



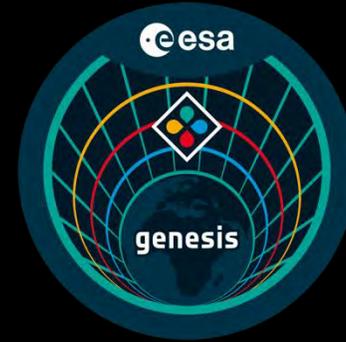
# ESA GSET WG-3 (VLBI)

## general overview

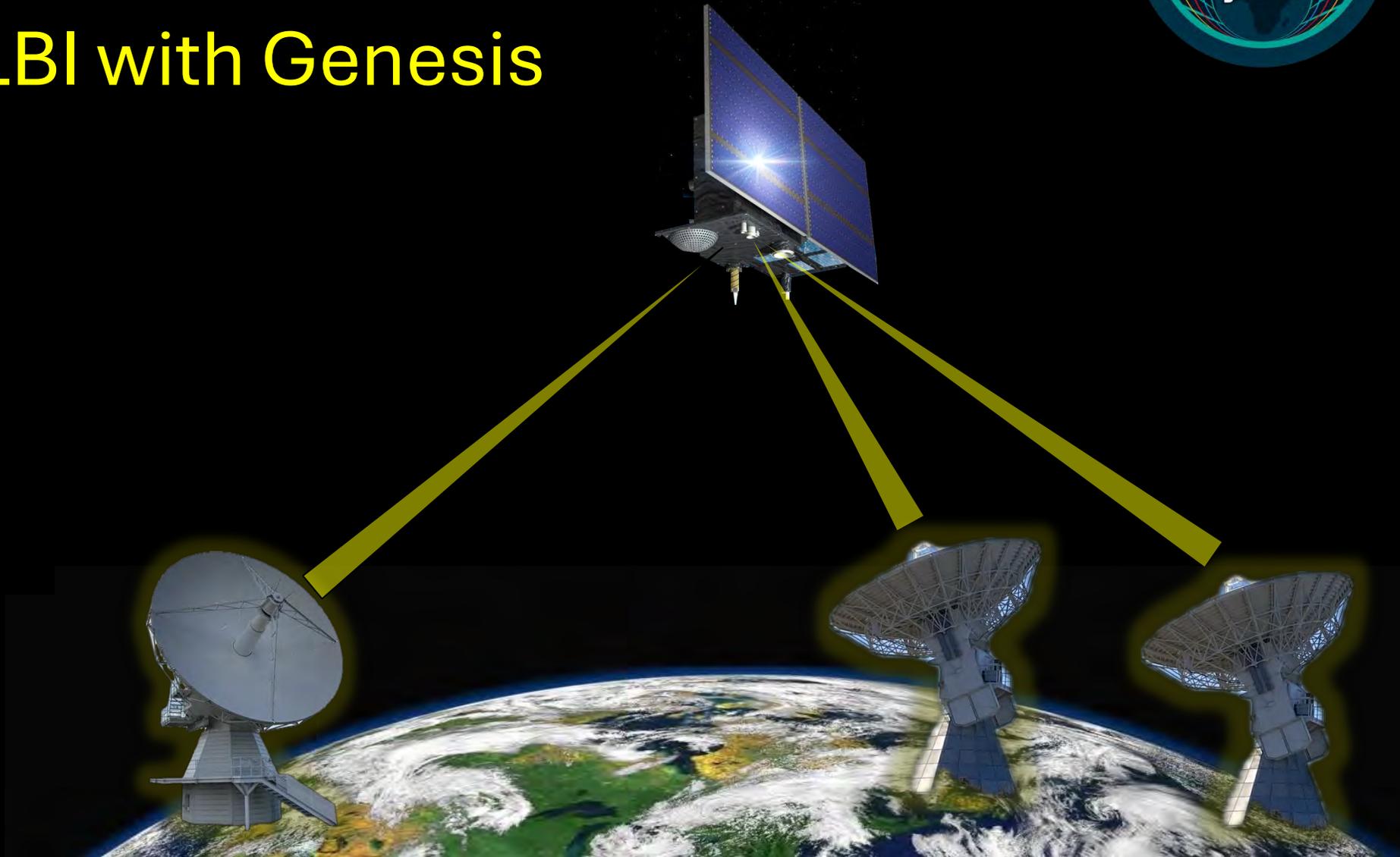
ESA Genesis Science Workshop 2026  
12–13 March 2026, Brussels, Belgium

Rüdiger Haas

Chalmers University of Technology



# VLBI with Genesis



# ESA GSET WG-3 members

- Simone Bernhart – BKG/MPIfR, DEU
- Johannes Böhm – TU Vienna, AUT
- Patrick Charlot – CNRS Bordeaux, FRA
- Christophe Craeye – UCL, BEL
- Thibault Deleu – RoB, BEL
- Pablo de Vicente – IGN, ESP
- Claudia Flohrer – BKG, DEU
- Susana Garcia-Espada – Kartverket, NOR
- Luciano Garramone – ASI, ITA
- Jakob Gruber – BEV Wien, AUT
- Rüdiger Haas – Chalmers, SWE
- Robert Heinkelmann – GFZ, DEU
- Masafumi Ishigaki – GSI, JAP
- Lucia McCallum – UTas Hobart, AUS
- Alexander Neidhardt – TU München, DEU
- Axel Nothnagel – TU Vienna, AUT
- Almine Özyildirim – RoB, BEL
- Christian Plötz – BKG, DEU

- Chet Rusczyk – MIT Haystack, USA
- Matthias Schartner – ETH Zürich, CHE
- Harald Schuh – GFZ Potsdam, DEU
- Gino Tuccari – INAF & MPIfR, ITA/DEU
- Rimsky Wolfs – Chalmers, SWE

## Ex-officio (ESA GSET coordinator & co-coordinator)

- Özgür Karatekin – RoB, BEL
- Francesco Vespe – ASI, ITA

## ESA

- Sara Bruni – ESOC, DEU
- Gaia Fusco – ESTEC, NLD
- Erik Schönemann – ESOC, DEU
- Pierre Waller – ESTEC, NDL
- Frank Zimmermann – ESOC, DEU

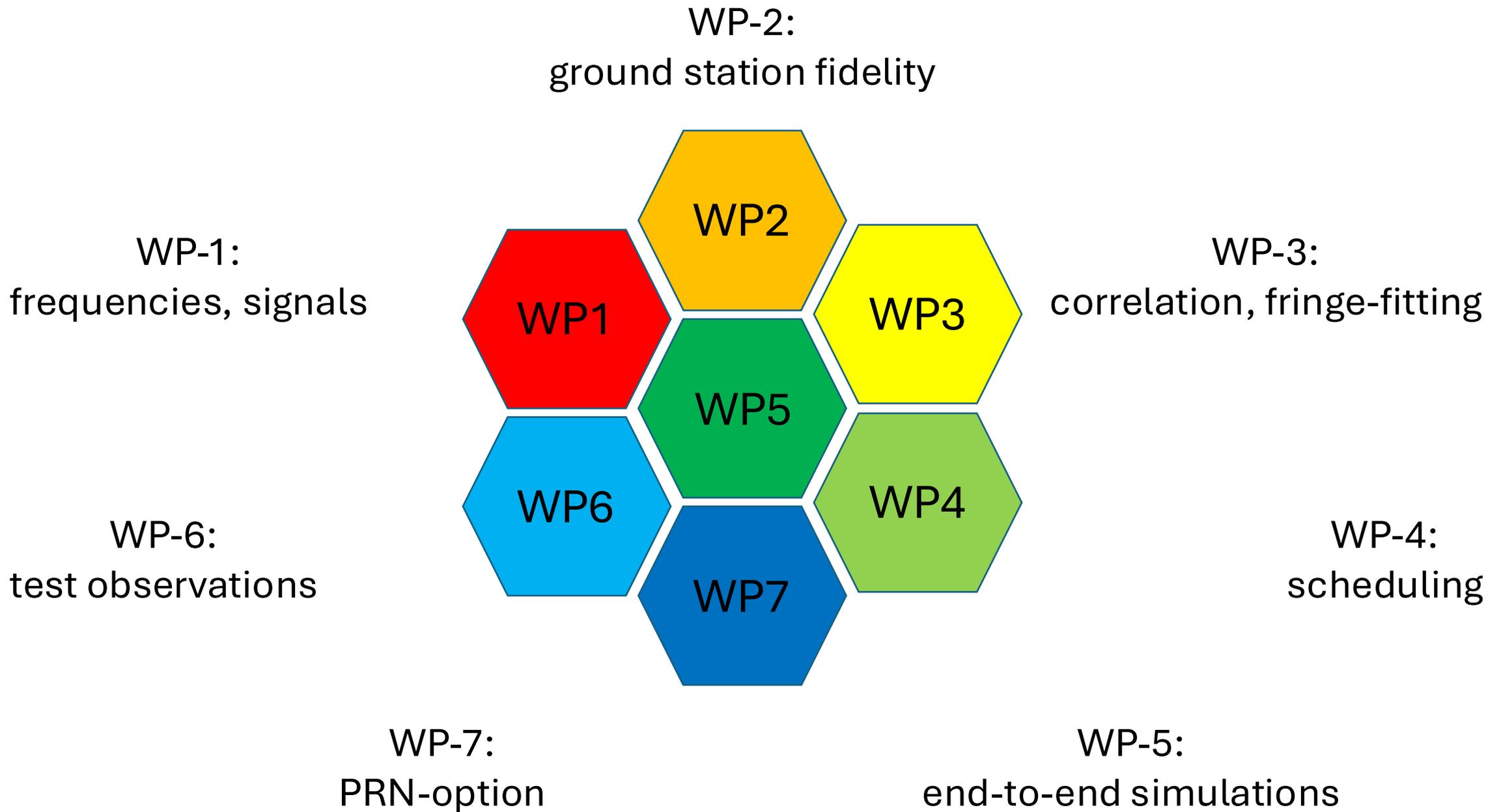


# ESA GSET WG-3 meetings

- 2024-07-15
- 2024-08-26
- 2024-09-16
- 2024-10-16
- 2024-11-29

- 2025-01-20
- 2025-02-24
- 2025-03-25
- 2025-05-26
- 2025-07-07
- 2025-08-27
- 2025-09-29
- 2025-11-17
- 2025-12-15

- 2026-02-09
- 2026-03-23



# WP-1: frequencies, signals

2026-01-21  
Genesis wide band

Band-A		Band-B		Band-C		Band-D	
start	stop	start	stop	start	stop	start	stop
3110	3290	5260	5560	8210	8390	9350	9750
(MHz)	(MHz)	(MHz)	(MHz)	(MHz)	(MHz)	(MHz)	(MHz)
3096,4	3128,4	5272,4	5304,4	8024,4	8056,4	9368,4	9400,4
3128,4	3160,4	5304,4	5336,4	8056,4	8088,4	9400,4	9432,4
3160,4	3192,4	5336,4	5368,4	8184,4	8216,4	9432,4	9464,4
3192,4	3224,4	5400,4	5432,4	8216,4	8248,4	9528,4	9560,4
3224,4	3256,4	5432,4	5464,4	8248,4	8280,4	9624,4	9656,4
3256,4	3288,4	5464,4	5496,4	8280,4	8312,4	9656,4	9688,4
3288,4	3320,4	5496,4	5528,4	8312,4	8344,4	9688,4	9720,4
3320,4	3352,4	5528,4	5560,4	8344,4	8376,4	9720,4	9752,4
channels	8	8	8	8	8	8	8

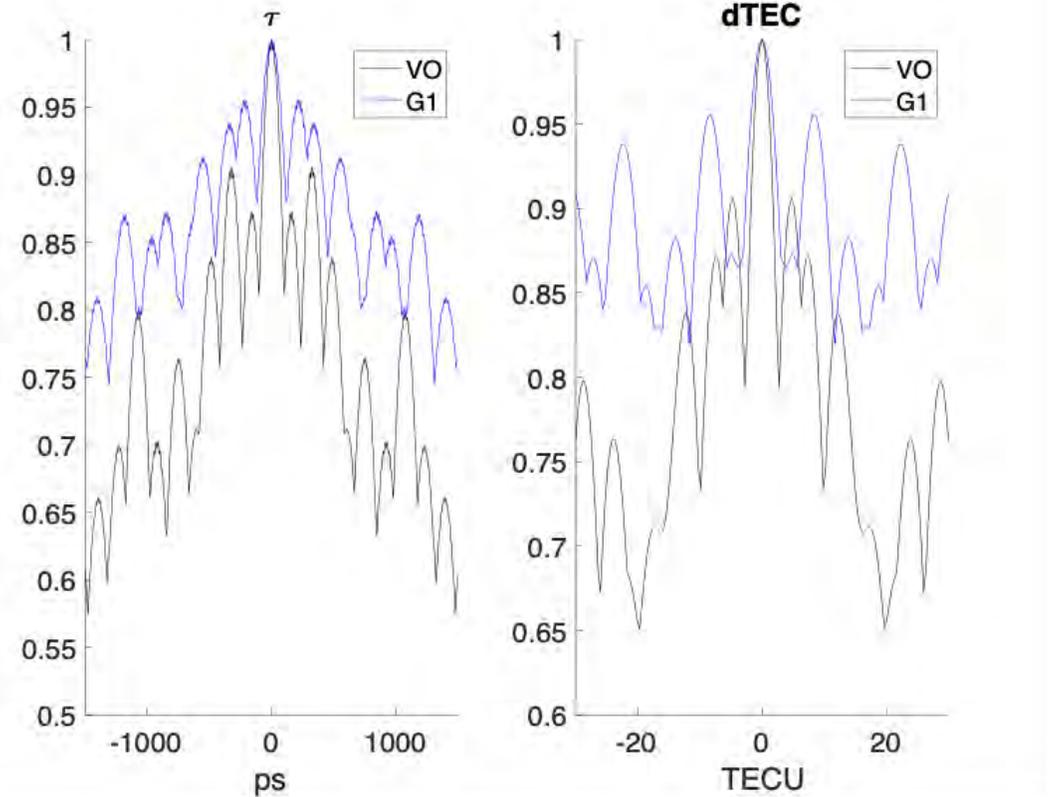
total bandwidth of Genesis signals:  
6624 MHz

Comments:

- 1) recording of 4x8 channels in 2 polarizations
- 2) the "pink" channels are outside the Genesis transmit band and will thus not be used for fringe fitting
- 3) "blue" channels are overlapping with current "standard VO setup"



Proposed Genesis frequency setup



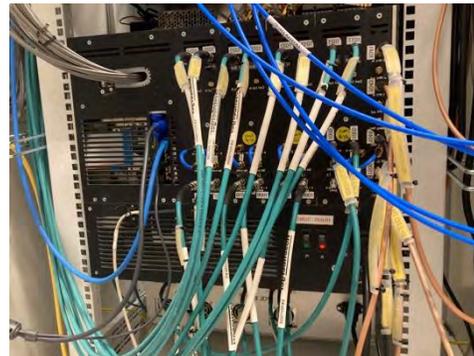
Delay resolution comparison to standard "VO" setup

