TECHNISCHE UNIVERSITÄT WIEN
Vienna University of Technology

RESEARCH GROUP ADVANCED GEODESY
Institute of Geodesy and Geophysics

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JD-7

Connecting kinematic and dynamic reference frames by VLBI

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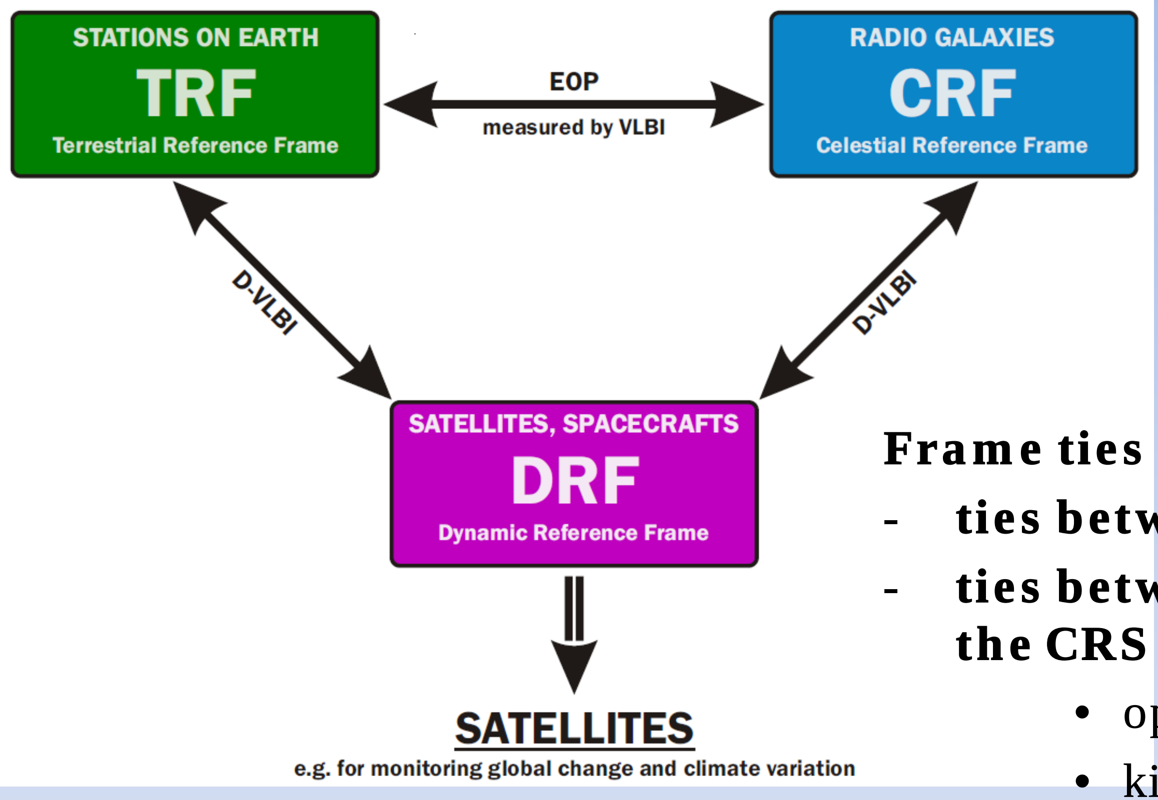
Motivation



Frame ties

- **ties between TRF and CRF by EOP**
- **ties between various realizations of the CRS**
  - optical ↔ radio frequencies
  - kinematic ↔ dynamic (ephemerides)

- but: direct ties between TRF ↔ DRF (satellites, spacecrafts) and CRF ↔ DRF are also needed

Frame ties: general remarks

- Ties between the ICRF and dynamical realizations of the ICRS (satellite orbits, spacecraft ephemerides) can be established by differential VLBI (D-VLBI) observations.

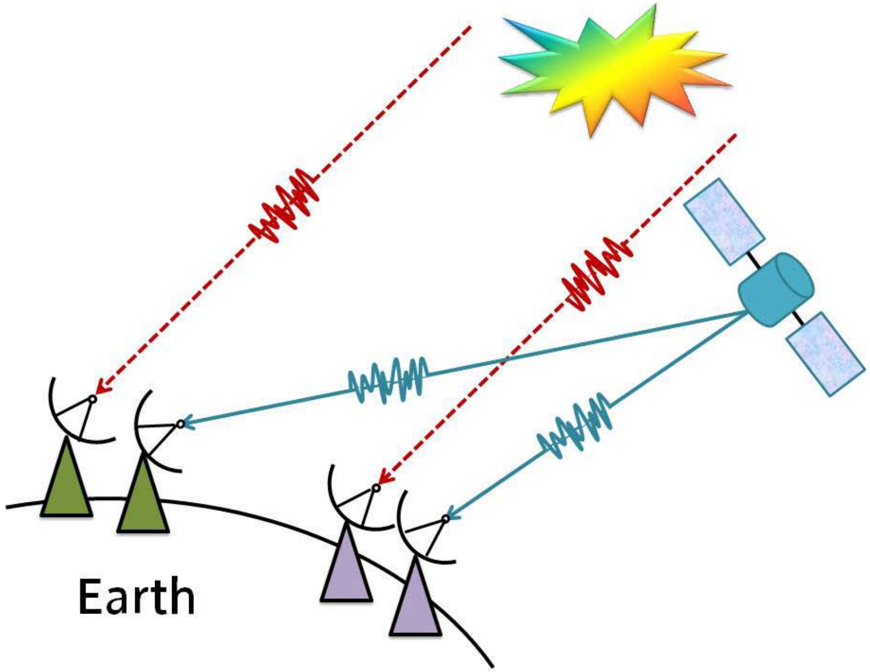
- The IERS Earth Orientation Parameters (EOP) provide the permanently changing tie between the ICRF and the ITRF.

- Inter-technique co-location sites are the backbone of the current combined solution of the ITRF.

- Local ties on ground (on fundamental geodetic sites) need to be improved for future ITRF improvement.

- Local ties in space (e.g. various techniques on the same satellite) need also to be established.

VLBI for space applications



… VLBI with sources (=targets) alternatively to quasars, mostly within the solar system

Observing modes (1)

