Design of the VLBI Transmitter for GRASP and E-GRASP and Simulations of Positioning Performance

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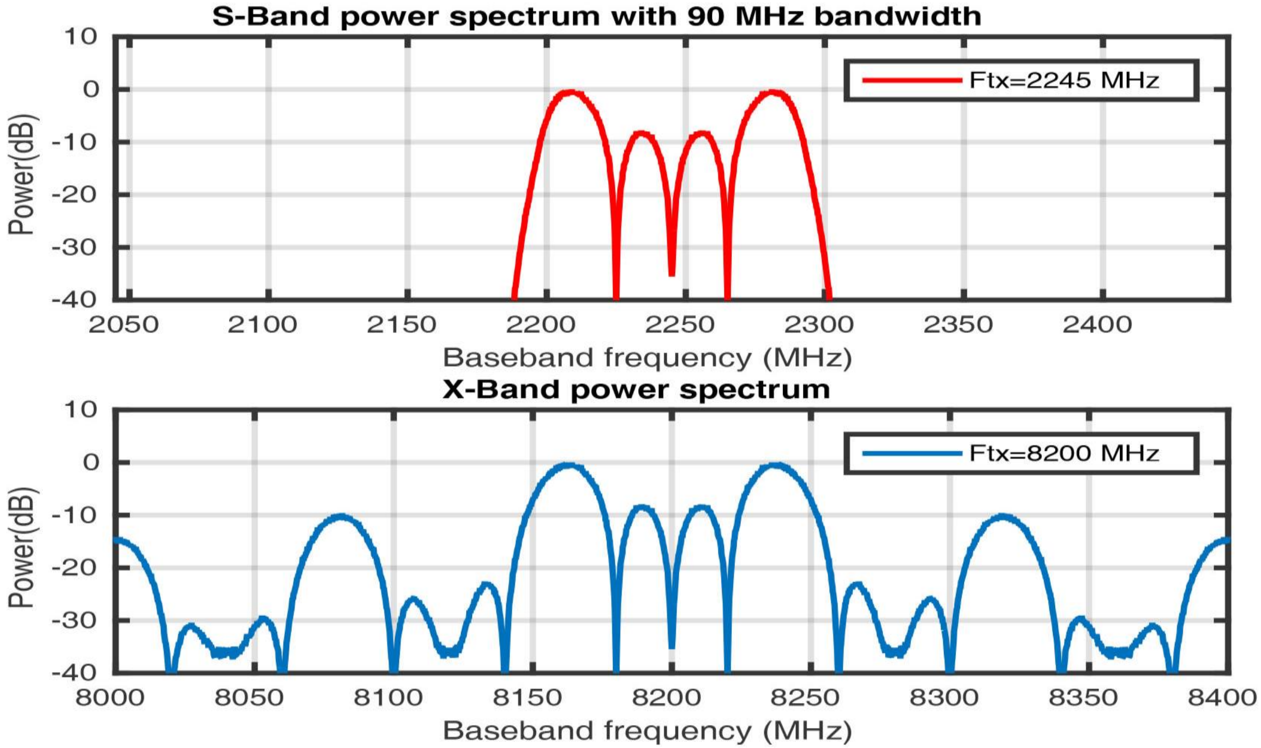
The GRASP VLBI Transmitter (VT)

Frequencies: 2.245 GHz and 8.2 GHz; Additional frequencies (e.g., Ku) to be considered after mission selection



Rationale for supporting only X- and S-bands at proposal time (2015):

- Uncertain schedule for migrating VLBI sites out of S-band, possibly after GRASP lifetime
- Lack of mature Ku-band flight hardware

Link Budget for a GPS-like Range Observables

JPL will initially extract phase and range observables from broadband VLBI measurement