# WP-2: ground station fidelity

- Setting up VLBI equipment for Genesis observations
- Satellite-tracking operations



Technical realisation

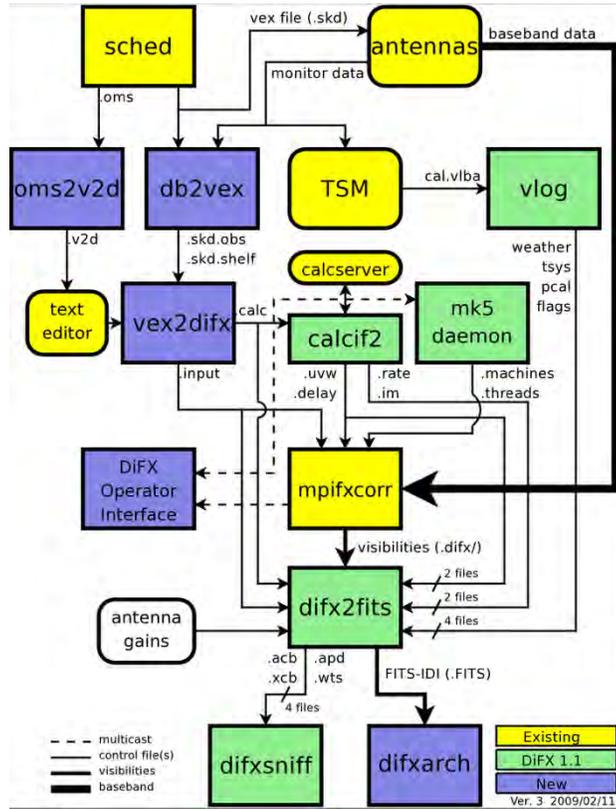


← Field-system control  
of VLBI backends

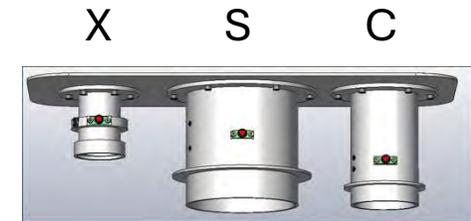
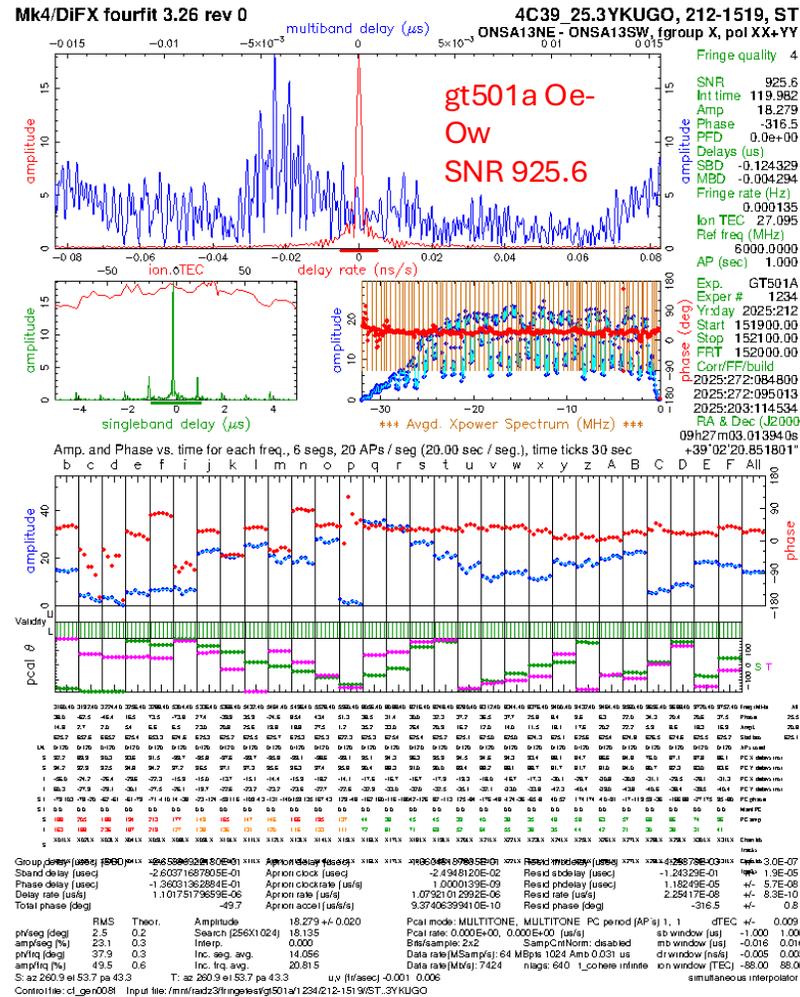


Field-system control  
With e.g. TLE

# WP-3: correlation, fringe-fitting



Near field model needed!



Handling of PCO/PCV (!) and geometric corrections for ARP/COM relation in Fringe-fitting process

Warning: XP spectrum is normalized for full band FFT - as spectrum is excluded XP amplitude increases. Amp and SNR calculations are approximately correct. 442 frequency notches from 31.28.399902 to 9748.500000

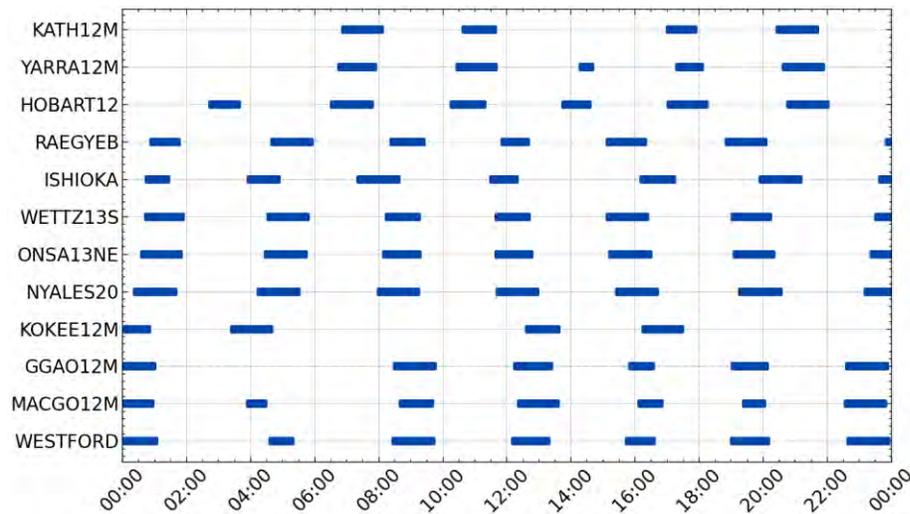
# WP-4: scheduling

- Satellite visibility?
- What scan length necessary?
- How to include Genesis in IVS-operations?

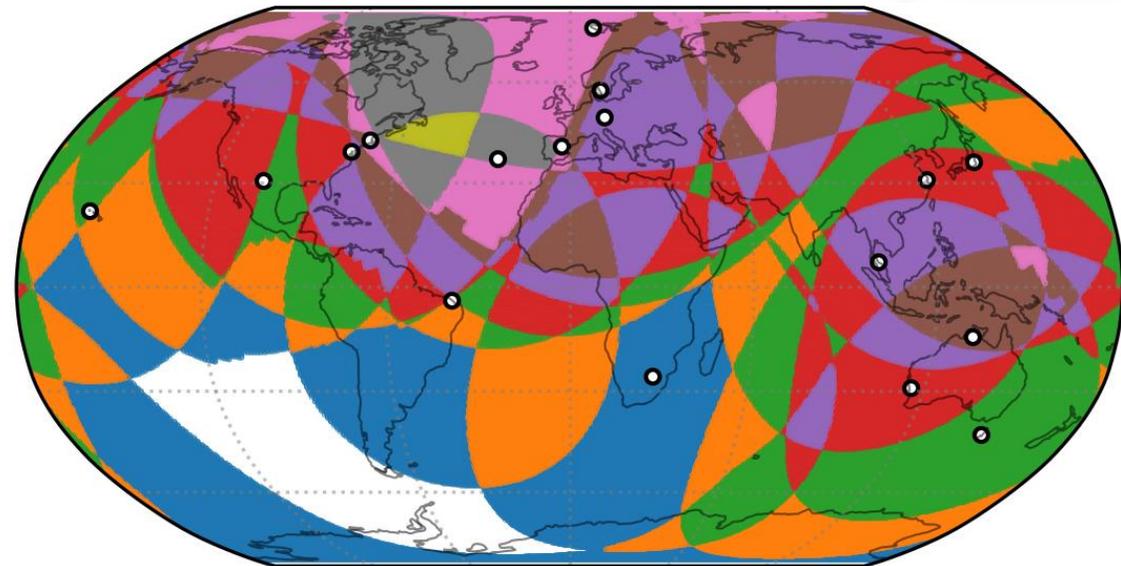
Common visibility



stations visible	
1 (19.6%)	6 (9.2%)
2 (13.3%)	7 (6.8%)
3 (14.1%)	8 (4.5%)
4 (12.2%)	9 (0.4%)
5 (13.0%)	10 (0.0%)

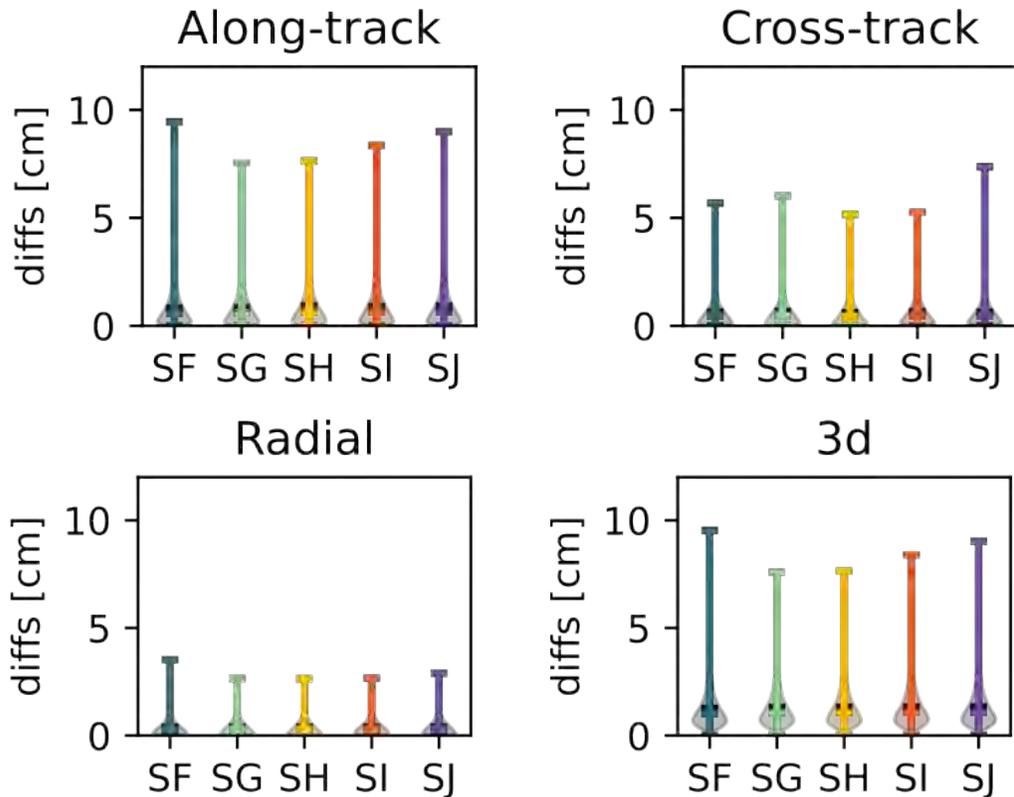


Common visibility

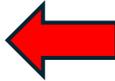


# WP-5: end-to-end simulations

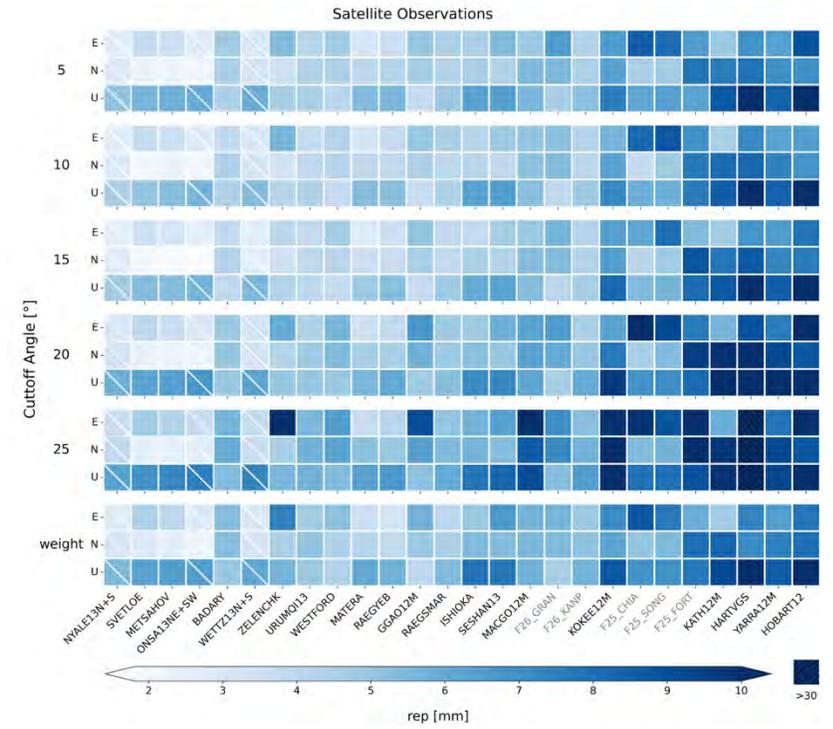
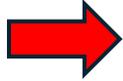
- What parameters can be estimated?
- What impact on "classical geodetic" parameters?