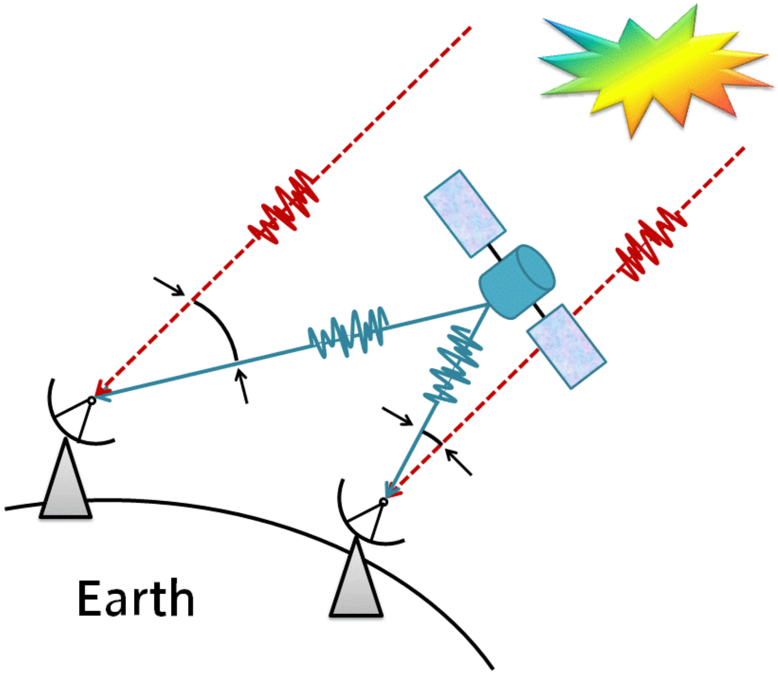
- „classical“ VLBI

- differential (D-)VLBI

  – switching between satellite/spacecraft and quasar

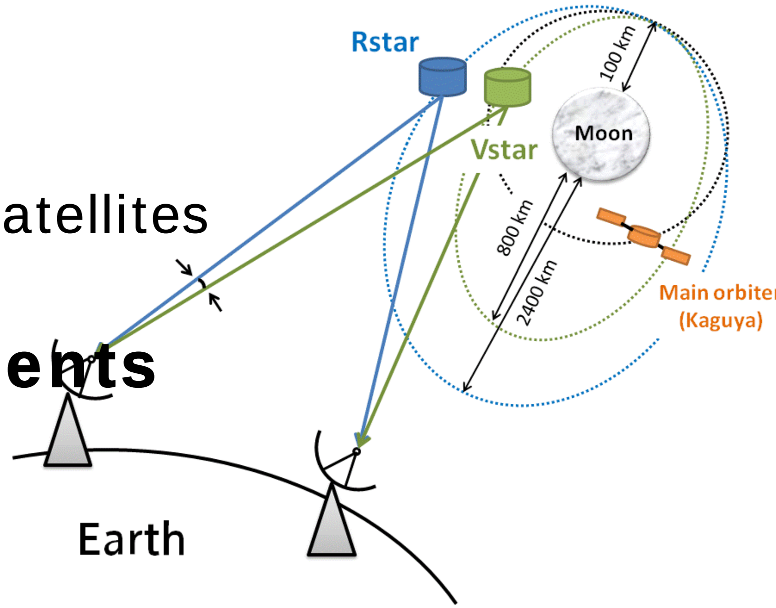
  – or same-beam method (e.g. SELENE, Chang‘e)

  – signals travel through the same atmosphere
    → many errors cancel out



Recent developments

- **Promising recent missions and tests**
  - Japanese SELENE lunar mission
  - Chinese Chang‘e lunar mission
  - VLBI observations to GLONASS satellites (Tornatore & Haas)
- **Recent technical developments**
  - VLBI transmitters as payload
  - VLBI2010
  - ‘Twin telescopes‘ (two identical radiotelescopes at same site, e.g. Wettzell) offer new observing modes



SELENE: same-beam D-VLBI improved the orbit consistency from several hundreds to several tens of meters (Goossens et al., JoG, 2010)

Level of cancellation for D-VLBI

… as determined empirically from SELENE D-VLBI observations [Plank et al., Proc. IVS GM 2012]

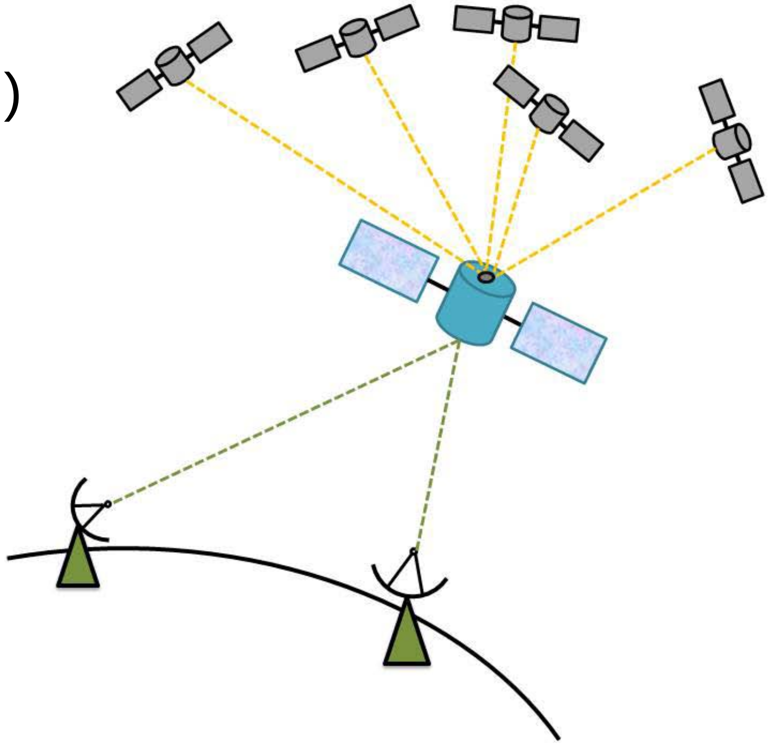
National Astronomical Observatory of Japan Mizusawa

(values in brackets repr. long baselines)	τ	$\Delta\tau$
GEOMETRY		
Antenna ±5 cm	300 ps	1-2 ps
Orbit ±10 m	150-1000 ps	2-8 ps
EOP	5 (60) ps	< 0.05 (0.1) ps
dUT1: 5 ms/xp,yp: 200 mas/dX,dY: 300 mas		
ATMOSPHERE		
Hydrostatic troposphere, a priori	2-20 (10-60) ns	30-300 (50-1000) ps
Wet troposphere, ECMWF	1-3 (4) ns	4-40 (10-60) ps
Ionosphere, TEC-maps	1.5 (2-10) ns	10 (80) ps

„single“ delay τ → approx. factor 100 → differenced delay $\Delta\tau$

Observing modes (2)