- Software can be distributed after validation and tuning

	S-Band	X-Band
Frequency (GHz)	2.245	8.2
Transmit Power (dBm)	0 (1 mW)	0 (1 mW)
Tx Antenna Gain (dBi)	0 (unity gain)	0 (unity gain)
Max Range (km)	3,930	3,930
Space Loss (dB)	-171.35	-182.61
Rx Antenna Gain (dBi)	47.46	58.71
Received Power (dBm)	-123.89	-123.89
Noise Temperature (K)	50	50
No (dBm/Hz)	-181.61	-181.61
Processing Loss (dB)	3	3
C/No (dB-Hz)	53.92	53.92
SNRv (V/V@1 sec)	701	701
1 sec Phase error (mm)	0.030	0.008
Ion-Free Phase error (mm)	$((0.08 \cdot \sigma S)^2 + (1.08 \cdot \sigma X)^2)^{1/2} = 0.01$	
1 sec Range error (mm)	1.7	1.7
Ion-Free Range error (mm)	$((0.08 \cdot \sigma S)^2 + (1.08 \cdot \sigma X)^2)^{1/2} = 1.84$	

0.01 mm projected phase noise

assuming sat at ~1400 km altitude, 12 m VLBI antenna @70% efficiency, Tsys = 50 K, 5° elevation

Positioning Simulations

Modeling and assumptions:

- Ionospheric-free biased range (carrier phase with ambiguous cycles), every 10 seconds, with 0.1 mm white noise (vs. 0.01 mm projected)
- GRASP orbit (1400 km x 925 km) is perfectly known in the 'GRASP TRF'
- Minimum 5° elevation for observations at any VLBI site
- VLBI station clocks with H maser (10^{-14} Allan Deviation) : 0.3 mm (1 ps) random walk every 10-second observation
- Zenith wet troposphere delay: 15% of VMF1GRID — GPT2 (~5 mm RMS)
- Wet troposphere mapping function: 100% VMF1GRID — Niell

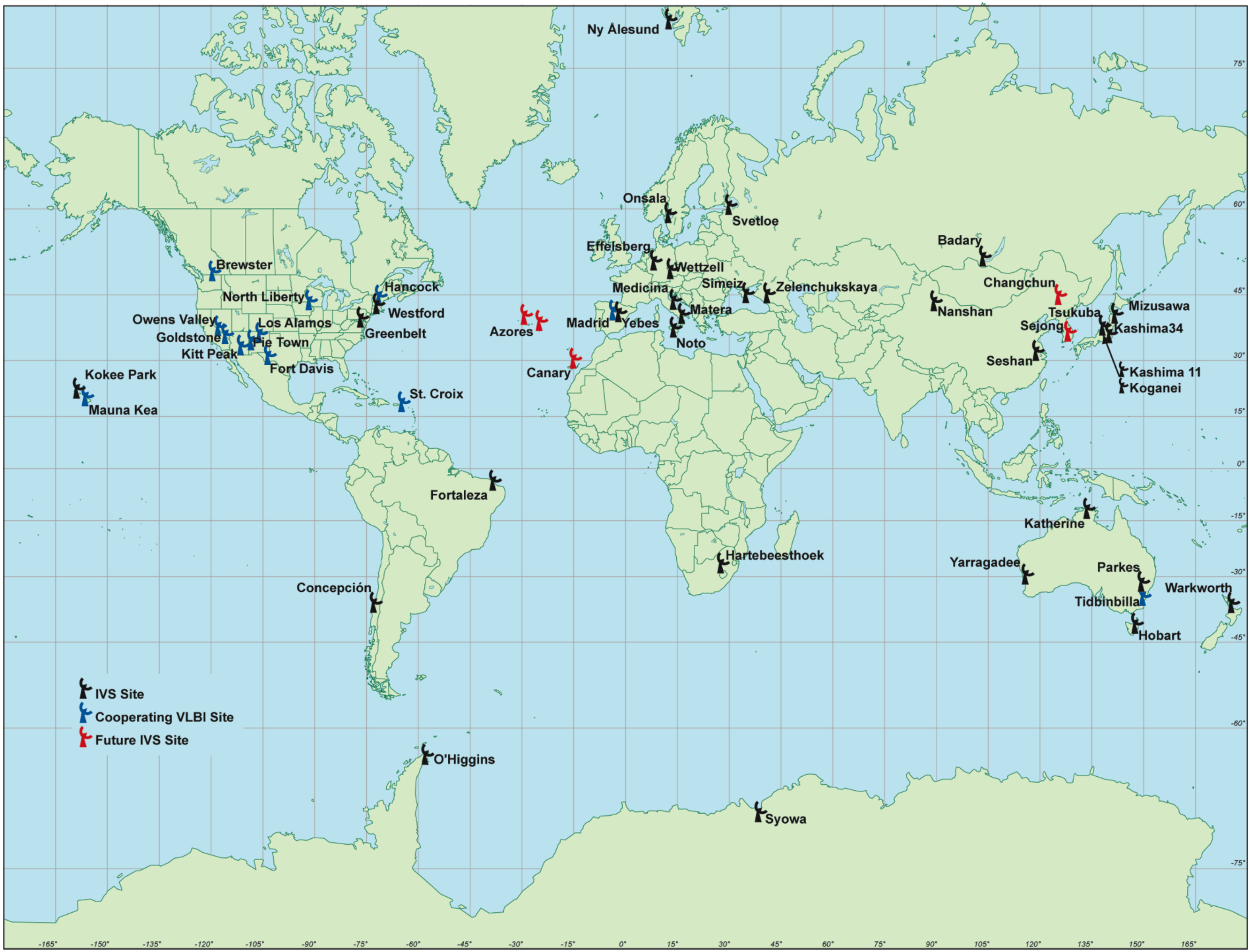
Estimated parameters:

- 3D station coordinates (with 1 m a priori uncertainty)
- GRASP clock (unconstrained white-noise update every 10 seconds)
- Phase biases (unconstrained per pass)
- Optional zenith wet troposphere (30-minute updates with 5-mm a priori uncertainty)

Estimating GRASP clock as white noise is equivalent to traditional VLBI approach of using differential range observations (different than ppp approach in GRASP 11' simulations**)**

Station 3D positioning errors reported as quadrature sum of formal error and perturbation

VLBI Sites

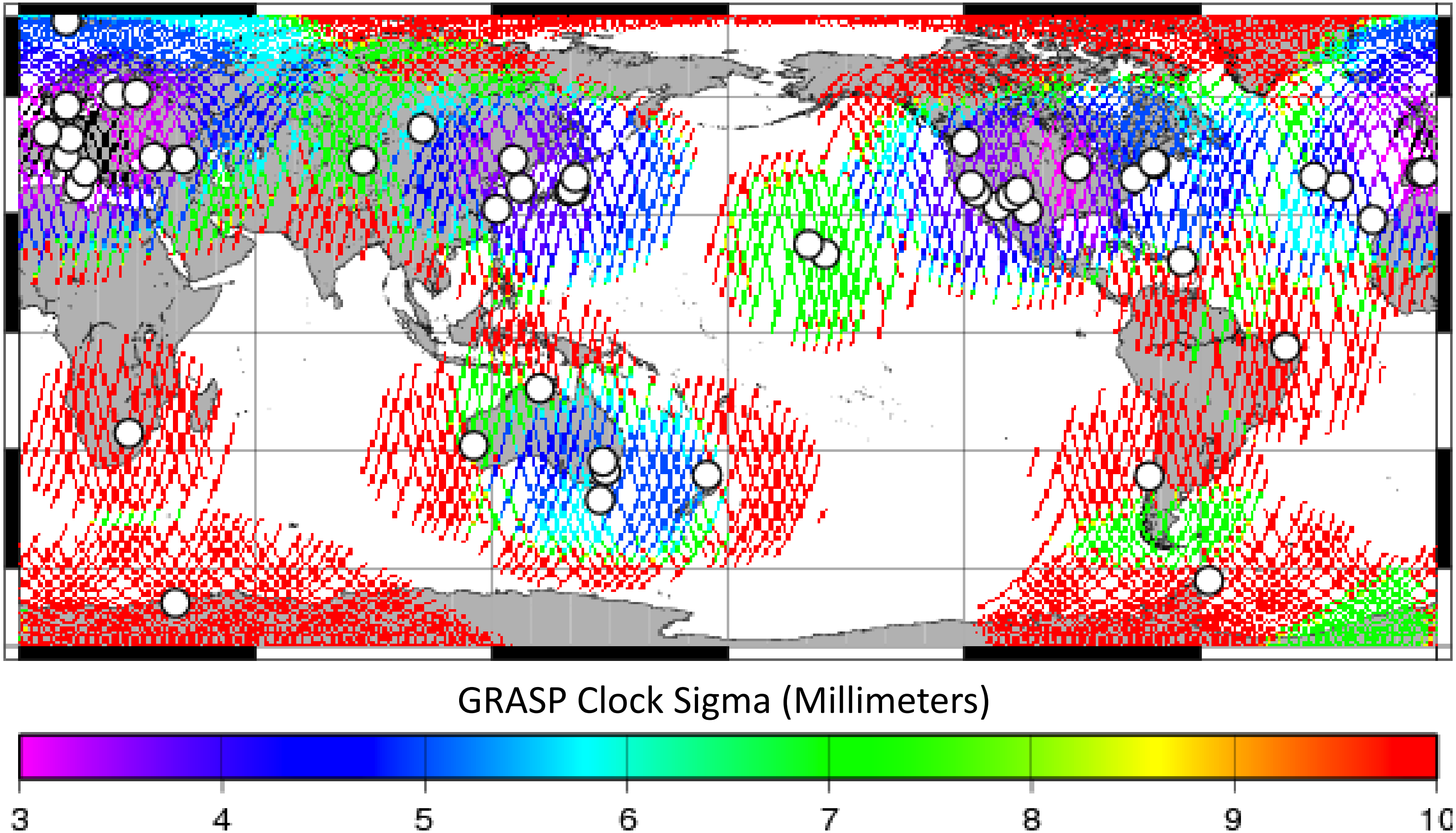


Ny Ålesund
Onsala
Svetloe
Effelsberg
Wettzell
Badary
Brewster
Hancock
North Liberty
Westford
Greenbelt
Medicina
Simeiz
Zelenchukskaya
Changchun
Owens Valley
Los Alamos
Goldstone
Pie Town
Kitt Peak
Fort Davis
Azores
Madrid
Yebes
Matera
Noto
Nanshan
Tsukuba
Mizusawa
Kashima34
Sejong
Seshan
Canary
Kokee Park
Mauna Kea
St. Croix
Kashima 11
Koganei
Fortaleza
Katherine
Hartebeesthoek
Yarragadee
Parkes
Warkworth
Concepción
Tidbinbilla
Hobart
IVS Site
Cooperating VLBI Site
Future IVS Site
O'Higgins
Syowa