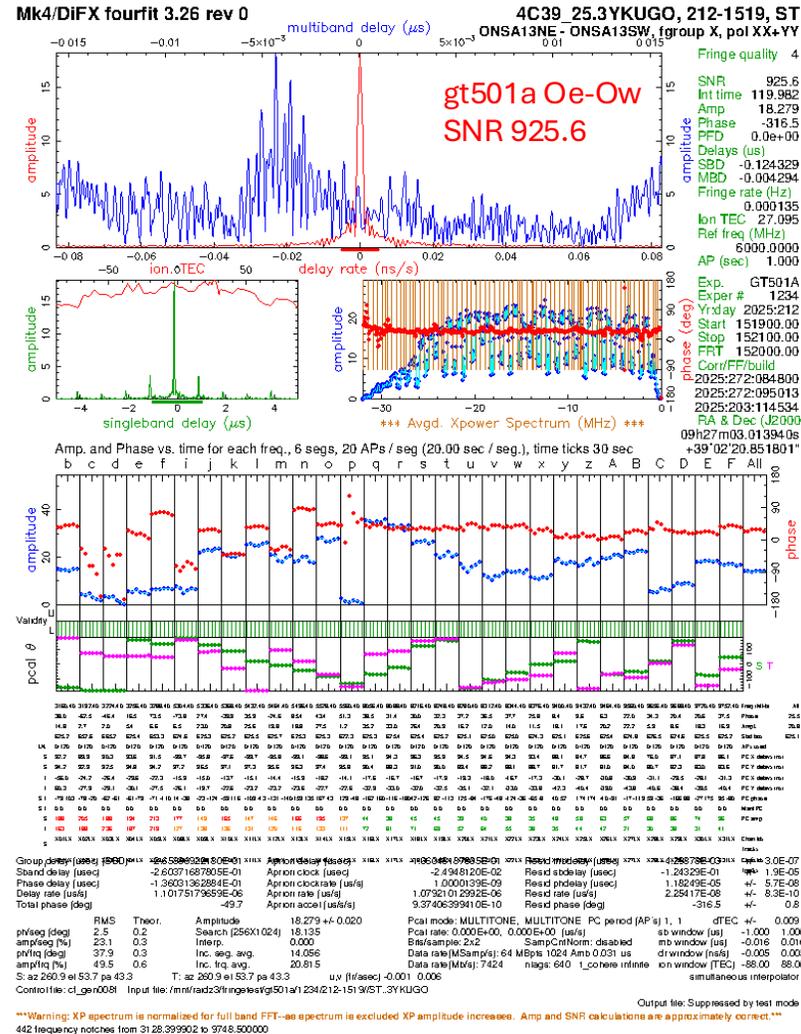
Orbit estimation



Station position estimation



# WP-6: test observations

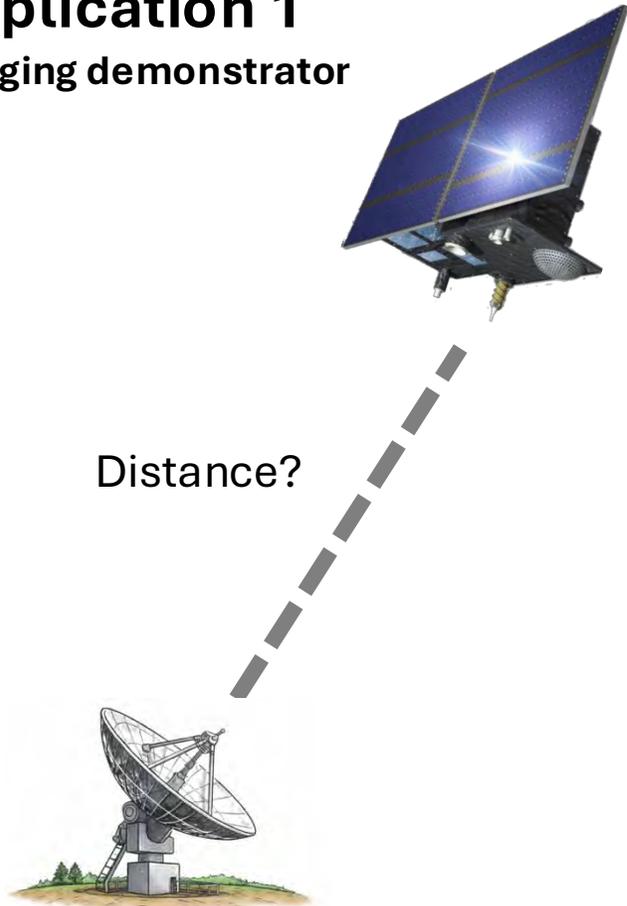


First fringe-tests using the proposed Genesis frequency setup

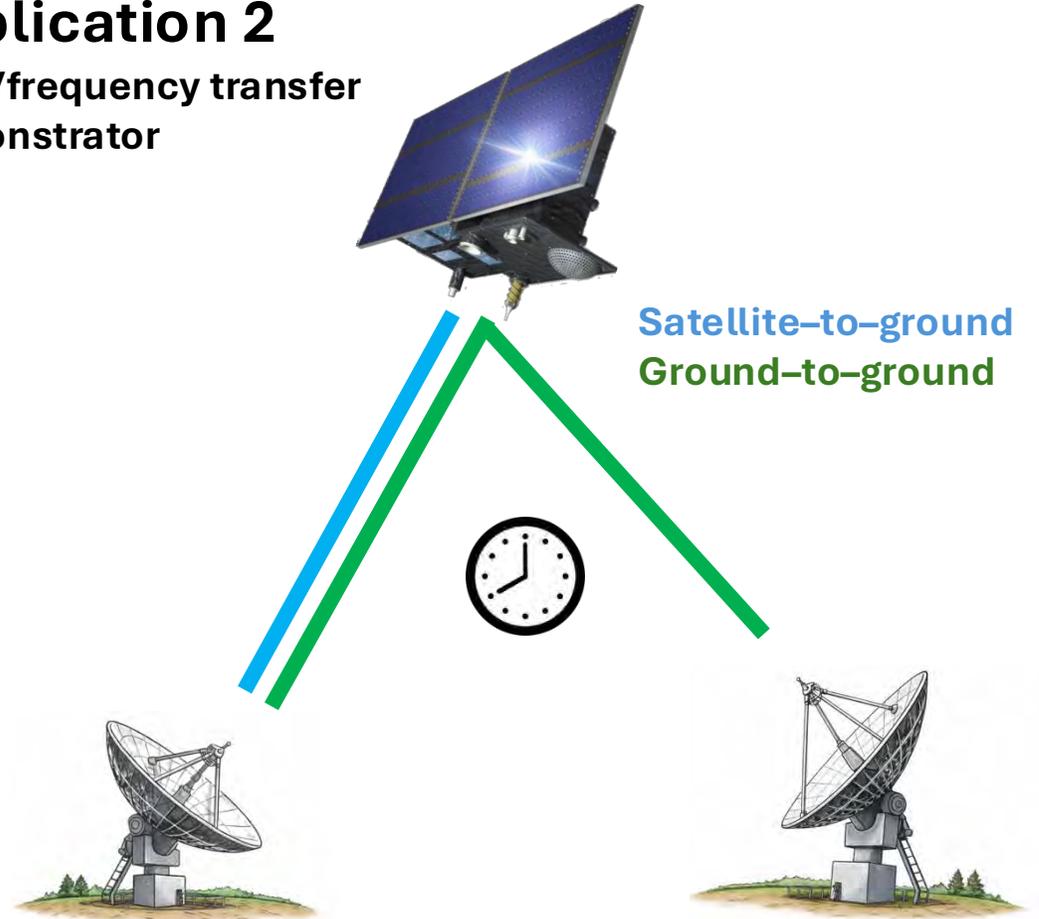
Plan for international 24 h session

# WP-7: PRN option

## Application 1 Ranging demonstrator



## Application 2 Time/frequency transfer demonstrator



One-way-ranging between satellite and ground stations

# Today's WG-3 programme

-----  
ESA GSET WG-3 (VLBI) presentations on the ESA Genesis Workshop 2026, Brussels  
-----

09:00–09:12 R. Haas "ESA GSET WG-3 general overview"

09:12–09:24 A. Neidhardt "WP-1 + WP-2"

09:24–09:36 S. Bernhart "WP-3 + WP-6"

09:36–09:48 J. Böhm "WP-4 + WP-5"

09:48–10:00 T. Deleu "WP-7"

10:00–10:29 Questions and discussion  
-----

# ESA GSET WG-3 (VLBI)

WP-1: frequencies, signal strength, etc.

WP-2: ground station fidelity, etc.

A. Neidhardt, Technical University of Munich  
IVS Network Coordinator

on behalf of the WG-3 team

- Simone Bernhart – BKG/MPIfR, DEU
- Johannes Böhm – TU Vienna, AUT
- Patrick Charlot – CNRS Bordeaux, FRA
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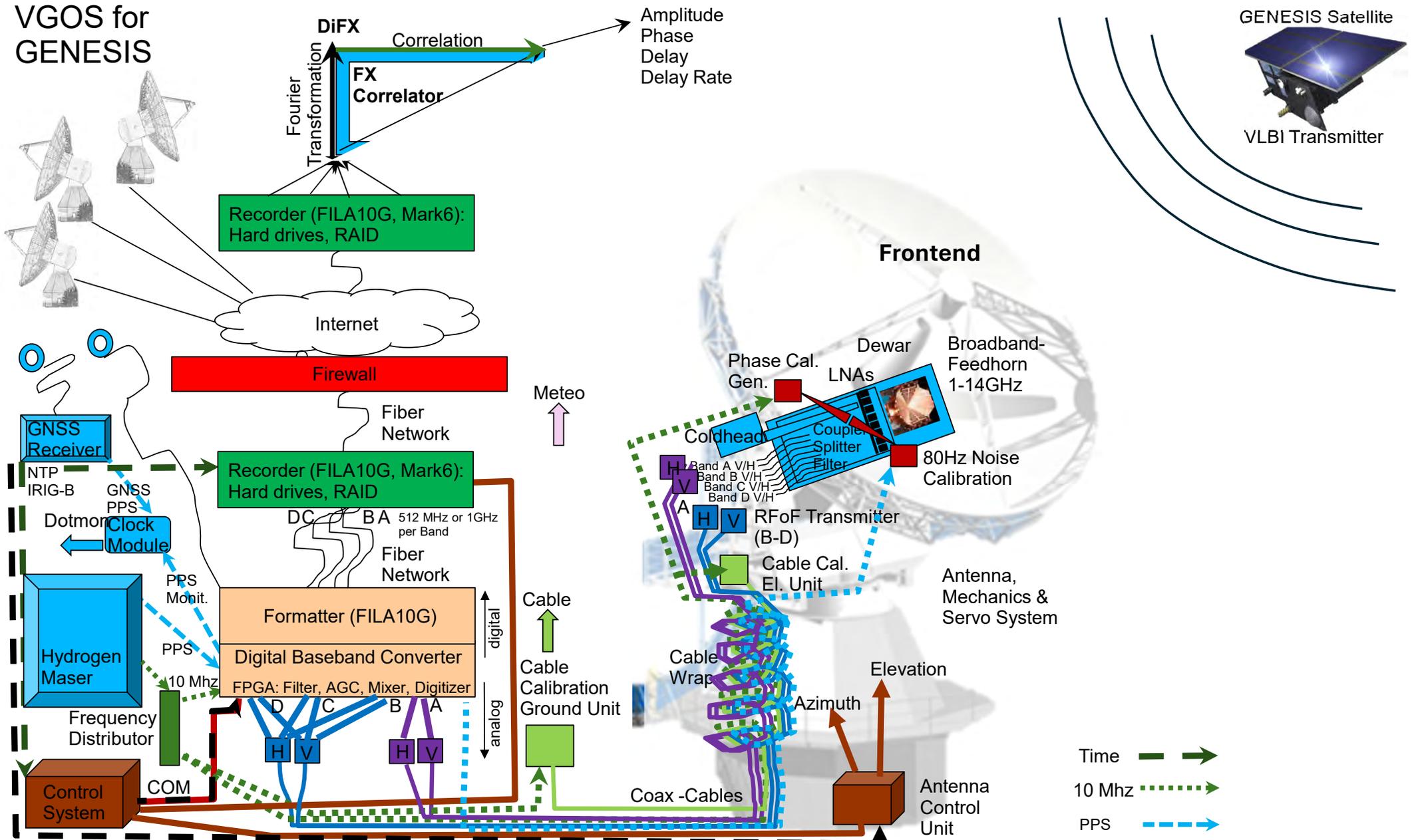
[ESA](#)

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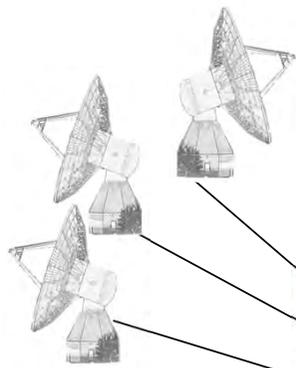
# Intro:

Complexity of the systems

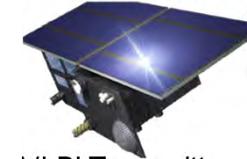
# VGOS for GENESIS



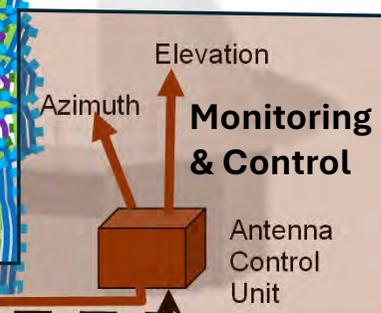
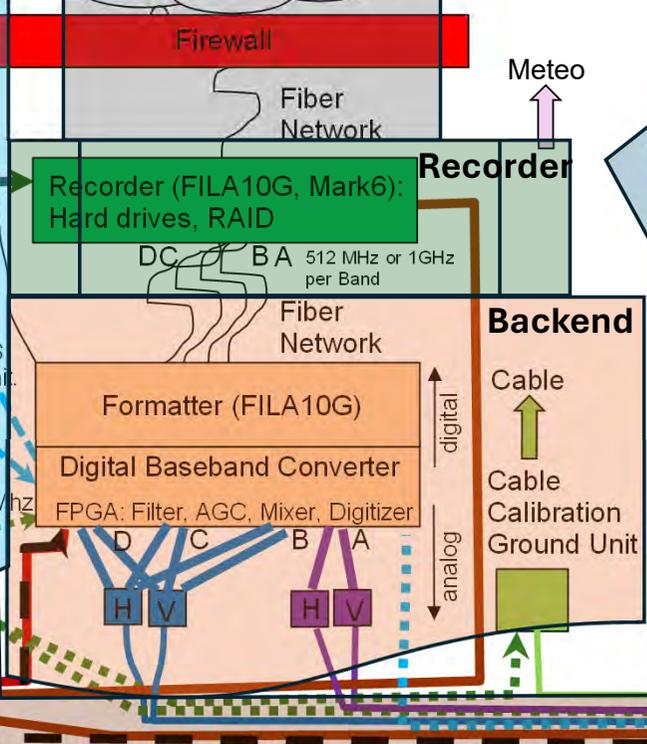
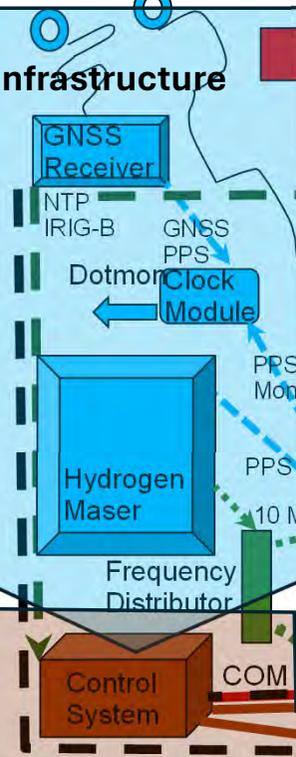
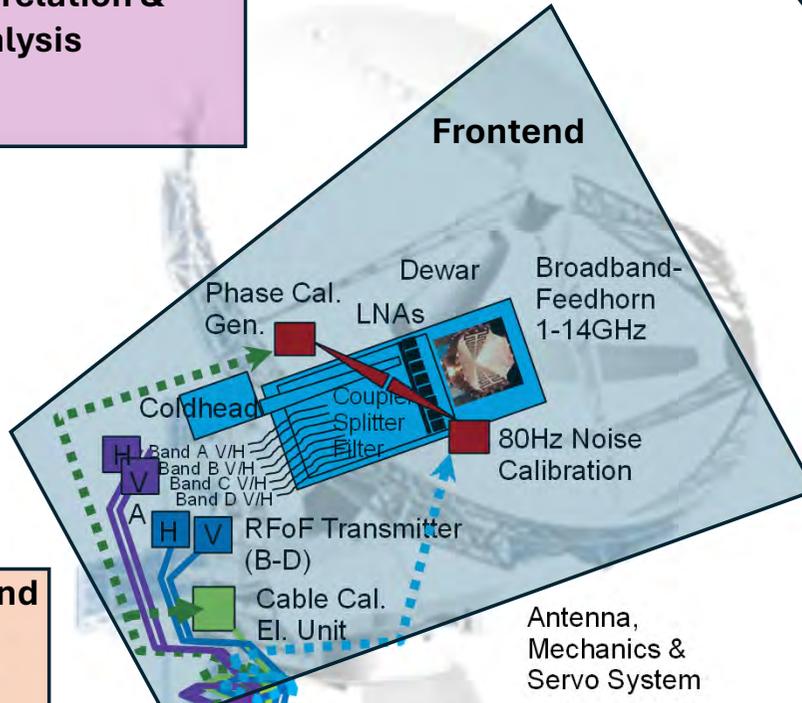
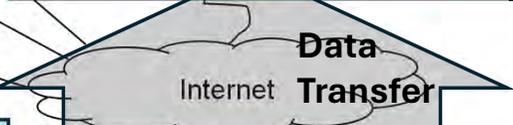
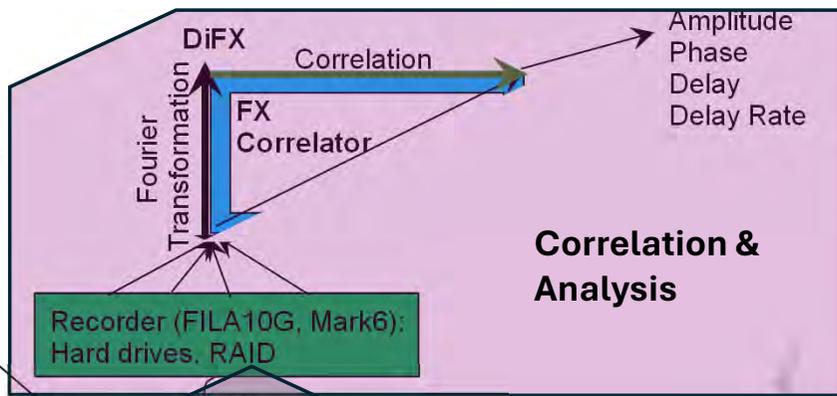
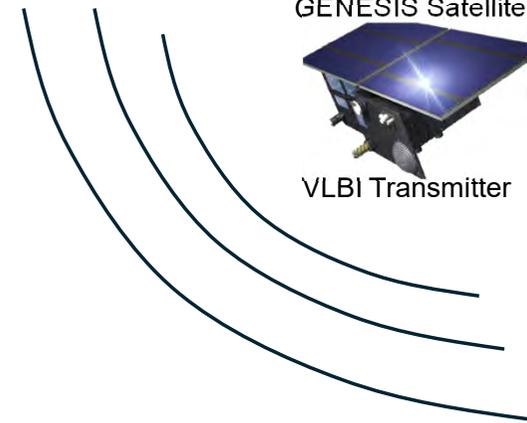
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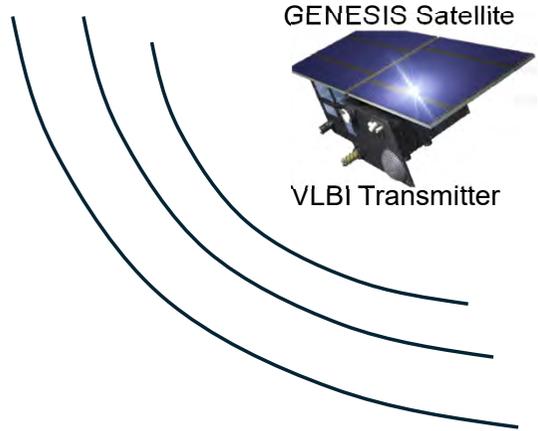
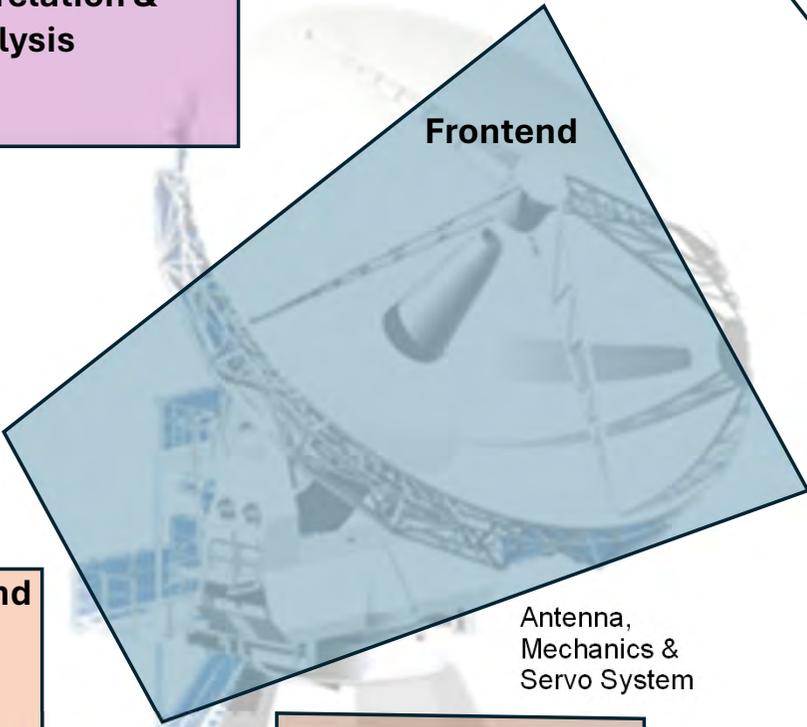
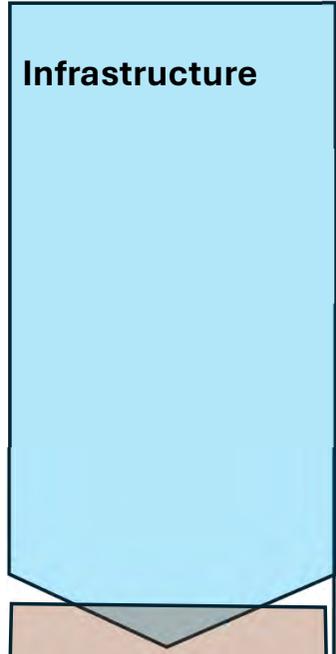
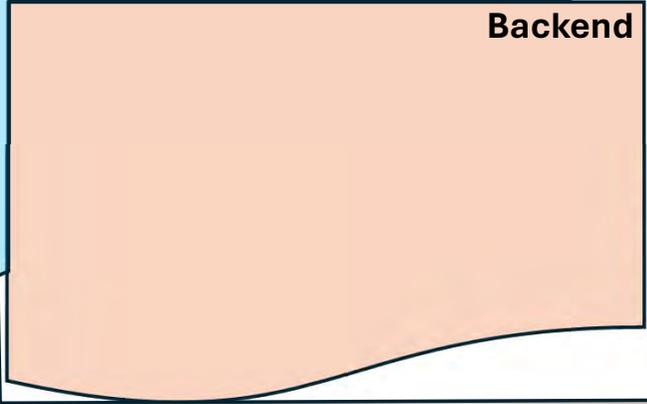
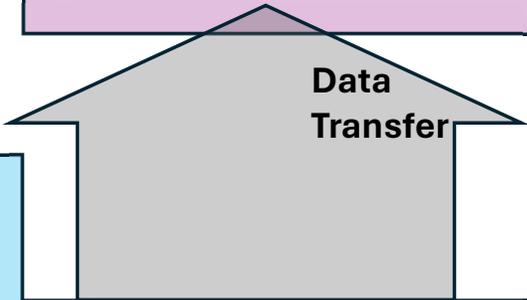
GENESIS Satellite



VLBI Transmitter



# VGOS for GENESIS



# WP-1:

frequencies, signal strength, etc.

**Sending equipment, requirements, losses**

**WP-1:**

frequencies, signal strength, etc.

# VGOS for GENESIS WP-1

## Antenna

- Gain losses (function of nadir angle)
- Gain variation: 3dB would be good, expected 5-6 dB
- Phase center characteristics

## Signal strength

- Simulations
- Signal strength 0.6 - 20 Jy in nadir

## Power Requirements on Ground

- the VLBI Tx shall generate power spectral flux density over the entire field of view
  - the Genesis VLBI Transmitter shall enable via telecommands commandability of its output RF power levels
- ➔ Tunable across 15 levels from a flux of 0.6 Jy (15 db attenuation) to 20 Jy (0 dB attenuation)

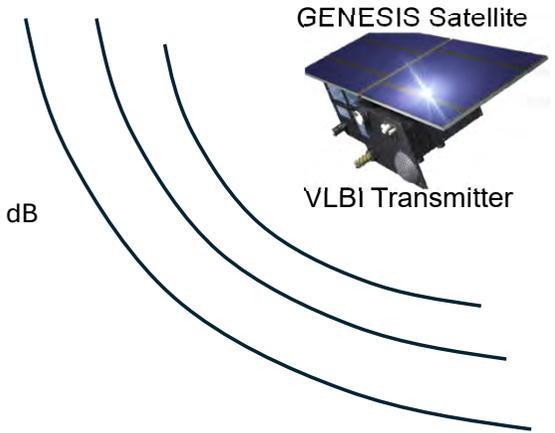
## Polarization

- Left-hand circular polarized

## Calibration

- Antenna system of three circular polarized antennas (1mm)

## SNR Goals



**Free space losses**

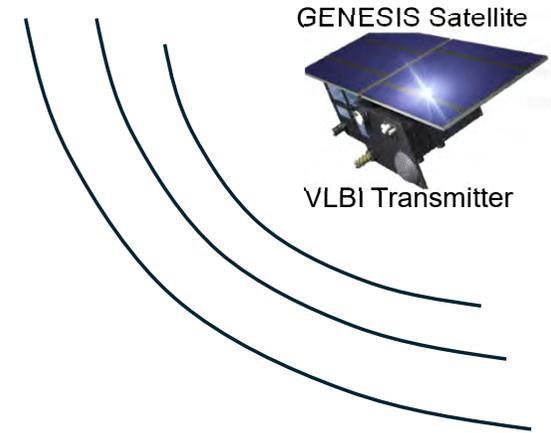
**WP-1:**

frequencies, signal strength, etc.

# VGOS for GENESIS WP-1

## Simulations

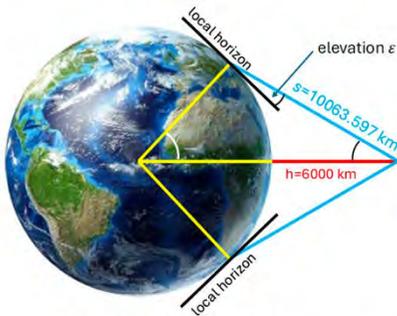
- Delay Resolution Function



## Free Space Path Losses

- Function of distance
- VLBI TX shall minimize the difference of the received power spectral flux density at the commonly observed telescopes.
- In practice: due to the atmospheric absorption and variations in stations instrumentations, the received flux is almost never the same at the 2 stations.

### Free space loss effect:



Free space loss:

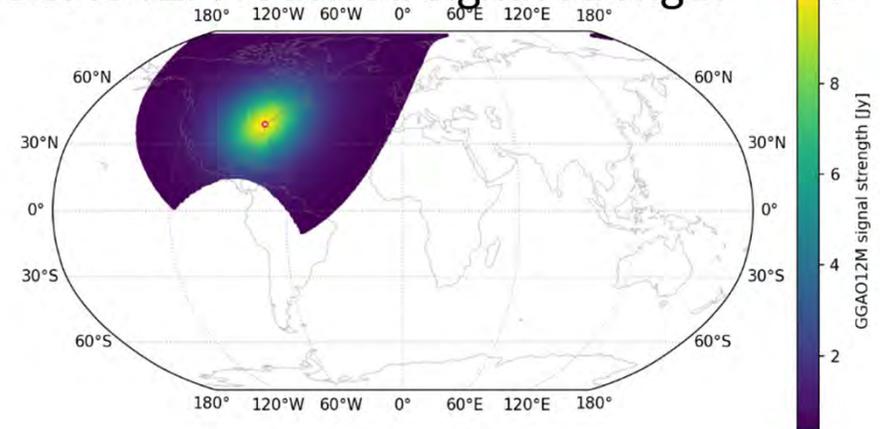
$$L_{FS} = \left( \frac{4 \cdot \pi \cdot R \cdot f}{c} \right)^2$$

Frequency	3.2 GHz	5.41 GHz	8.3 GHz	9.55 GHz
$L_{FS\_nadir}$	178.1 dB	182.7 dB	186.4 dB	187.6 dB
$L_{FS\_edge}$	182.6 dB	187.2 dB	190.9 dB	192.1 dB
$\Delta L_{FS}$	4.5 dB	4.5 dB	4.5 dB	4.5 dB

Assuming an HPBW opening angle of  $61.732^\circ$ ,  
i.e. corresponding to  $\epsilon_{min} = 5^\circ$