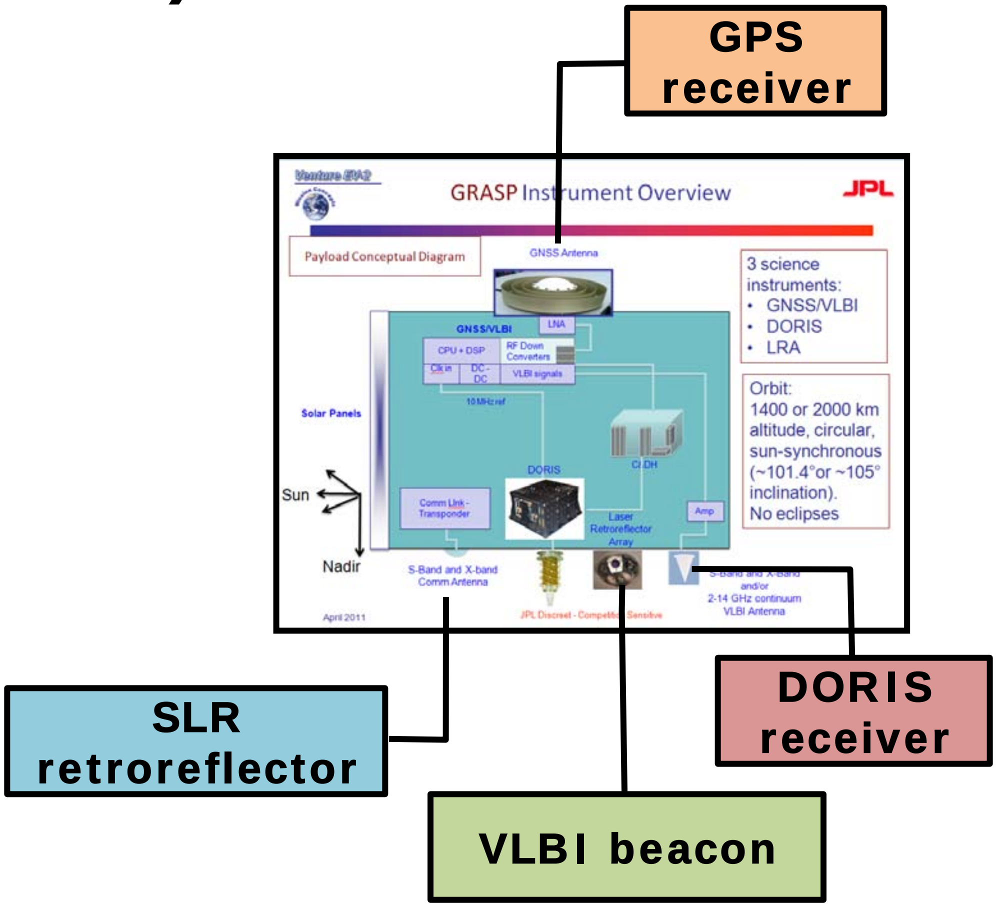
- **Differential (D-) VLBI**
- **Co-location in space**
  - VLBI-transmitters as payload
  - Studies: GRASP (JPL), Micro-GEM, Nano-GEM (GFZ)



Co-location in Space

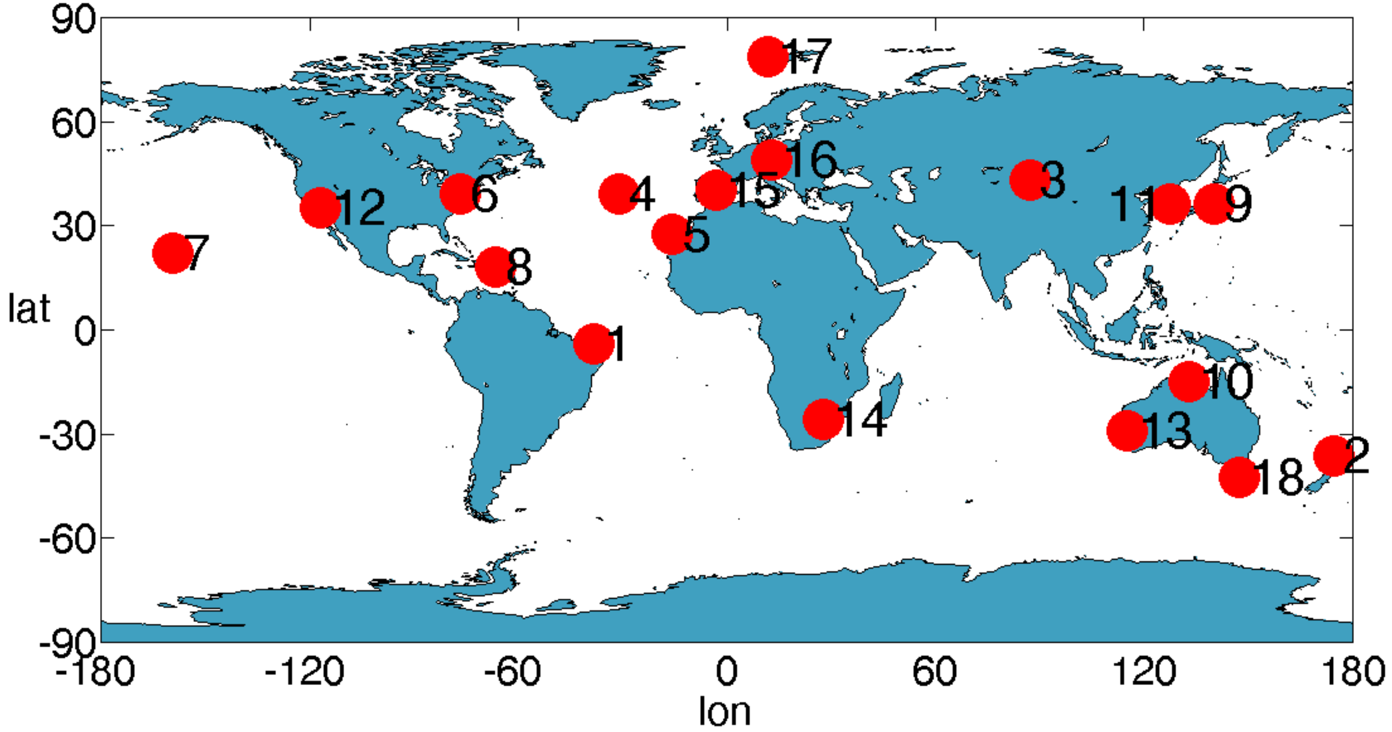
Proposed NASA Mission: Geodetic Reference Antenna in Space (GRASP)

- Co-location of geodetic techniques contributing to the TRF
- Determine TRF with 1 mm accuracy and 0.1 mm/yr stability
- Orbit:
  1350 x 850 km
  polar, sun-synchronous