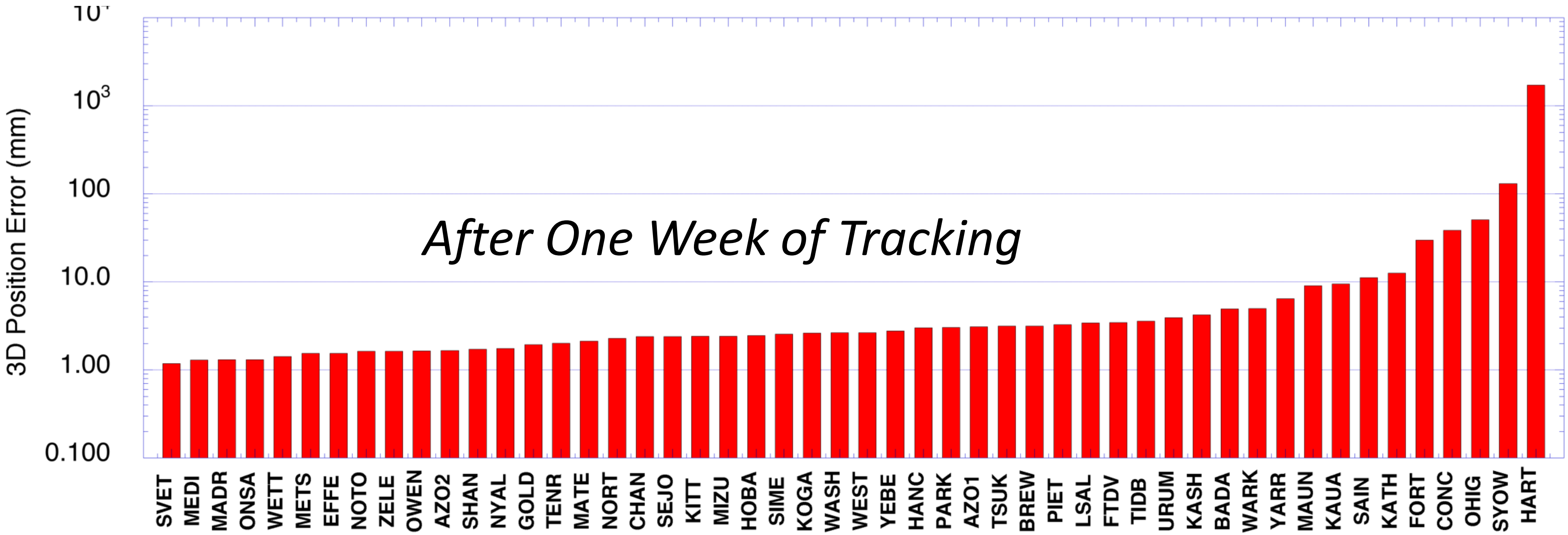
VLBI Station Connectivity via GRASP (over one week)

GRASP's clock formal error (below, as a function of ground track) is a proxy for the number of VLBI sites simultaneously tracking GRASP

Isolated VLBI sites (e.g., Hartebeesthoek) cannot be effectively positioned through GRASP, but can be positioned with classical VLBI relative to GRASP-determined sites



Accuracy of VLBI Stations Positions From Simulations



- **Main sources of error**
  - Troposphere
  - VLBI station clocks
- **Isolated sites are slightly sensitive to the selected week due to elliptical orbit**

VLBI Regional Network	***Number of sites***	***Error after 1 week***	***Error after 3 years (n=18)***
Europe (including Azores/Tenerife)	16	1.6 mm	0.4 mm
North America (excluding Hawaii)	11	2.7 mm	0.6 mm
Japan/China	9	2.6 mm	0.6 mm
Australia/New Zealand	6	4.3 mm	1.0 mm
Tropical (Hawaii/St Croix)	3	9.5 mm	2.2 mm
South America	2	34.2 mm	8.1 mm
Antarctica	2	90.7 mm	21.3 mm
Africa	1	n/a	n/a

Conclusions

Simulations support mm-level reference frame transfer from GRASP to many VLBI stations using one week of intense observations

Isolated VLBI sites can derive their position (in the GRASP TRF) from the well-positioned sites using classical VLBI observations

Differential observation approach significantly reduces sensitivity to the VT instrumental stability – an advantage over the ppp approach of GRASP 11'

Intensive weekly campaigns (~6 per year) seem to be sufficient to meet TRF accuracy goals of 1 mm positioning accuracy within the GRASP TRF

- Reduces year-long burden of tracking GRASP
- Focuses on dense arrays of sites
- But offers limited incentive for isolated sites to track GRASP