Slide 5 from ESA GSET WG-3 (VLBI), Meeting 2024:04, 2024-10-16 UT 11:00-12:30

## GGAO12M received signal strength



## Changing geometry

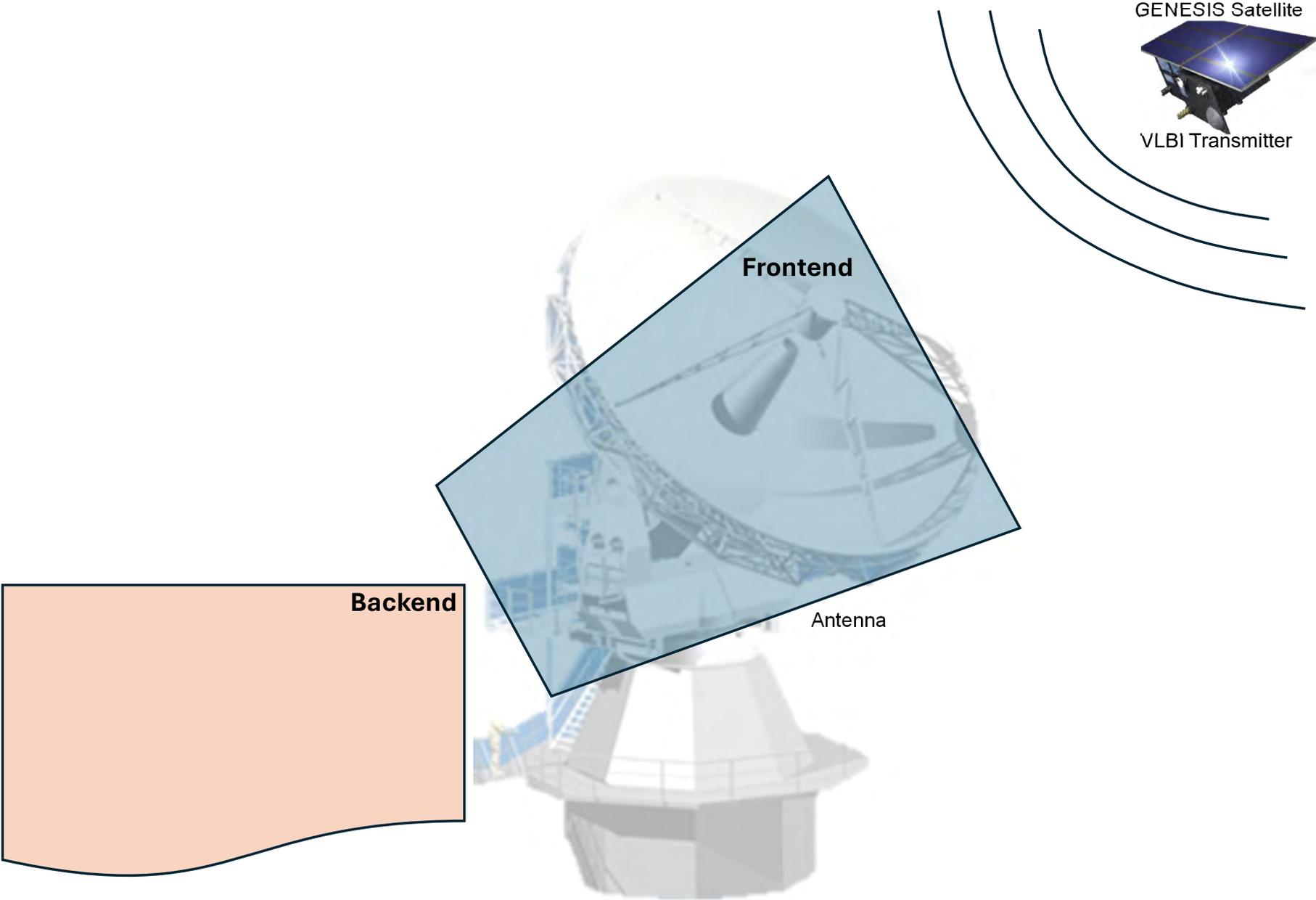
- Center of mass
- Rotating satellite => corrections  $\leq 1$  s

**Frequencies throughout the system**

**WP-1:**

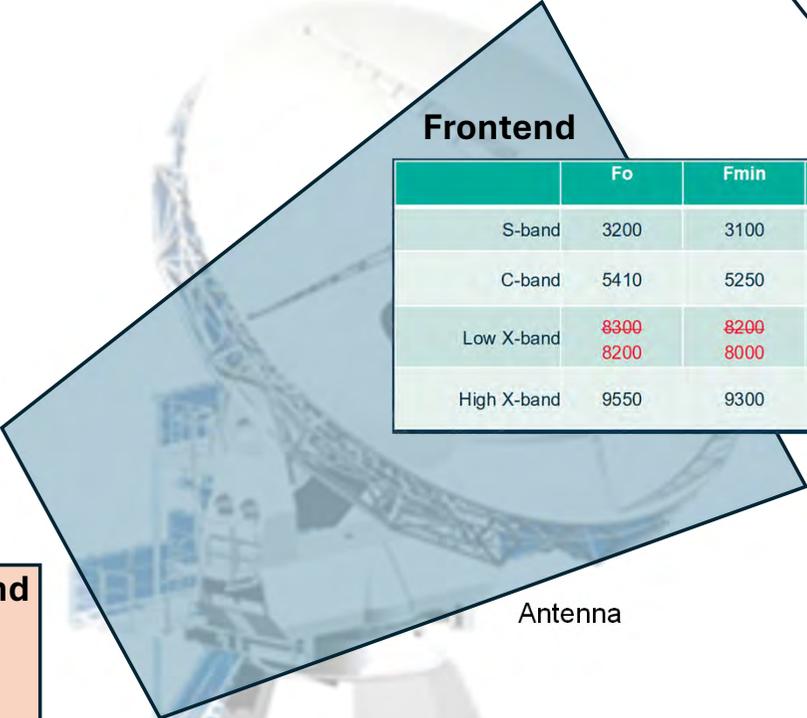
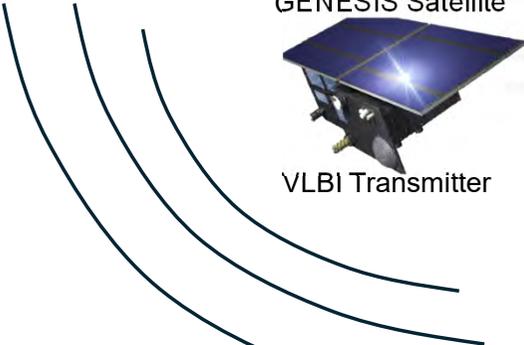
frequencies, signal strength, etc.

VGOS for  
GENESIS  
WP-1

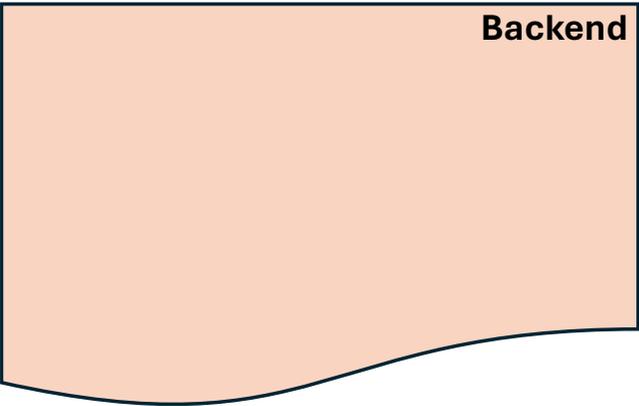


VGOS for  
GENESIS  
WP-1

Frequencies throughout the system

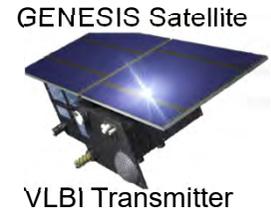


	Fo	Fmin	Fmax	BW (occupied)	BW (actual)
S-band	3200	3100	3300	200	180
C-band	5410	5250	5570	320	310
Low X-band	<del>8300</del> 8200	<del>8200</del> 8000	8400	<del>200</del> 400	390
High X-band	9550	9300	9800	500	490



# VGOS for GENESIS WP-1

## Frequencies throughout the system



### Frontend

	Fo	Fmin	Fmax	BW (occupied)	BW (actual)
S-band	3200	3100	3300	200	180
C-band	5410	5250	5570	320	310
Low X-band	8300 8200	8200 8000	8400	200 400	390
High X-band	9550	9300	9800	500	490

### Backend

Band-A		Band-B		Band-C		Band-D	
start	stop	start	stop	start	stop	start	stop
3110	3290	5260	5560	8010	8390	9350	9750
(MHz)							
3096,4	3128,4	5272,4	5304,4	8024,4	8056,4	9368,4	9400,4
3128,4	3160,4	5304,4	5336,4	8056,4	8088,4	9400,4	9432,4
3160,4	3192,4	5336,4	5368,4	8184,4	8216,4	9432,4	9464,4
3192,4	3224,4	5400,4	5432,4	8216,4	8248,4	9528,4	9560,4
3224,4	3256,4	5432,4	5464,4	8248,4	8280,4	9624,4	9656,4
3256,4	3288,4	5464,4	5496,4	8280,4	8312,4	9656,4	9688,4
3288,4	3320,4	5496,4	5528,4	8312,4	8344,4	9688,4	9720,4
3320,4	3352,4	5528,4	5560,4	8344,4	8376,4	9720,4	9752,4
8		8		8		8	

180 MHz

300 MHz

380 MHz

400 MHz

Antenna

8 BBC channels H  
plus  
8 BBC channels V  
for each of the 4 bands

64 BBC channels

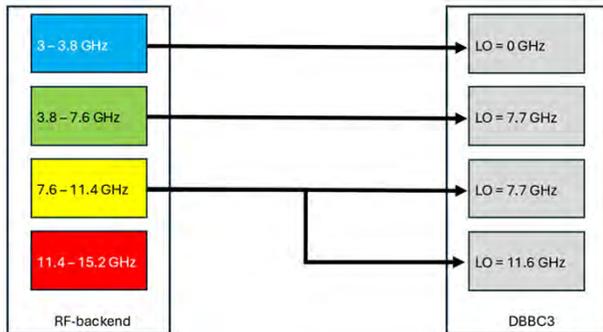
# VGOS for GENESIS WP-1

## Frequencies throughout the system



**WP-6**  
Basis for test observations

"Genesis-VGOS" @ OSO



**WP-2**  
10 different LO-setting groups for the 15 antennas

- 3100-3300 MHz
- 5250-5570 MHz
- 8000-8400 MHz
- 9300-9800 MHz

**Frontend**

	Fo	Fmin	Fmax	BW (occupied)	BW (actual)
S-band	3200	3100	3300	200	180
C-band	5410	5250	5570	320	310
Low X-band	8300 8200	8200 8000	8400	200 400	390
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**Backend**

Band-A		Band-B		Band-C		Band-D	
start	stop	start	stop	start	stop	start	stop
3110	3290	5260	5560	8010	8390	9350	9750
(MHz)	(MHz)	(MHz)	(MHz)	(MHz)	(MHz)	(MHz)	(MHz)
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3224,4	3256,4	5432,4	5464,4	8248,4	8280,4	9624,4	9656,4
3256,4	3288,4	5464,4	5496,4	8280,4	8312,4	9656,4	9688,4
3288,4	3320,4	5496,4	5528,4	8312,4	8344,4	9688,4	9720,4
3320,4	3352,4	5528,4	5560,4	8344,4	8376,4	9720,4	9752,4
8		8		8		8	
<b>180 MHz</b>		<b>300 MHz</b>		<b>380 MHz</b>		<b>400 MHz</b>	

Antenna

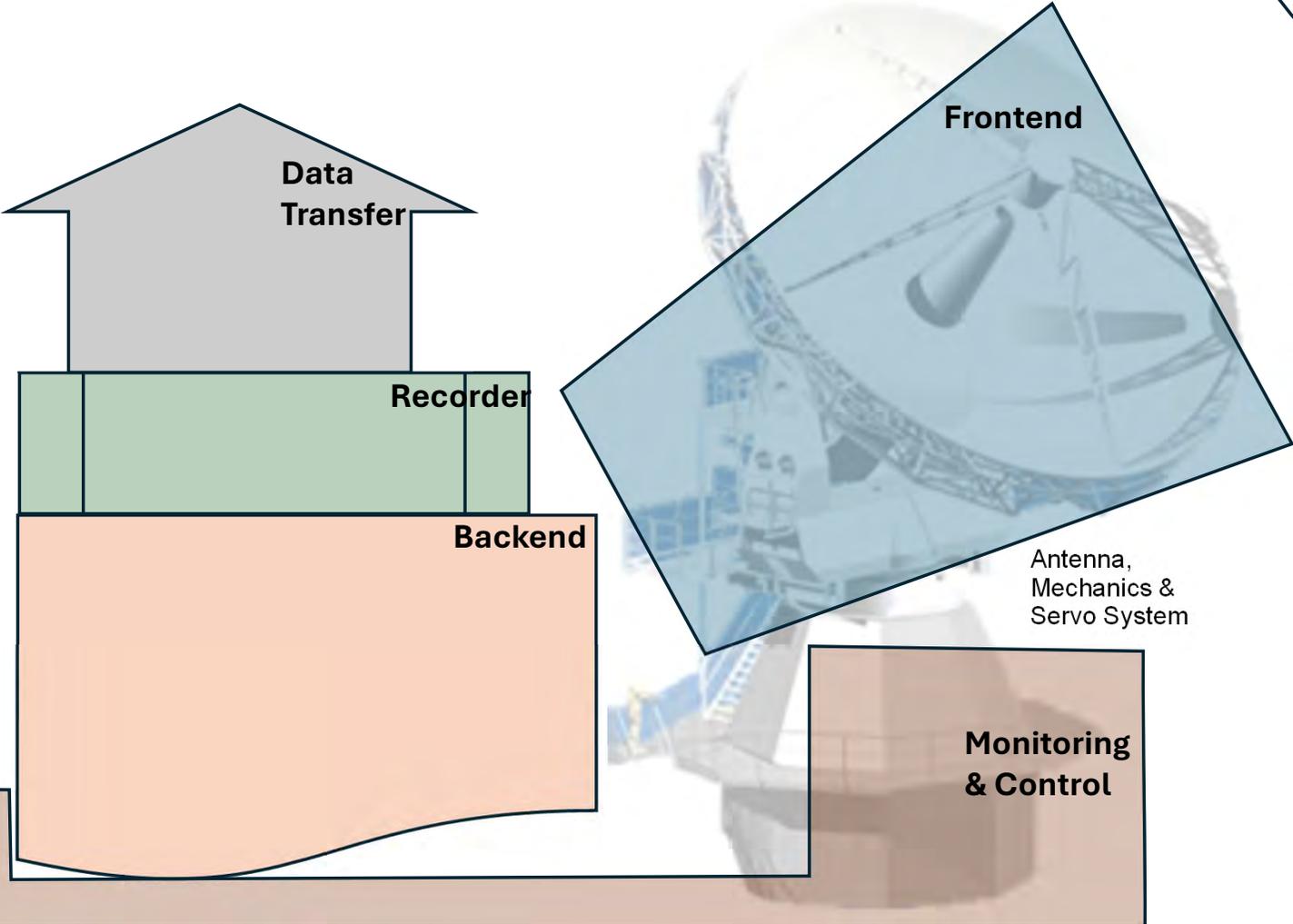
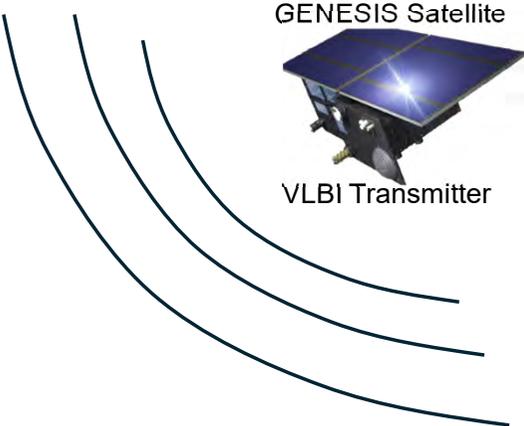
8 BBC channels H  
plus  
8 BBC channels V  
for each of the 4 bands

64 BBC channels

# WP-2:

ground station fidelity, etc.