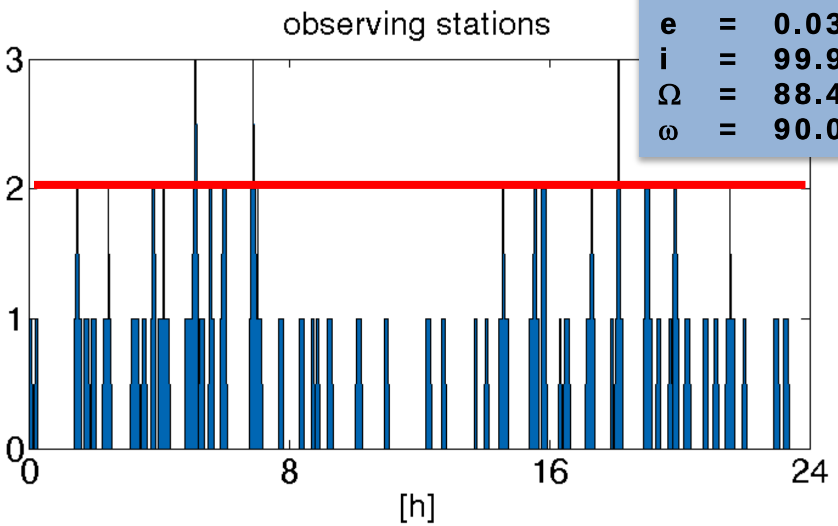
Visibility

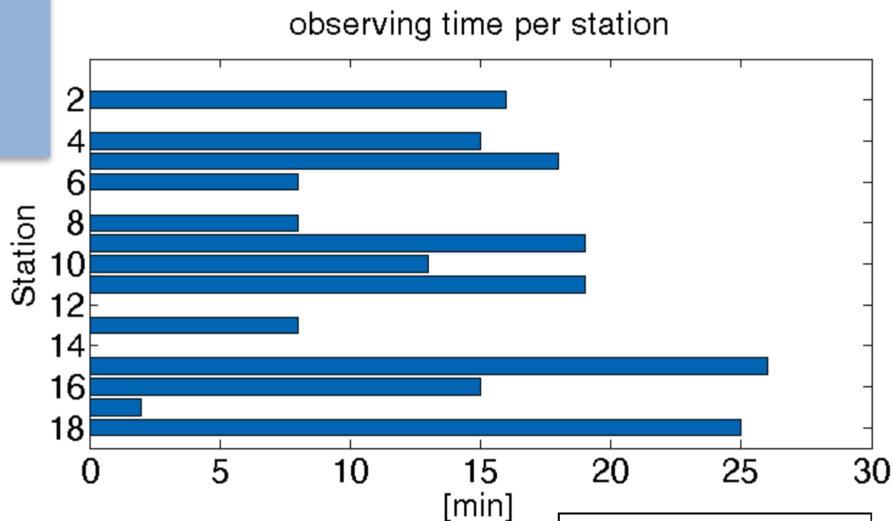
- **Can we observe satellites in VLBI mode?**
- **Visibility study with possiple VLBI2010 network**



GRASP visibilities

a = 7478.136 km
e = 0.033
i = 99.919 °
Ω = 88.402
ω = 90.000



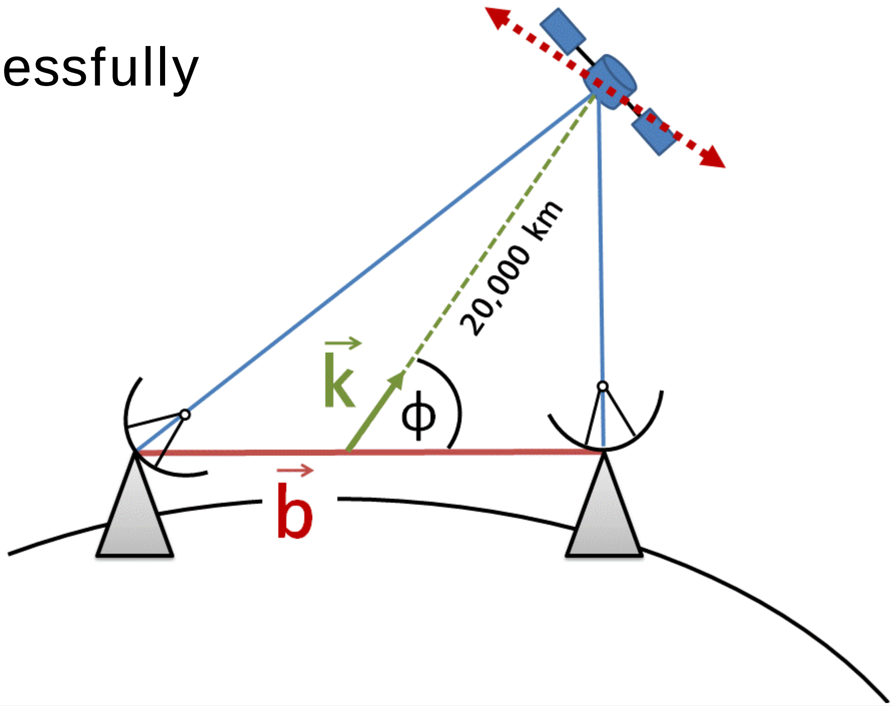


1	Ft	FORTLEZA
2	Wk	WARKWORT
3	Ur	URUMQI
4	Az	AZOR2010
5	Cn	CNARY IS
6	Gg	GGAO2010
7	Kk	KOKEE
8	Ar	ARECIBO
9	Ts	TSUKUB32
10	Ke	KATH12M
11	Kr	KOREA
12	Gd	GOLD2010
13	Yg	YARRA12M
14	Hh	HARTRAO
15	Yb	YEBE2010
16	Wz	WETZ2010
17	Ny	NYALES20
18	Mp	MT PLSNT

- GRASP can be observed in VLBI mode only partly,
- by 2 to max. 3 regional antennas at the same time.
- June 2012: GRASP was not selected by NASA but further studies/projects are planned.

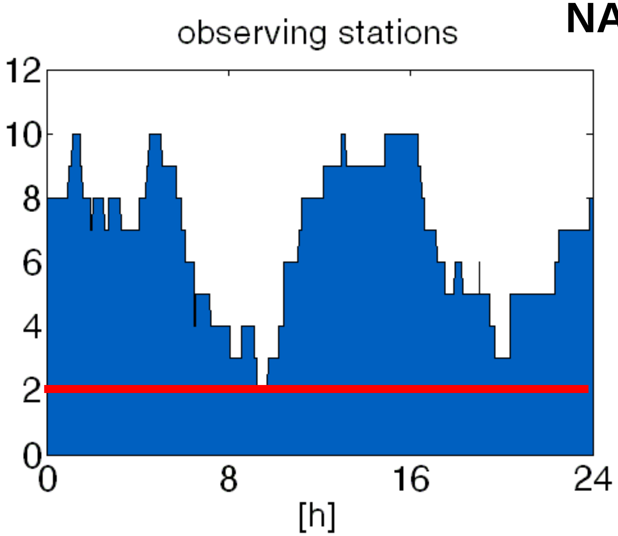
Observing modes (3)

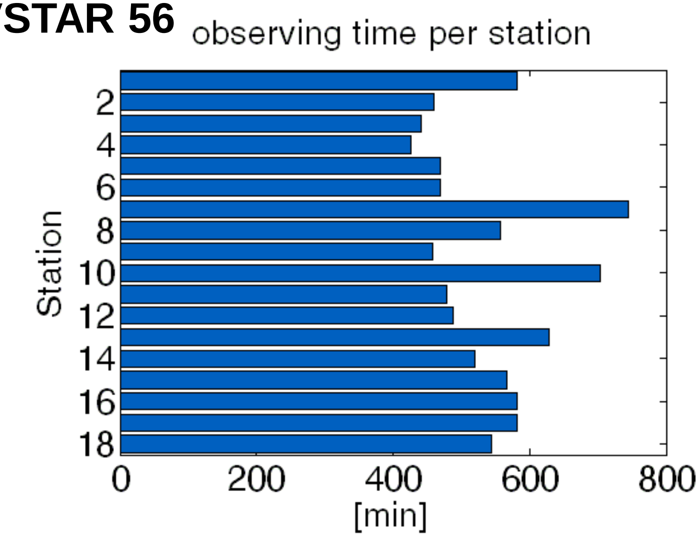
- Differential (D-) VLBI
- Co-location in space
- **VLBI observations of GNSS-Satellites**
  - VLBI observations of GLONASS-Satellites successfully done (Tornatore & Haas)



