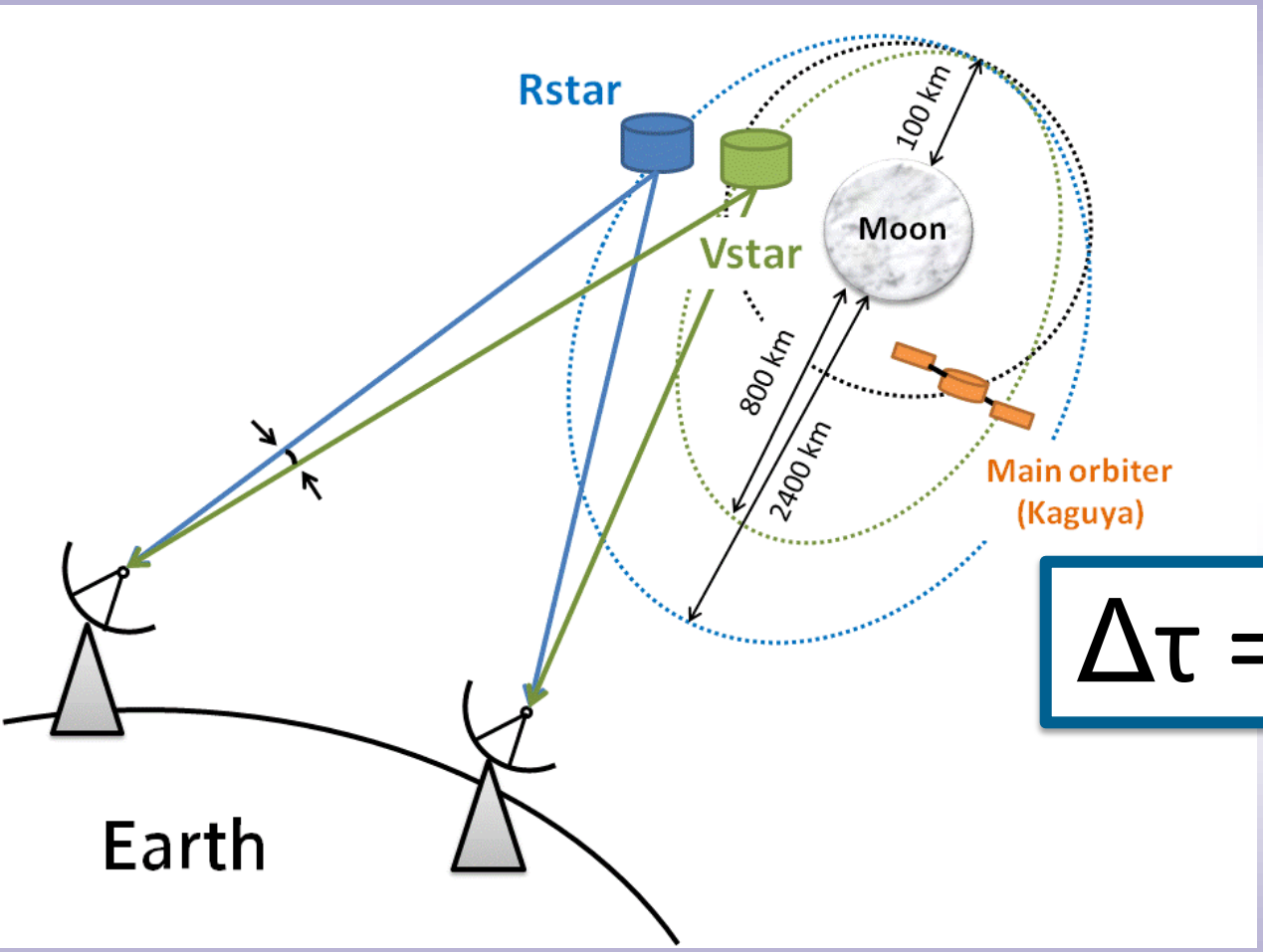
3 experiments:

1. Same beam differential VLBI data from Selene **provided by NAOJ Mizusawa**

2. Chang'e-1 VLBI tracking in single-mode
   provided by SHAO & BACC

3. Tracking of GNSS satellites with VLBI
   in cooperation with V. Tornatore

1. SELENE



- differential (D-) VLBI data
- same beam, phase delay

$$\Delta\tau = \tau_{RSTAR} - \tau_{VSTAR}$$

- many effects are the same for τRSTAR and τVSTAR

D-VLBI delay model

- Fukushima & Sekido, 2006:
- *"A VLBI delay model for radio sources at finite distance"*