VGOS for  
GENESIS  
WP-2



**Antenna & Control**

**WP-2:**

ground station fidelity, etc.

VGOS for  
GENESIS  
WP-2

**Antenna & Control**



VGOS for  
GENESIS  
WP-2

Antenna & Control



**Generally**  
All antennas should be capable of satellite tracking, both mechanically and with respect to the servo system.

# VGOS for GENESIS WP-2

## Antenna & Control

SP3-c



(Ideas at TU of Munich: local SW projects for session-based TLEs)

TLE

EURASIA,  
South Africa

### Antenna types

- Fast VGOS antennas: OHB (MT Mechatronics), Vertex Antennentechnik

→ TLE

### Different implementation

- Standardization to „satellite=„ command
- Sample code under development

USA,  
Australia

- Slower „Patriot-style“ antennas: Intertronic Solutions, Inc.

→ TLE →

Orbital reference point list

### Kinematic-stop-and-go tracking (Australia)

- Under investigation
- Not yet supported (USA)
- Under development by NVI because of GRITTS

Asia

- Chinese-type

→ ?

Antenna,  
Mechanics &  
Servo System

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SP3-c



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TLE



Possibility for auto-download in VLBI Field System



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Antenna,  
Mechanics &  
Servo System

### VLBI Field System (former NASA Field System)

- Open-source project by NVI Inc.



### Monitoring & Control

Antenna  
Control  
Unit

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## Antenna & Control

SP3-c



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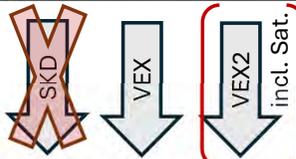
Asia

- Chinese-type

Orbital reference point list

Antenna, Mechanics & Servo System

```
scan 212-1505;
start = 2025y212d15h05m00s;
mode = VGOS_G1501X;
source = genesis;
station = Gs : 0 sec : 60 sec : 0 ft : 1A : &n : 1;
station = Mg : 0 sec : 60 sec : 0 ft : 1A : &ccw : 1;
station = Oe : 0 sec : 60 sec : 0 ft : 1A : &cw : 1;
station = Ow : 0 sec : 60 sec : 0 ft : 1A : &cw : 1;
station = Sa : 0 sec : 60 sec : 0 ft : 1A : &cw : 1;
station = WF : 0 sec : 60 sec : 0 ft : 1A : &n : 1;
station = Wn : 0 sec : 60 sec : 0 ft : 1A : &cw : 1;
station = Ws : 0 sec : 60 sec : 0 ft : 1A : &cw : 1;
endscan;
```



Under development

### VLBI Field System (former NASA Field System)

- Open-source project by NVI Inc.



### Generally

All antennas should be capable of satellite tracking, both mechanically and with respect to the servo system.

# VGOS for GENESIS WP-2

## Antenna & Control

SP3-c



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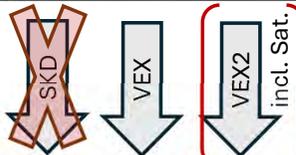
Asia

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Orbital reference point list

Antenna, Mechanics & Servo System

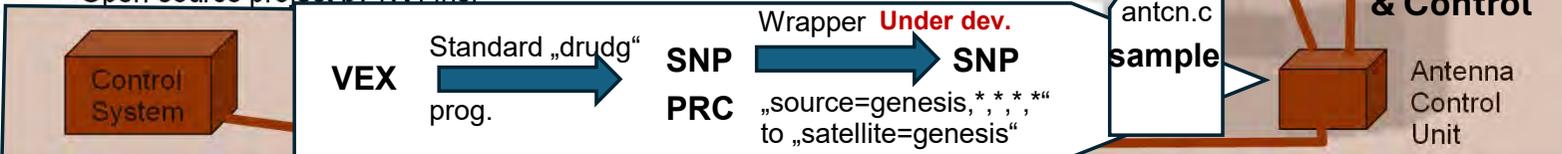
```
scan 212-1505;
start = 2025y212d15h05m00s;
mode = VGOS_G1501X;
source = genesis;
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station = Oe : 0 sec : 60 sec : 0 ft : 1A : &cw : 1;
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station = Wn : 0 sec : 60 sec : 0 ft : 1A : &cw : 1;
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endscan;
```



Under development

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### Generally

All antennas should be capable of satellite tracking, both mechanically and with respect to the servo system.

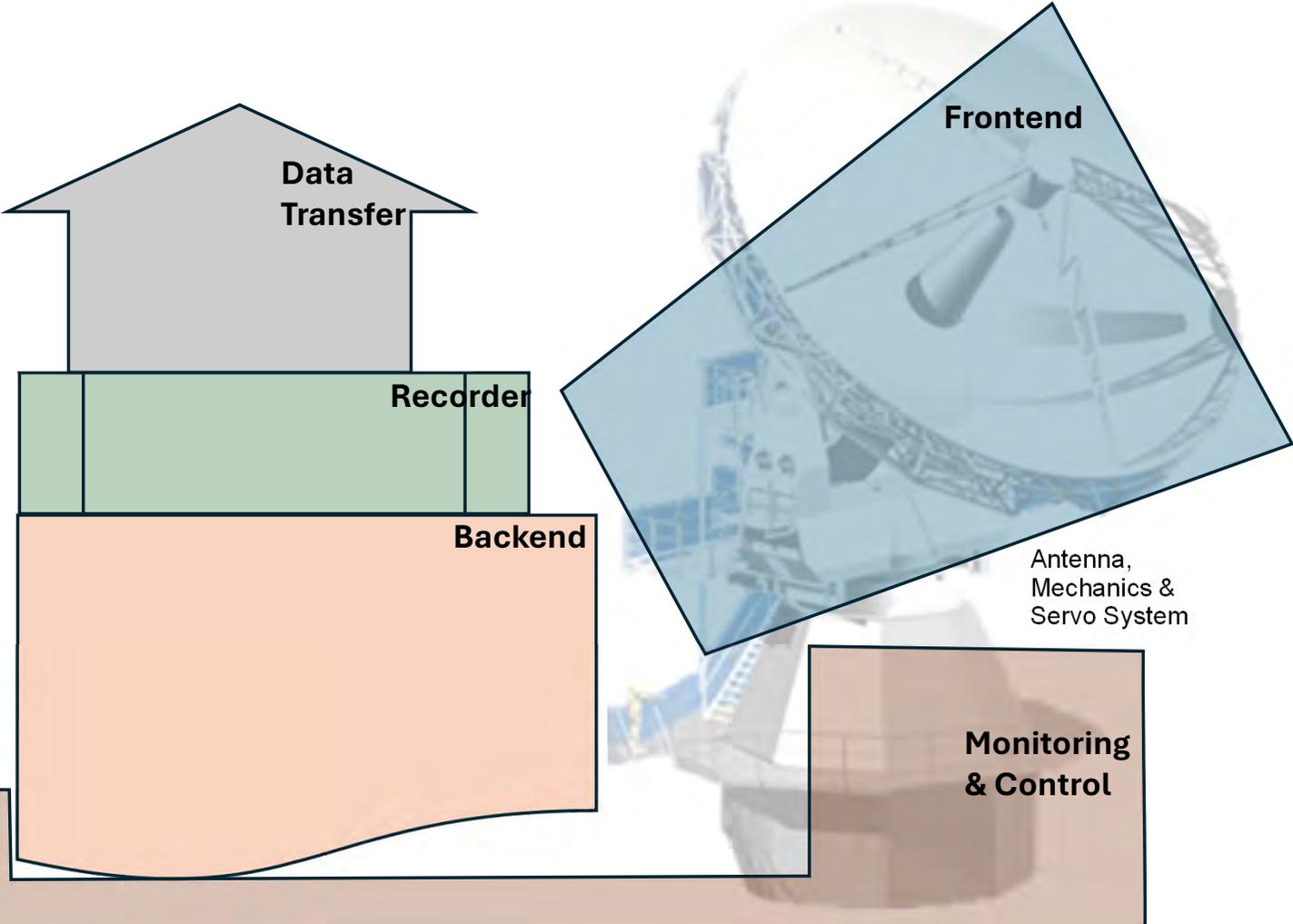
**RF/IF Chain**

**WP-2:**

ground station fidelity, etc.

VGOS for  
GENESIS  
WP-2

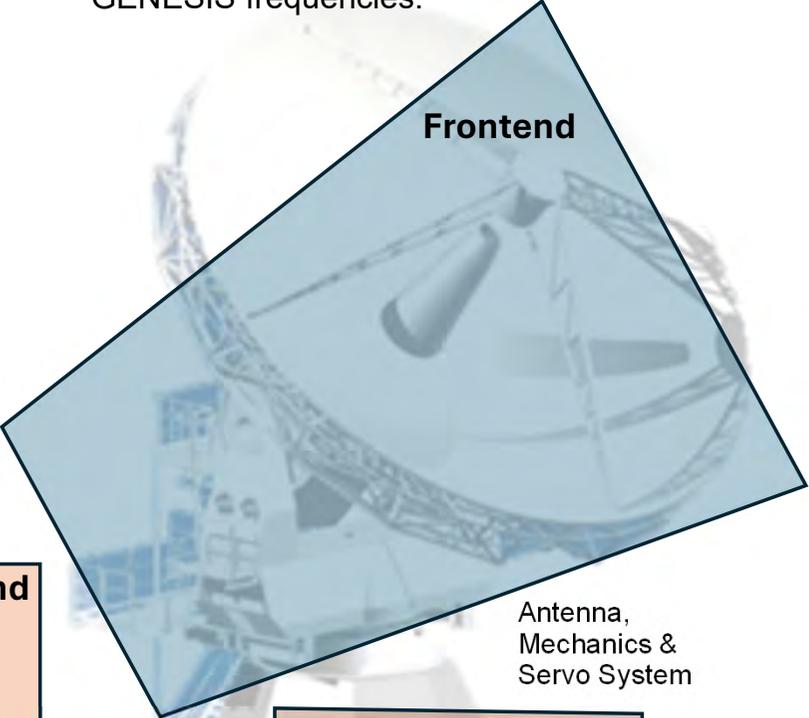
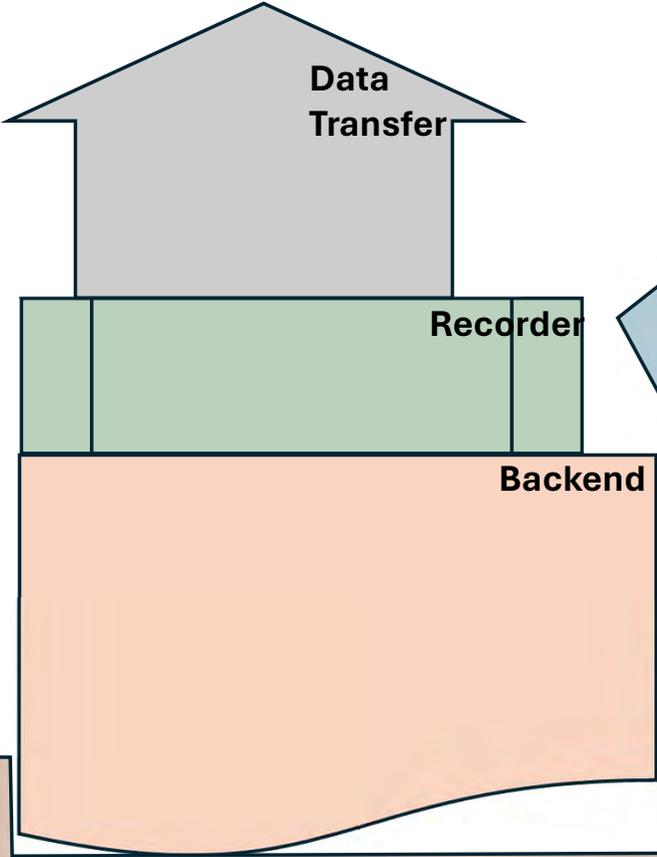
RF/IF Chain



VGOS for  
GENESIS  
WP-2

**RF/IF Chain**

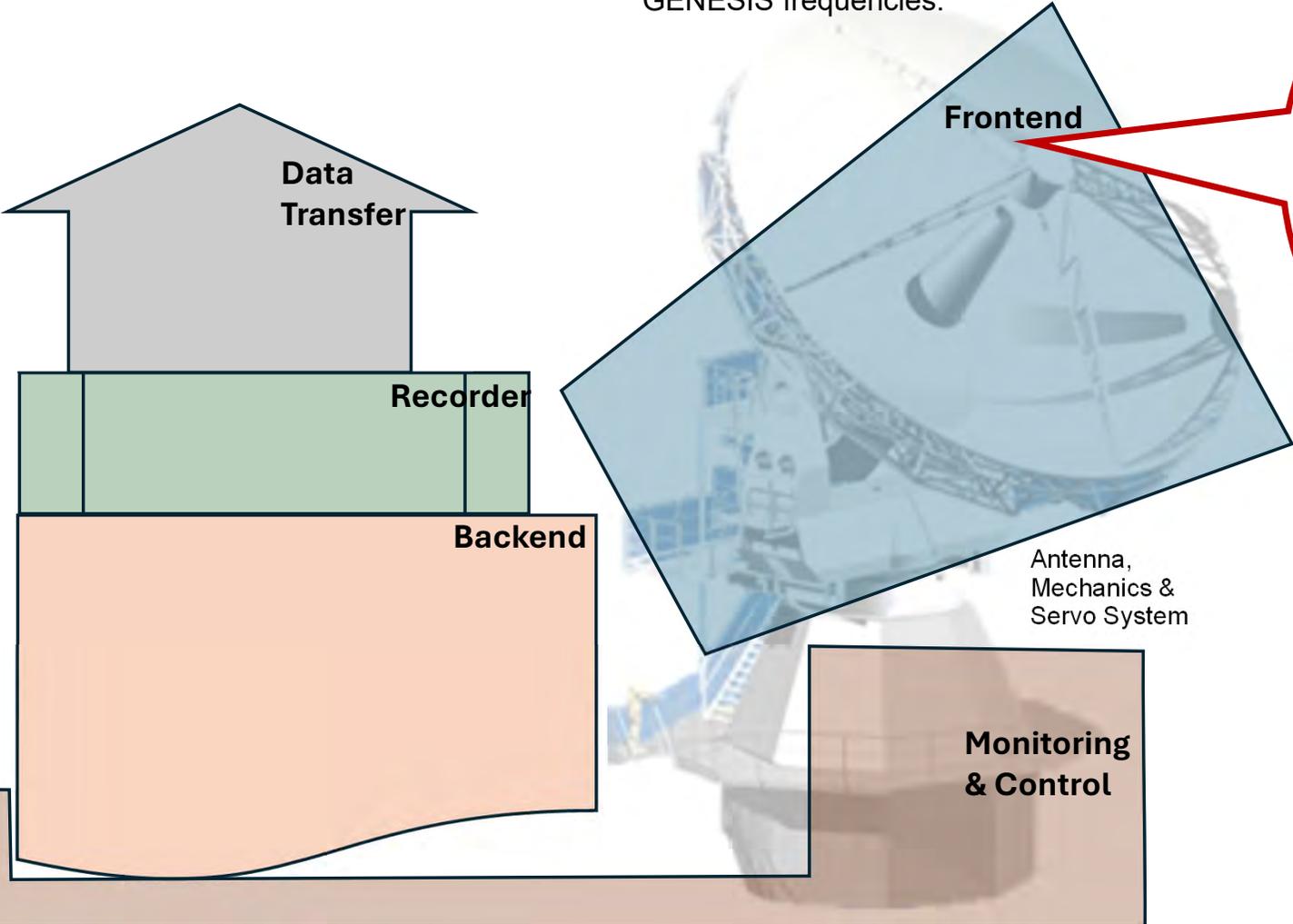
**Generally**  
All VGOS frontends  
should be capable of  
GENESIS frequencies.