GNSS visibilities

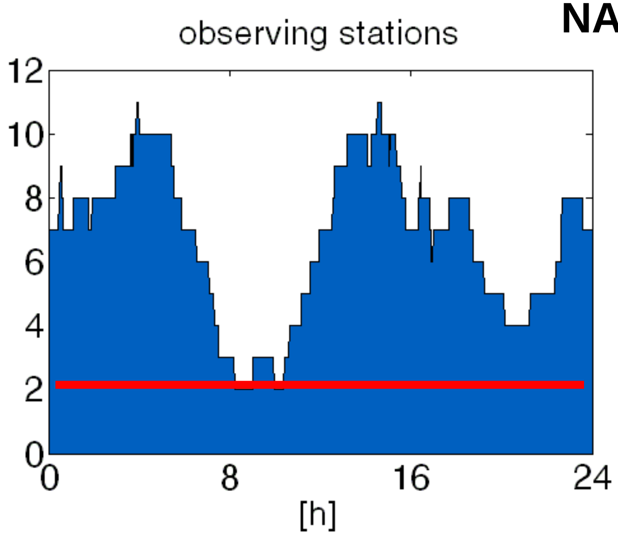
NAVSTAR 56

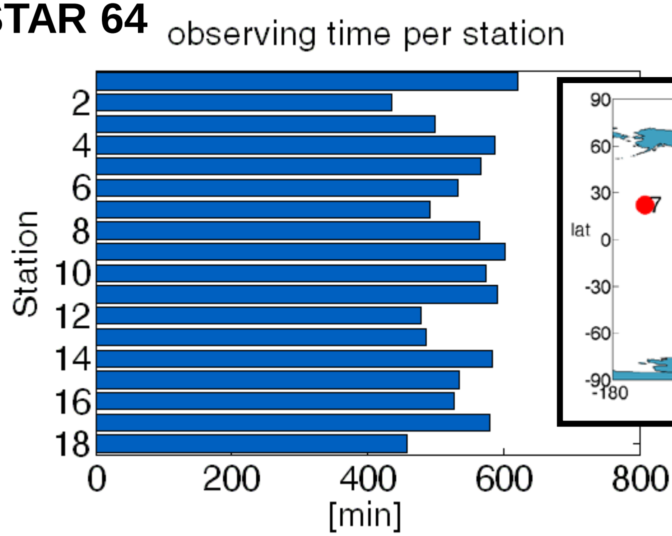


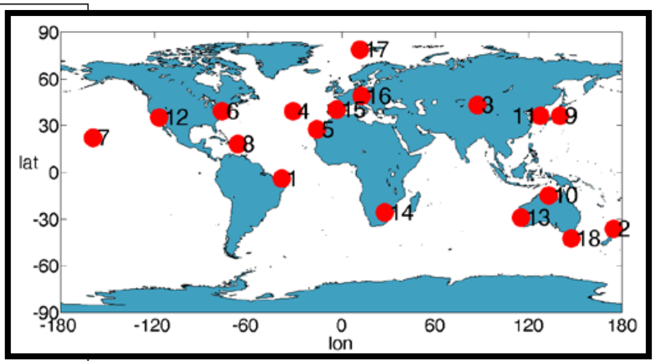


GNSS satellites can be observed in VLBI mode easily!

NAVSTAR 64







Target parameters

e.g.

- **Satellite orbit / spacecraft position**
  - not sensitive in line-of-sight
    - → constrain satellite height

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- **satellite position / orbit**
  - not sensitive in line of sight
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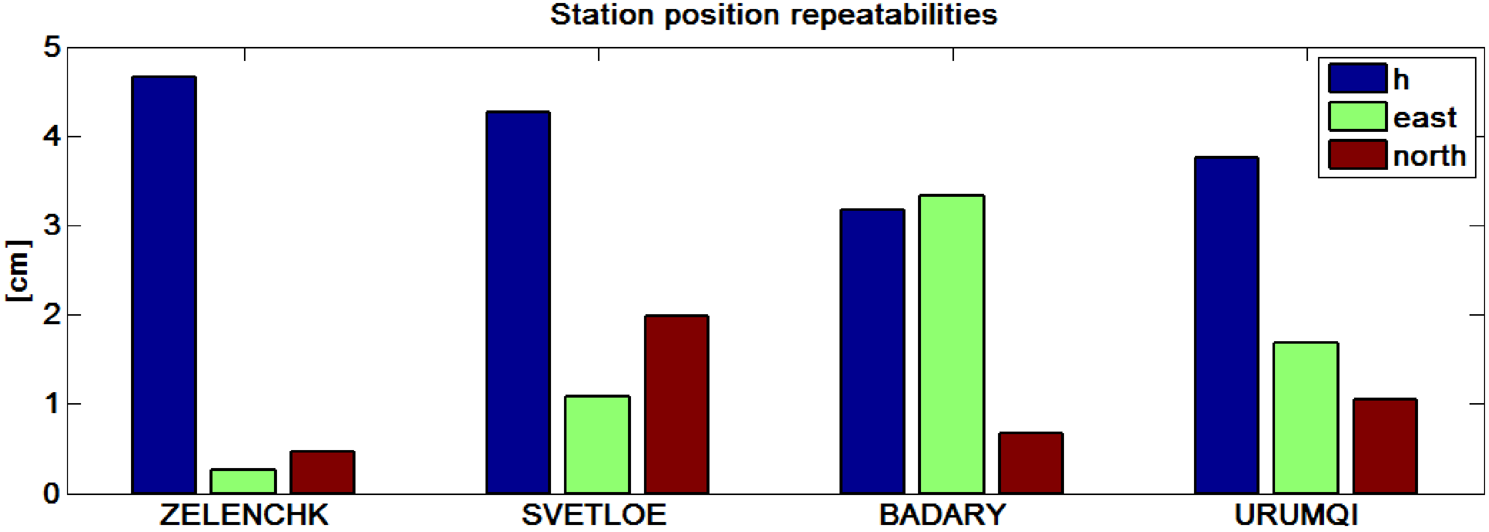
- **station position repeatabilities**
  - simulations with GNSS networks (4 stations)
  - accuracies are not very good yet (cm-level)
    → special scheduling strategies are needed