- **Light time iteration**

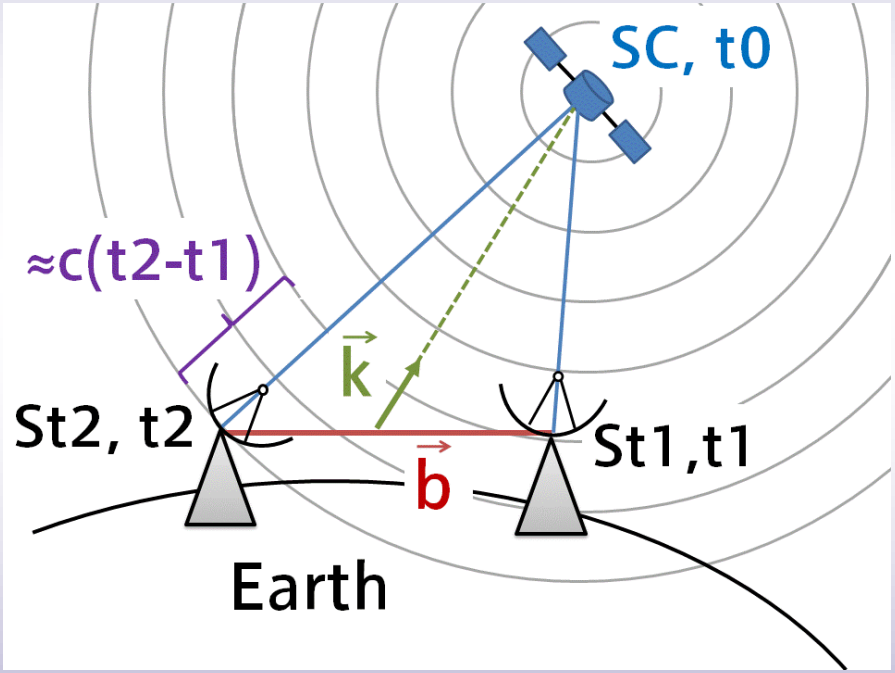
$$t_0(i+1) = t_0(i) - \frac{SC_{t0} - St1_{t1}}{c} - \tau_{grav}$$

- **Pseudo direction vector**

$$\vec{k} = \frac{\vec{R}_1(t_1) + \vec{R}_2(t_1)}{R_1(t_1) + R_2(t_1)}$$

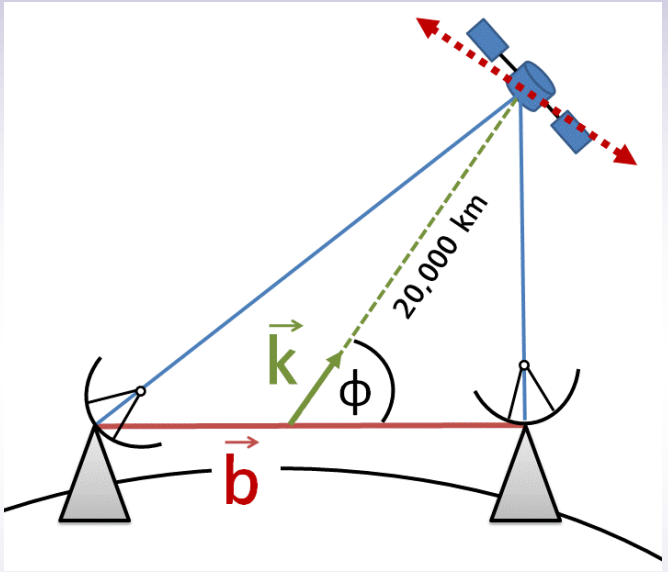
- **Correction term**

$$\approx \vec{v}_2(t_2 - t_1)/c$$



VLBI tracking “single”

- Observe GLONASS satellites with VLBI
  - Tornatore et al., 2010
  - Single source VLBI
- Delay model:
  - Klioner, 1991 (GCRS) for GNSS
  - Fukushima & Sekido for Chang‘e
- Simulations performed:
  - Vie_sim
    - Parameter: $\phi_0 + d\phi$
    - Partial: $d\tau / d\phi$
  - Vie_lsm:
    - e. g. effect of measurement error on estimated position



Summary and outlook

- We successfully used VieVS to model delays of space VLBI applications; we implemented
  - Selene same beam data processing
  - Chang‘e-1 VLBI tracking data processing
  - Glonass GNSS observations
- Vie_lsm was adapted to estimate spacecraft positions and can be used for simulations

TO DO:

- Verify delay model as realized in VieVS
- Continue work with real data
- Implement VieVS_SC to VieVS_1d

THE END

Thank You for listening!

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References:

Kikuchi et al., 2009: *Pico-second accuracy VLBI of the two sub-satellites of SELENE (KAGUYA) using multi-frequency and same-beam methods*, Radio Sci. 44(RS2008).

Klioner, 1991: *General relativistic model of VLBI observables.* In: Carter WE (eds) Proceedings of AGU Chapman conference on geodetic VLBI: monitoring of global change. NOAA Technical Report NOS 137 NGS 49, AGU, Washington DC, pp 188-202.

Sekido & Fukushima, 2006: *A VLBI delay model for radio sources at a finite distance,* J. Of Geodesy, 80:137-149, DOI 10.1007/s00190-006-0035-y.

Tornatore et al., 2010: *Planning of an Experiment for VLBI Tracking of GNSS Satellites*, D. Behrend and K. D. Baver (eds), IVS2010 GM Proceedings, VLBI2010: From Vision to Reality.