# VGOS for GENESIS WP-2

## RF/IF Chain

**Generally**  
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**Different implementation**

- Down-Conversion
- Up-Down-Conversion
- RFoF Transmitting
- Bandwidth filters
- Crygenic filters (RFI)

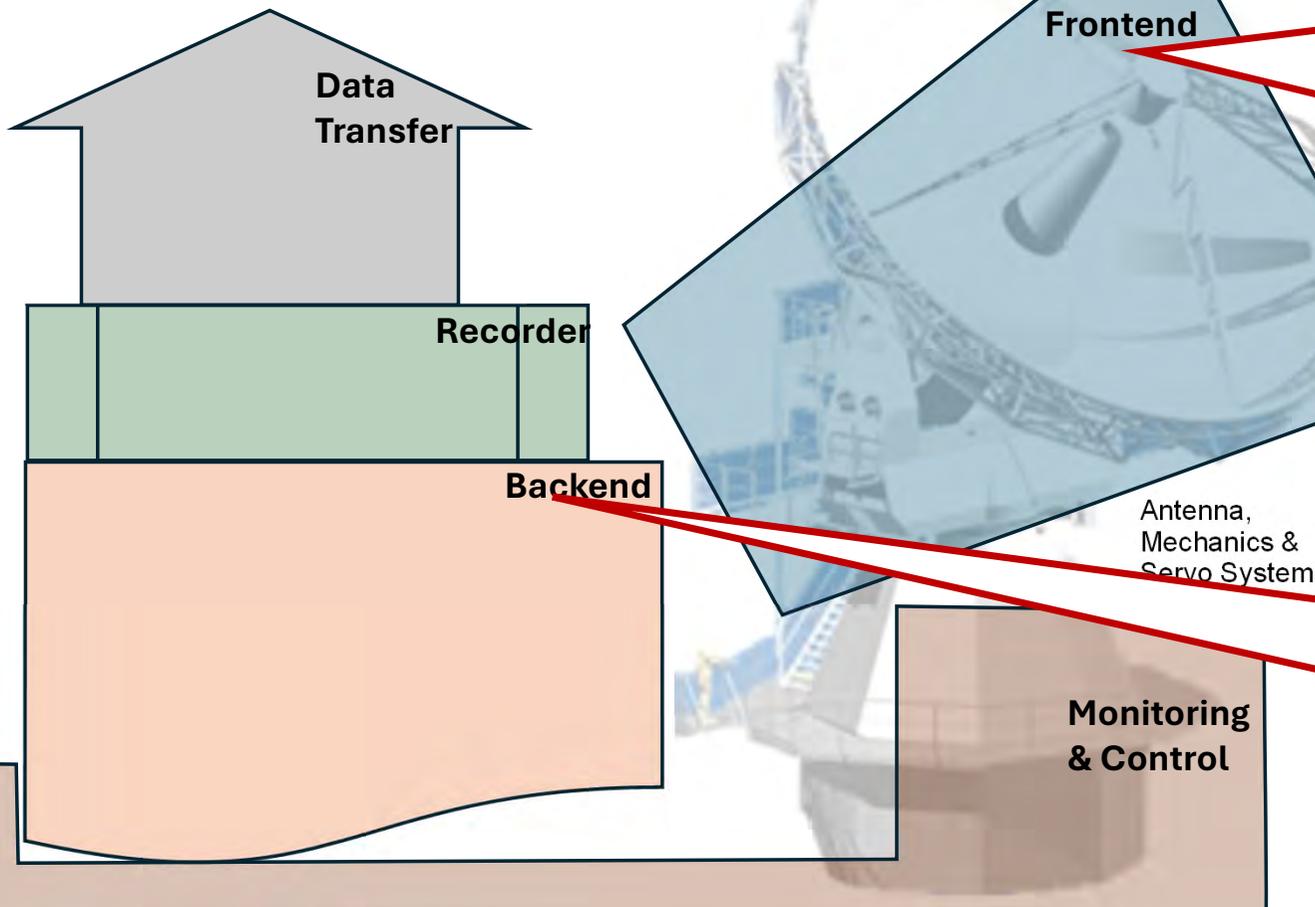
**Issue:**  
Maybe manual cabling required

→ Antennas must become capable to switch instantaneously

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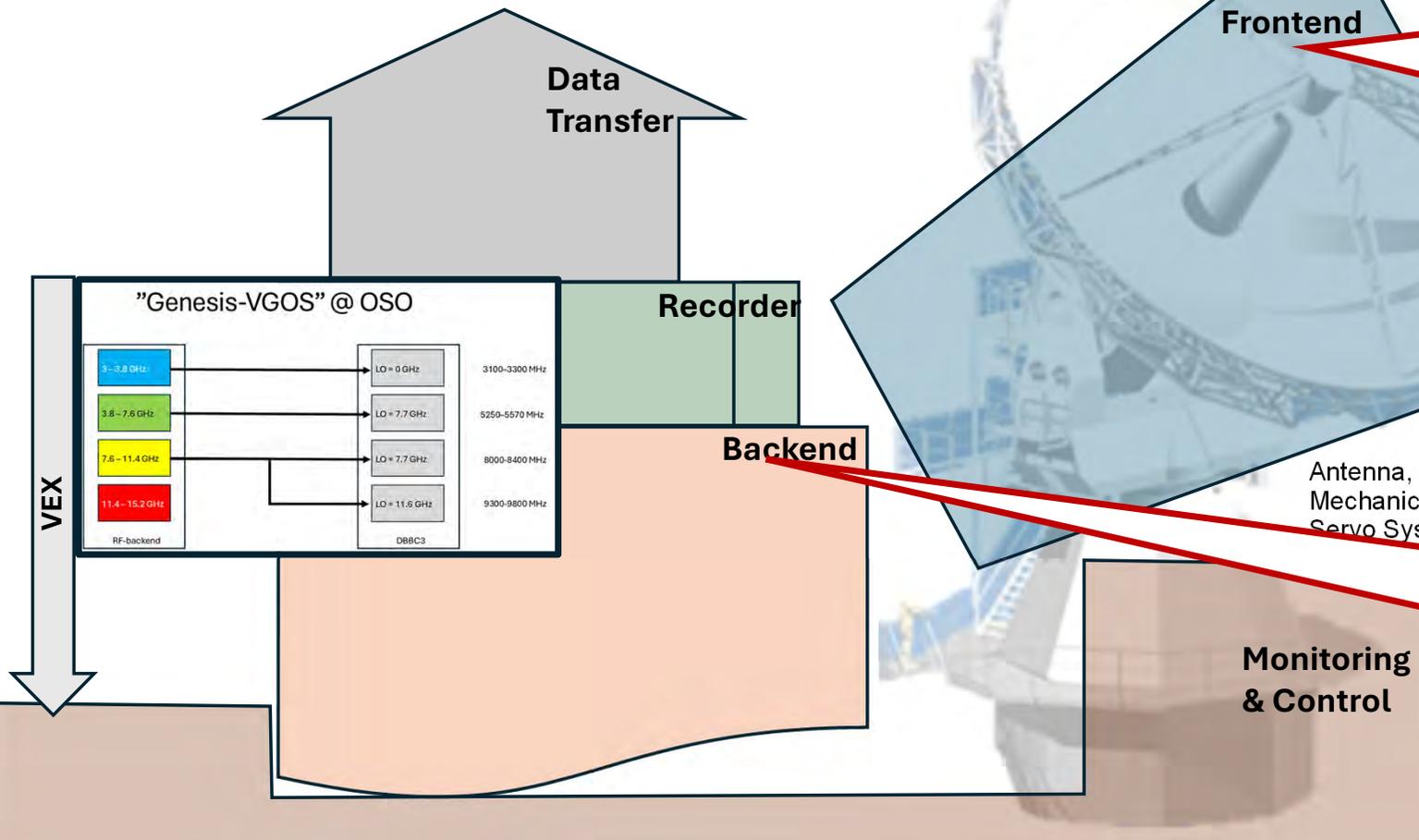
### Different implementation

- RDBE, R2DBE and follow-on
- GENESIS not yet impl. but possible
- DBBC3
- OK
- Chinese systems
- ?

# VGOS for GENESIS WP-2

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# VGOS for GENESIS WP-2

## RF/IF Chain

Generally  
All VGOS frontends  
should be capable of  
GENESIS frequencies.

VEX can also be directly used by correlator

"Genesis-VGOS"



VEX

```
def VGOS_5MHz_NnNs0e0w;
def VGOS_5MHz_Ws;
* Special frequency setting
def VGOS_5MHz_GsWF;
if def = &IF_...
if def = &IF_...
if def = &IF_...
if def = &IF_D : D2 : Y : 7000.0 MHz : L : 5 MHz : 0 Hz;
if def = &IF_E : E2 : X : 6000.0 MHz : U : 5 MHz : 0 Hz;
if def = &IF_F : F2 : Y : 6000.0 MHz : U : 5 MHz : 0 Hz;
if def = &IF_G : G2 : X : 9500.0 MHz : U : 5 MHz : 0 Hz;
if def = &IF_H : H2 : Y : 9500.0 MHz : U : 5 MHz : 0 Hz;
endif;
enddef;
```

10 different LO-setting groups

```
$FREQ;
def VGOS_std;
chan_def = &X : 3352.4 MHz : L : 32.000 MHz : &Ch01 : &BBC01 : &L_cal;
chan_def = &X : 3320.4 MHz : L : 32.000 MHz : &Ch02 : &BBC02 : &L_cal;
chan_def = &X : 3288.4 MHz : L : 32.000 MHz : &Ch03 : &BBC03 : &L_cal;
chan_def = &X : 3256.4 MHz : L : 32.000 MHz : &Ch04 : &BBC04 : &L_cal;
chan_def = &X : 3224.4 MHz : L : 32.000 MHz : &Ch05 : &BBC05 : &L_cal;
chan_def = &X : 3192.4 MHz : L : 32.000 MHz : &Ch06 : &BBC06 : &L_cal;
chan_def = &X : 3160.4 MHz : L : 32.000 MHz : &Ch07 : &BBC07 : &L_cal;
chan_def = &X : 3128.4 MHz : L : 32.000 MHz : &Ch08 : &BBC08 : &L_cal;
chan_def = &X : 3352.4 MHz : L : 32.000 MHz : &Ch09 : &BBC09 : &L_cal;
chan_def = &X : 3320.4 MHz : L : 32.000 MHz : &Ch10 : &BBC10 : &L_cal;
chan_def = &X : 3288.4 MHz : L : 32.000 MHz : &Ch11 : &BBC11 : &L_cal;
chan_def = &X : 3256.4 MHz : L : 32.000 MHz : &Ch12 : &BBC12 : &L_cal;
chan_def = &X : 3224.4 MHz : L : 32.000 MHz : &Ch13 : &BBC13 : &L_cal;
chan_def = &X : 3192.4 MHz : L : 32.000 MHz : &Ch14 : &BBC14 : &L_cal;
chan_def = &X : 3160.4 MHz : L : 32.000 MHz : &Ch15 : &BBC15 : &L_cal;
chan_def = &X : 3128.4 MHz : L : 32.000 MHz : &Ch16 : &BBC16 : &L_cal;
chan_def = &X : 5560.4 MHz : L : 32.000 MHz : &Ch17 : &BBC17 : &L_cal;
chan_def = &X : 5528.4 MHz : L : 32.000 MHz : &Ch18 : &BBC18 : &L_cal;
chan_def = &X : 5496.4 MHz : L : 32.000 MHz : &Ch19 : &BBC19 : &L_cal;
chan_def = &X : 5464.4 MHz : L : 32.000 MHz : &Ch20 : &BBC20 : &L_cal;
chan_def = &X : 5432.4 MHz : L : 32.000 MHz : &Ch21 : &BBC21 : &L_cal;
chan_def = &X : 5368.4 MHz : L : 32.000 MHz : &Ch22 : &BBC22 : &L_cal;
chan_def = &X : 5336.4 MHz : L : 32.000 MHz : &Ch23 : &BBC23 : &L_cal;
chan_def = &X : 5304.4 MHz : L : 32.000 MHz : &Ch24 : &BBC24 : &L_cal;
chan_def = &X : 5560.4 MHz : L : 32.000 MHz : &Ch25 : &BBC25 : &L_cal;
chan_def = &X : 5528.4 MHz : L : 32.000 MHz : &Ch26 : &BBC26 : &L_cal;
chan_def = &X : 5496.4 MHz : L : 32.000 MHz : &Ch27 : &BBC27 : &L_cal;
chan_def = &X : 5464.4 MHz : L : 32.000 MHz : &Ch28 : &BBC28 : &L_cal;
chan_def = &X : 5432.4 MHz : L : 32.000 MHz : &Ch29 : &BBC29 : &L_cal;
chan_def = &X : 5368.4 MHz : L : 32.000 MHz : &Ch30 : &BBC30 : &L_cal;
chan_def = &X : 5336.4 MHz : L : 32.000 MHz : &Ch31 : &BBC31 : &L_cal;
```

2-3 different FREQ settings

```
$BBC;
def VGOS_std;
BBC_assign = &BBC01 : 01 : &IF_A;
BBC_assign = &BBC02 : 02 : &IF_A;
BBC_assign = &BBC03 : 03 : &IF_A;
BBC_assign = &BBC04 : 04 : &IF_A;
BBC_assign = &BBC05 : 05 : &IF_A;
BBC_assign = &BBC06 : 06 : &IF_A;
BBC_assign = &BBC07 : 07 : &IF_A;
BBC_assign = &BBC08 : 08 : &IF_A;
BBC_assign = &BBC09 : 09 : &IF_B;
BBC_assign = &BBC10 : 10 : &IF_B;
BBC_assign = &BBC11 : 11 : &IF_B;
BBC_assign = &BBC12 : 12 : &IF_B;
BBC_assign = &BBC13 : 13 : &IF_B;
BBC_assign = &BBC14 : 14 : &IF_B;
BBC_assign = &BBC15 : 15 : &IF_B;
BBC_assign = &BBC16 : 16 : &IF_B;
BBC_assign = &BBC17 : 17 : &IF_C;
BBC_assign = &BBC18 : 18 : &IF_C;
BBC_assign = &BBC19 : 19 : &IF_C;
BBC_assign = &BBC20 : 20 : &IF_C;
BBC_assign = &BBC21 : 21 : &IF_C;
BBC_assign = &BBC22 : 22 : &IF_C;
BBC_assign = &BBC23 : 23 : &IF_C;
BBC_assign = &BBC24 : 24 : &IF_C;
BBC_assign = &BBC25 : 25 : &IF_D;
BBC_assign = &BBC26 : 26 : &IF_D;
BBC_assign = &BBC27 : 27 : &IF_D;
BBC_assign = &BBC28 : 28 : &IF_D;
BBC_assign = &BBC29 : 29 : &IF_D;
BBC_assign = &BBC30 : 30 : &IF_D;
```

One BBC-setting

Antenna, Mechanics & Servo System

Monitoring & Control

**Different implementation**

- Down-Conversion
- Up-Down-Conversion
- RFoF Transmitting
- Bandwidth filters
- Cryogenic filters (RFI)

**Issue:**

Maybe manual cabling required

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**Different implementation**

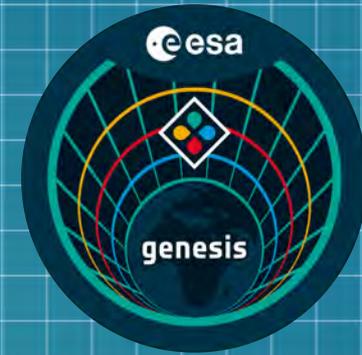
- RDBE, R2DBE and follow-on
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- DBBC3
- OK
- Chinese systems
- ?