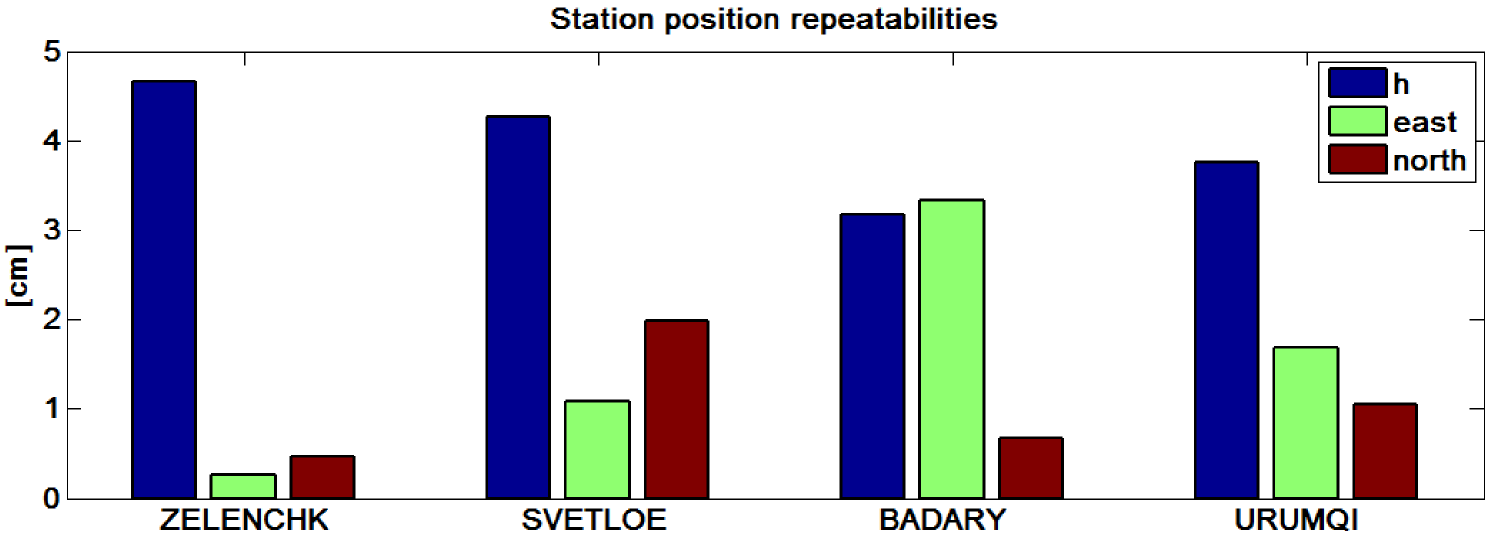
TRF

GNSS simulation

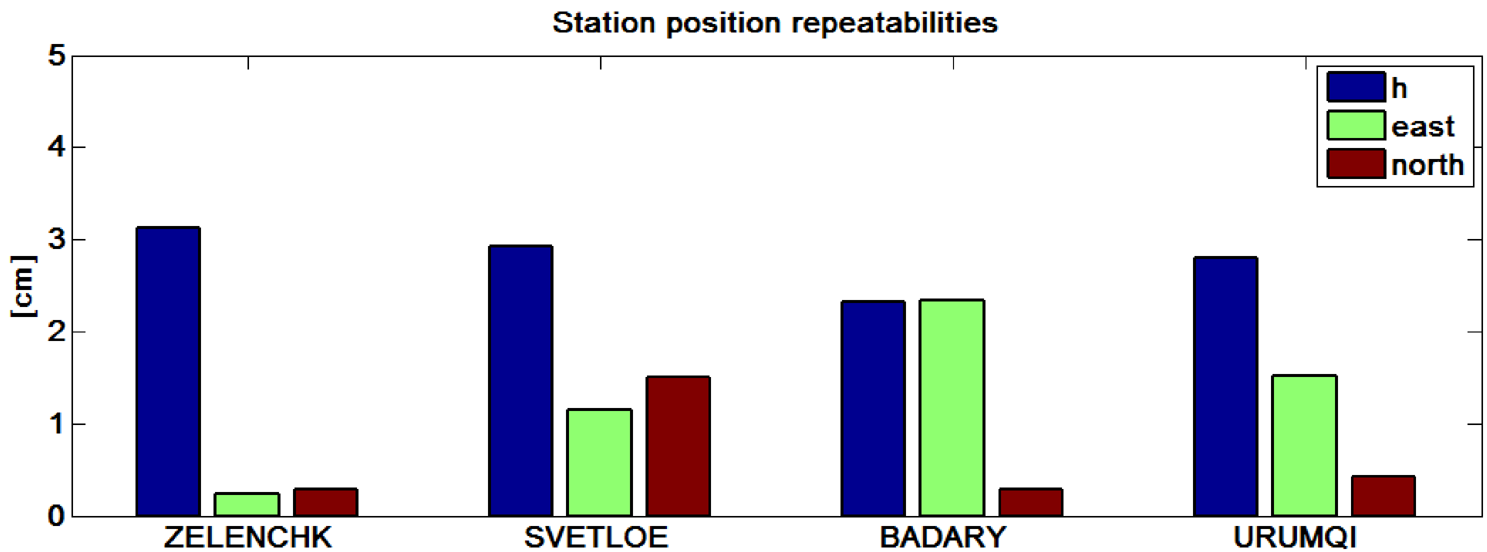


turbulent
Cn = 2.5e-7

GNSS simulation



turbulent
Cn = 2.5e-7

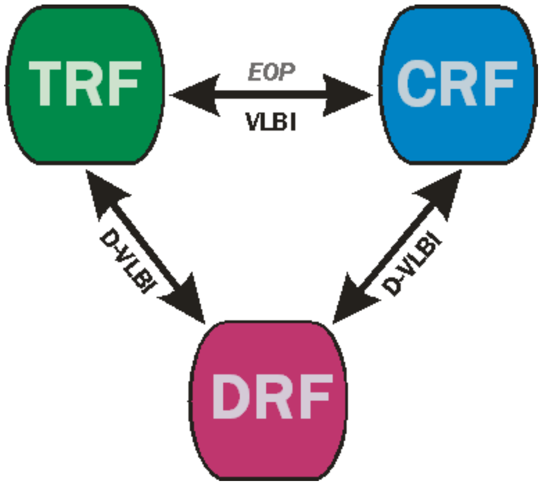


less turbulent
Cn = 1.0e-7

Target parameters

e.g.

- **satellite position / orbit**
  - not sensitive in line of sight
    → constrain satellite height
- **station repeatabilities**
  - simulations with GNSS networks (4 stations)
  - accuracies are not very good yet (cm-level)
    → better scheduling is needed
- **frame ties (described by e.g. 3 angles)**



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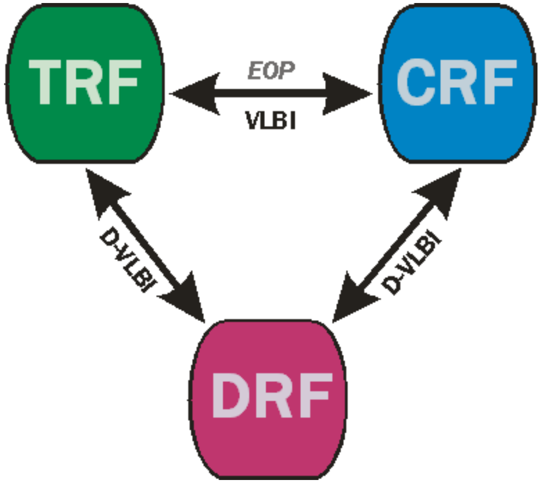

Remark: troposphere is once again the limiting factor!

Conclusions

- **Recent results motivate to use VLBI measurements to satellites for local ties, space ties, and frame ties.**

- **However, more research on the technical realization and observing strategies is needed.**

- **Modified VLBI Software (e.g. Vienna VLBI Software, VieVS) allows to simulate observations to satellites and gain information about achievable accuracies.**

- **Currently, VLBI observations to GNSS satellites are tested and several proposals for missions with a dedicated VLBI ‘signal‘ are going on.**

THANK YOU FOR YOUR ATTENTION!

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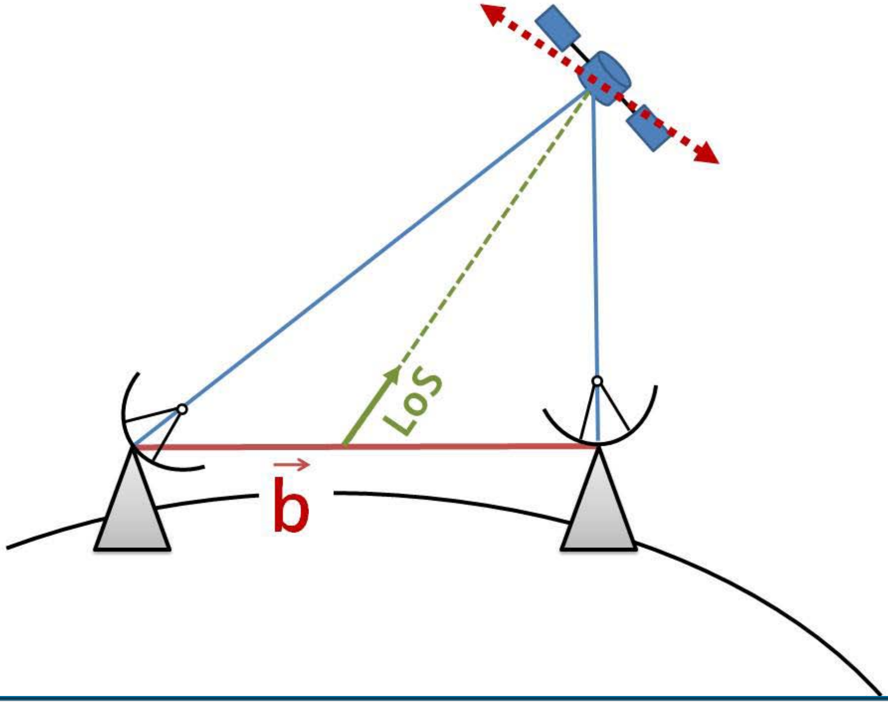
D-VLBI
DFG Research Group FOR 1503

Motivation 1

Navigation in space

- deep space navigation
  - routinely done (NASA, ESA)
  - sensitive perpendicular to the line of sight (LoS)
- lunar missions
  - SELENE, Chang‘e



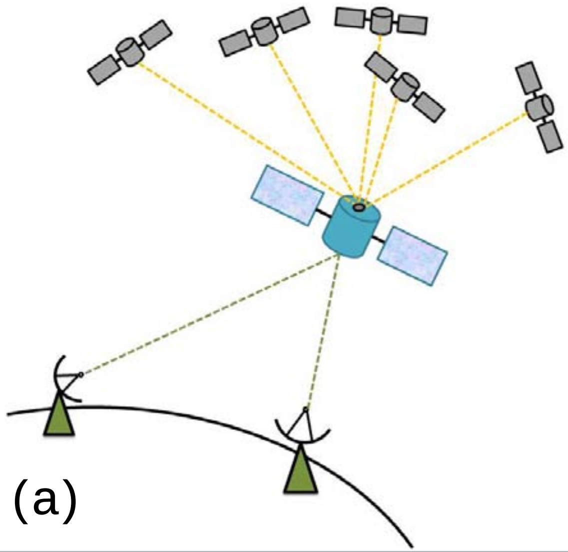
Motivation 3

Co-location in space

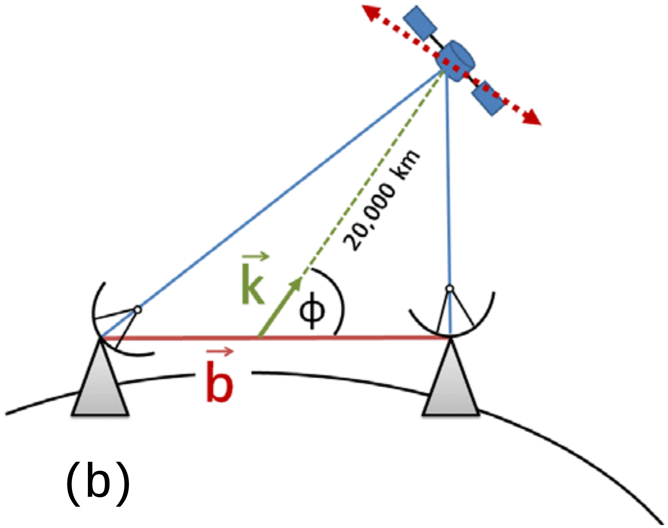
Inter-technique ties in space: e.g. GNSS-VLBI

Realizations:

- co-location in space (a)
  - studies: GRASP (JPL), MicroGEM (GFZ),...
- using GNSS satellites as VLBI targets (b)



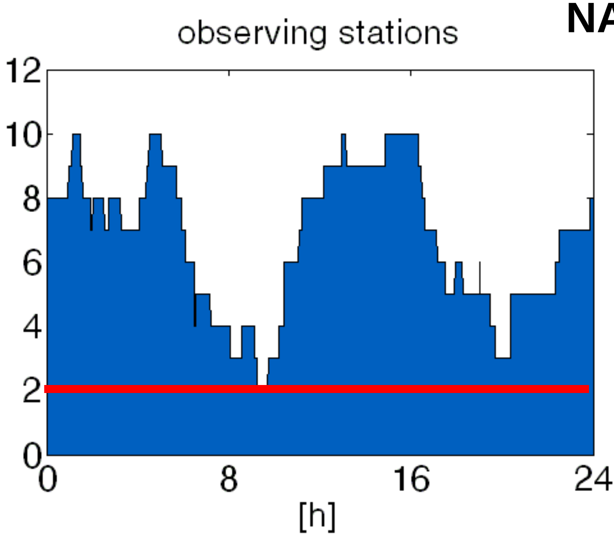
(a)

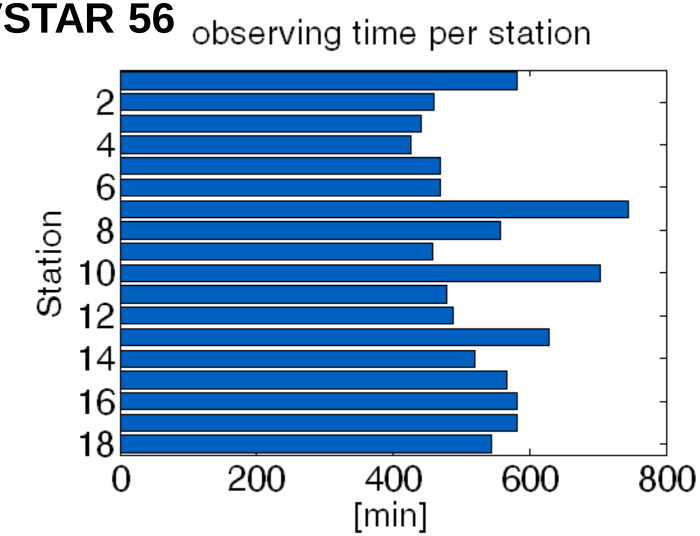


(b)

GNSS visibilities

NAVSTAR 56





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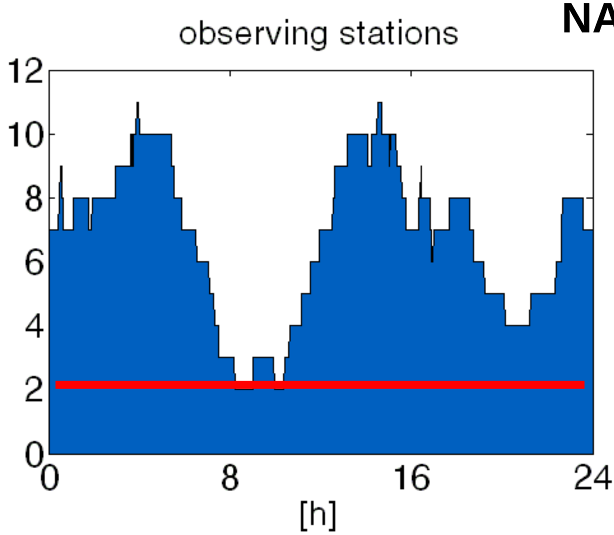
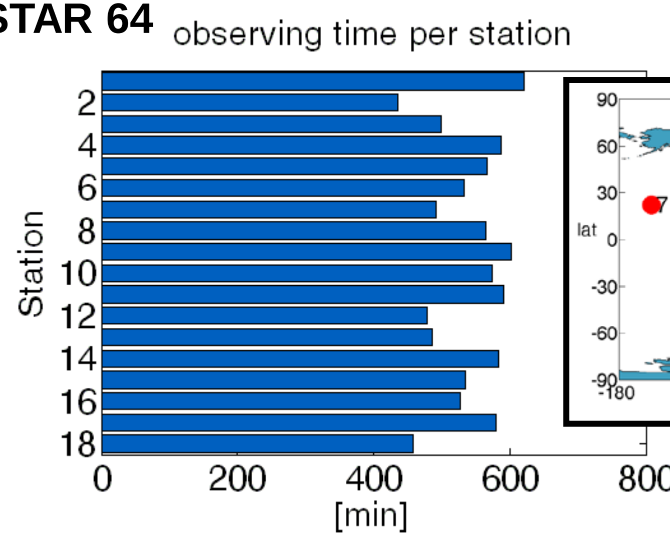
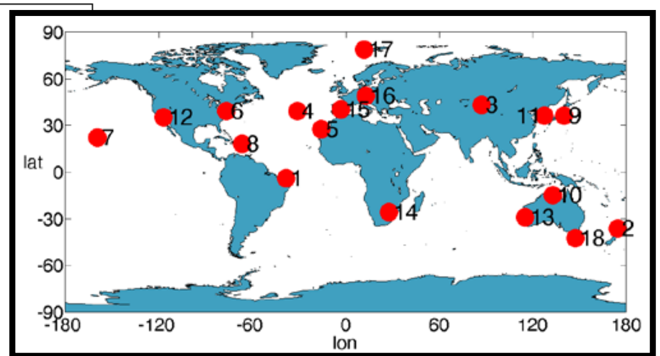




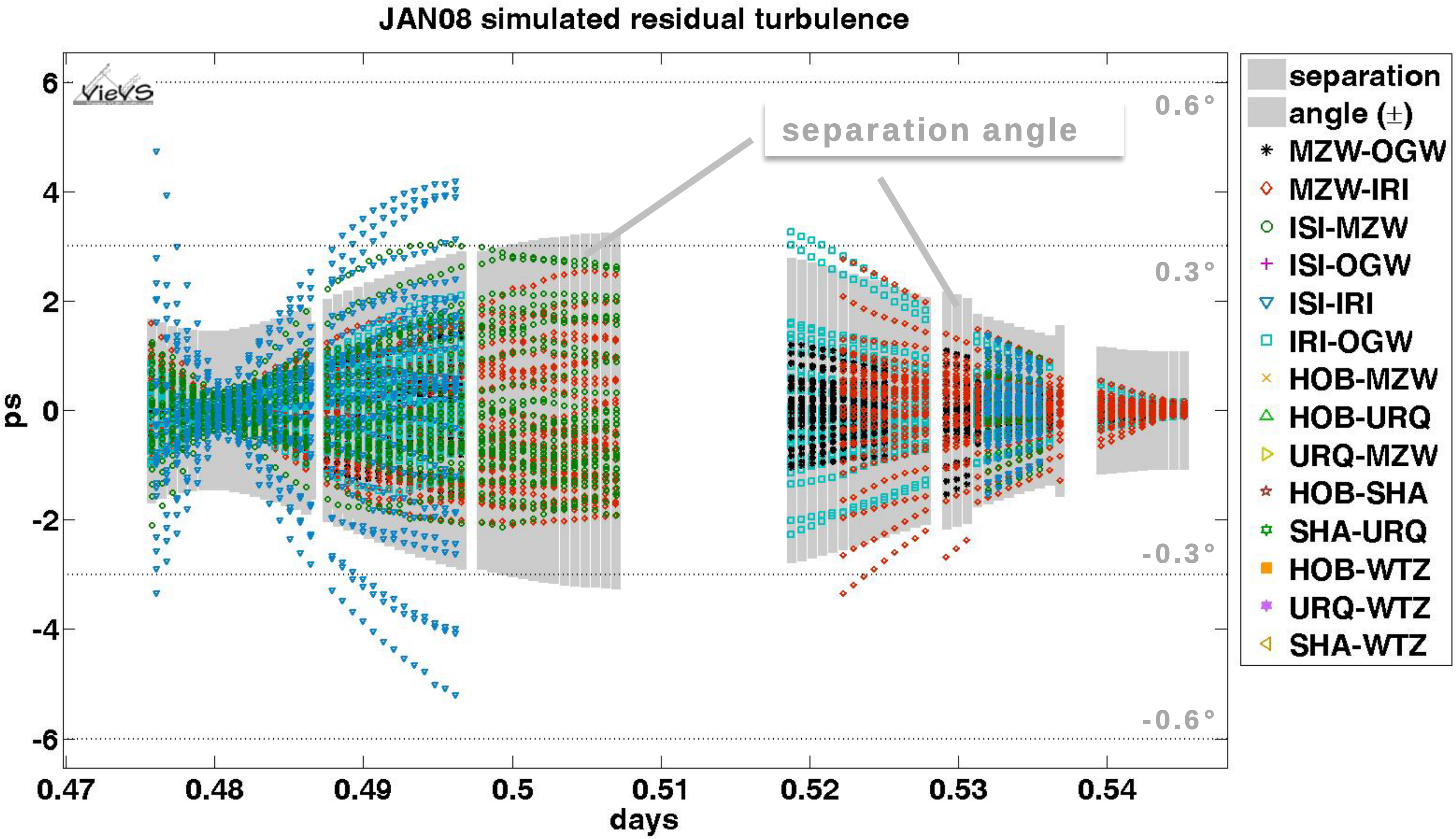


Simulated turbulence

- **Vienna VLBI Software (VieVS) simulator [Pany et al., 2010]; N = 30**

Effect of trop. turbulence in diff. delays

- **VieVS-simulator [Pany et al., 2010]; N = 30**



D-VLBI

- **but: for close satellites / spacecrafts it is difficult to find nearby radio sources**
  - e.g. SELENE (sc-sc): max. separation angle **0.56°** (same beam)
  - 4-station GNSS network:

    the satellite vector is different for each baseline

    → angular distance between satellite & quasar:

Δel = ± 4°

Δaz = ± 10°