# ESA GSET WG-3 (VLBI)

WP-1: frequencies, signal strength, etc.

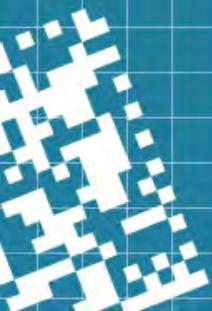
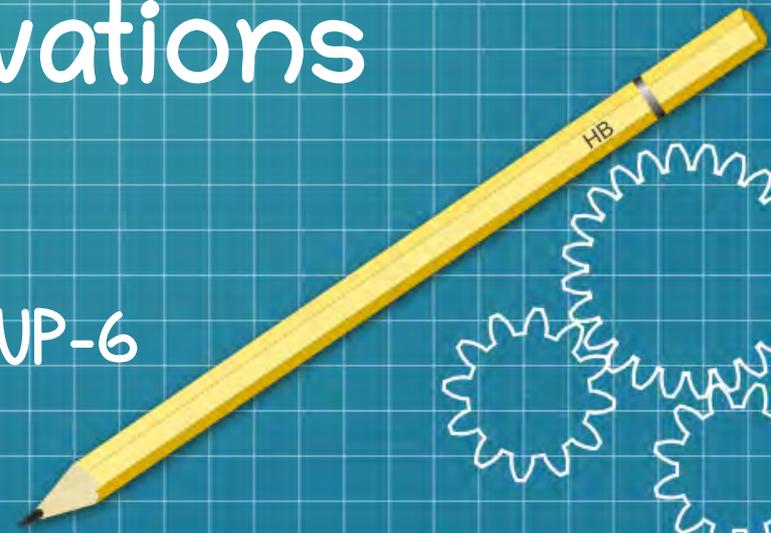
WP-2: ground station fidelity, etc.

*Thank you for  
your attention*

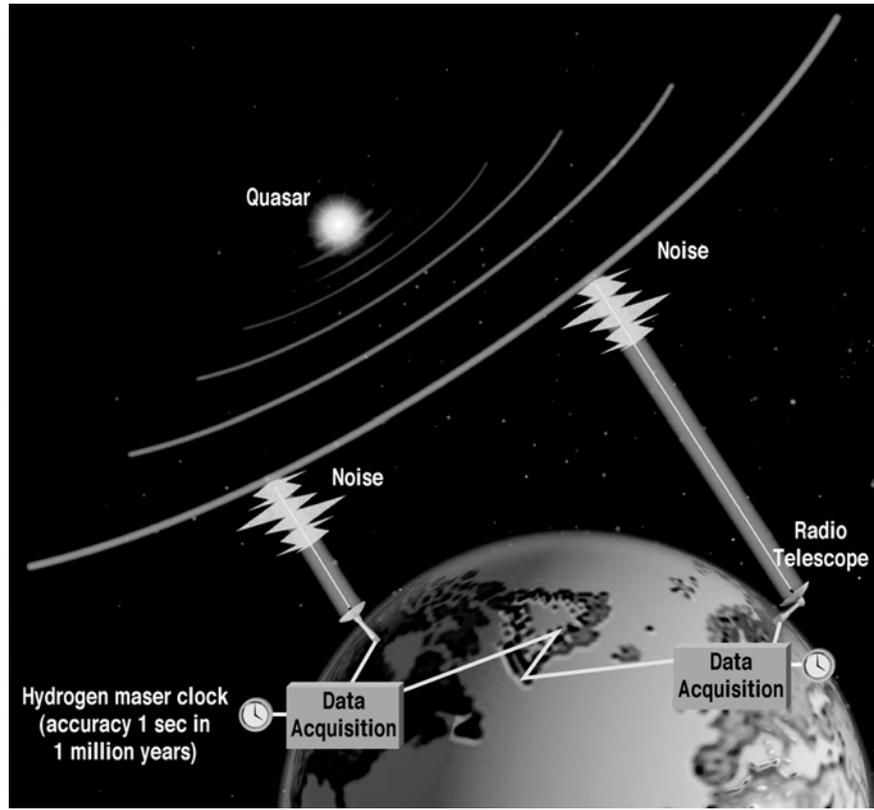


# WP-3 Delay Resolution and Correlation + WP-6 Test Observations

Simone Bernhart  
on behalf of WP-3, WP-6



# WP-3 - Quasar vs. Near-field VLBI



©[https://ivsc.gsfc.nasa.gov/about/vlbi/vlbi\\_conceptnew.jpg](https://ivsc.gsfc.nasa.gov/about/vlbi/vlbi_conceptnew.jpg)



©ESA - F. Zonno

# VLBI Correlation of Quasar Data

- DiFX (Distributed FX) mode of operation:
  - Receives digitized signals→applies correlator model→decomposes data in chunks of Accumulation Periods→performs FFT→fractional delay correction →complex multiplication in frequency domain→outputs complex visibilities

INTEGRATION TIME

Tens of seconds up to 2 minutes

INTEGRATION BANDWIDTH (typical)

Per sub-channel of 32 MHz

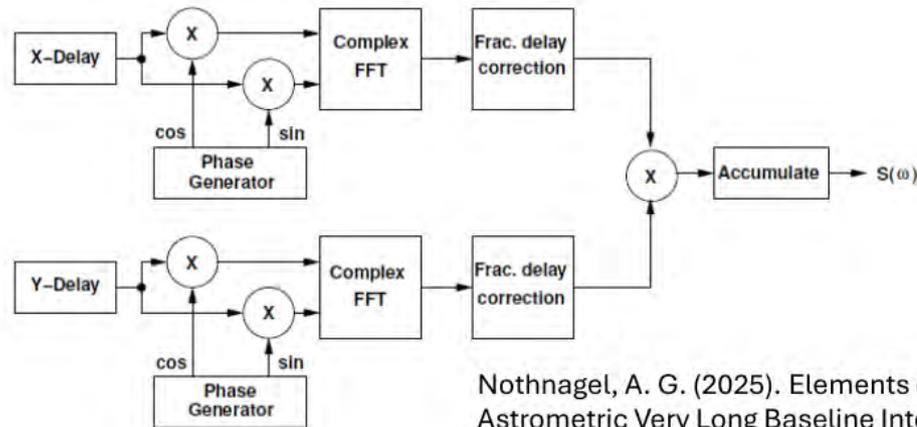
GEOMETRIC DELAY MODEL

Non-dispersive

ELECTRONIC DELAY COMPENSATION

At visibility level (after correlator)

GEOMETRIC DELAY COMPENSATION



Nothnagel, A. G. (2025). Elements of Geodetic and Astrometric Very Long Baseline Interferometry (4.2).

# Genesis Specifics and Compensation Approach



Genesis specifics	Order of magnitude	Approach
Higher orbital speed	Genesis: $4.6 \cdot 10^{-4}$ rad/s Earth: $7.3 \times 10^{-5}$ rad/s	Shorter FFT size
Antenna phase variations with direction	Variation rate $< 0.03^\circ/s$	Can be compensated at <b>visibility level</b> (Compensation at AP level also possible)
Antenna phase error within a sub-band	Maximum 0.1 degree (after linear slope removal)	Impact seems negligible
Antenna group delay variations within a band	Up to 300 ps	Must be compensated at <b>visibility level</b> (since delay model is non-dispersive)
Multiple antenna with different delay variations	Delay variation up to millimetres within integration time of 60 seconds (Assuming 10 cm between antennas)	Must be compensated at <b>visibility level</b> (since delay model is non-dispersive)
Attitude variations from satellite	?	TBD

# Phase Center Offsets and Variations

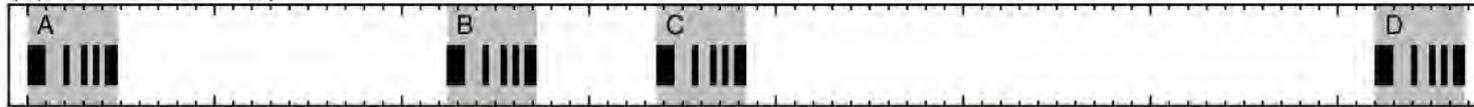


Satellite design requires:

- geometric corrections for AOR/CoM  
(antenna reference point to center of mass relation)
- antenna reference point :-)

# Phase Center Offsets and Variations

(a) Traditional setup



(b) Genesis setup



3 4 5 6 7 8 9 10  
Frequency [GHz] ©Frederic Jaron



S-band  
Antenna



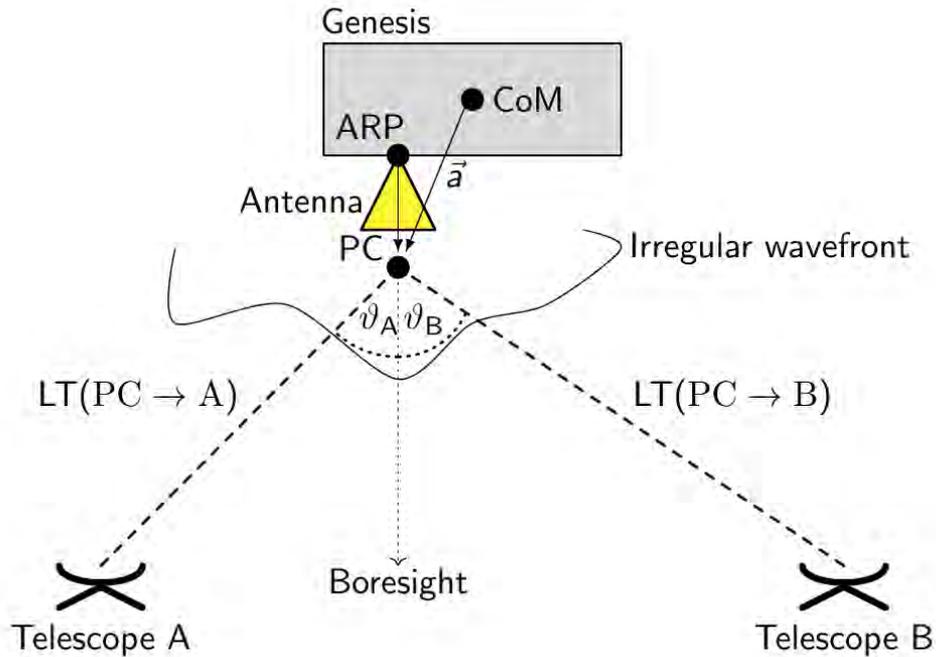
C-band  
Antenna



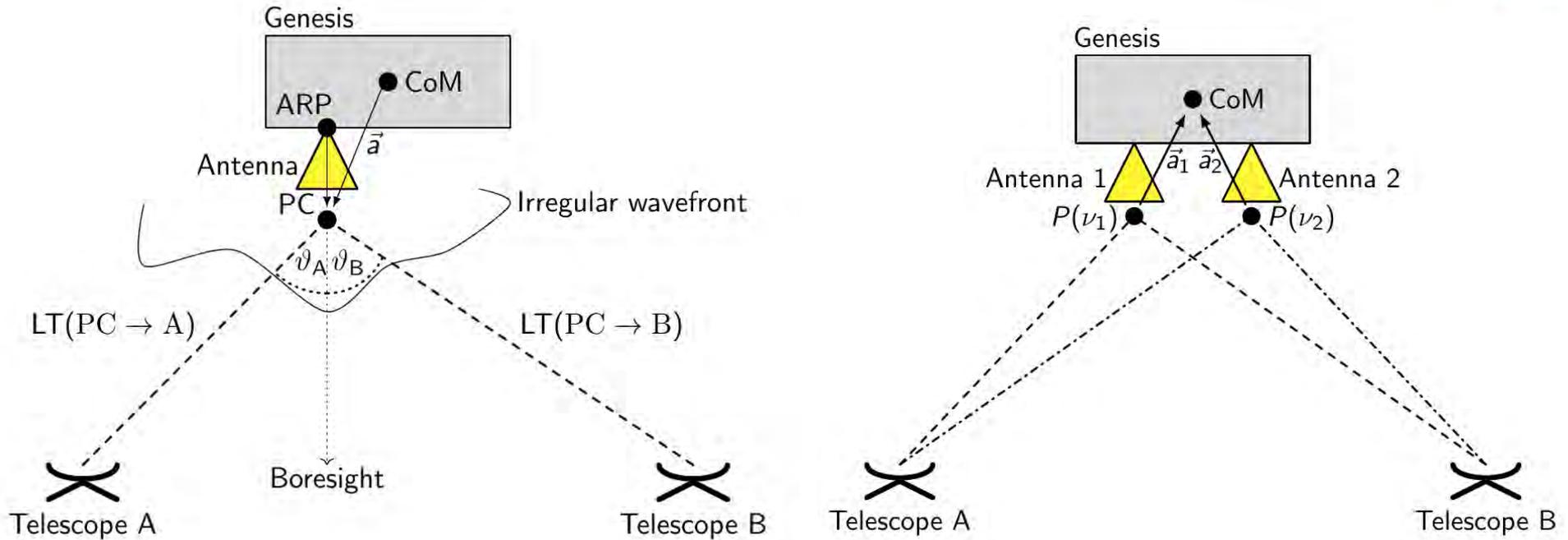
X-band  
Antenna

Problem: different VLBI transmitter positions lead to *different delays* corresponding to their frequency ranges.

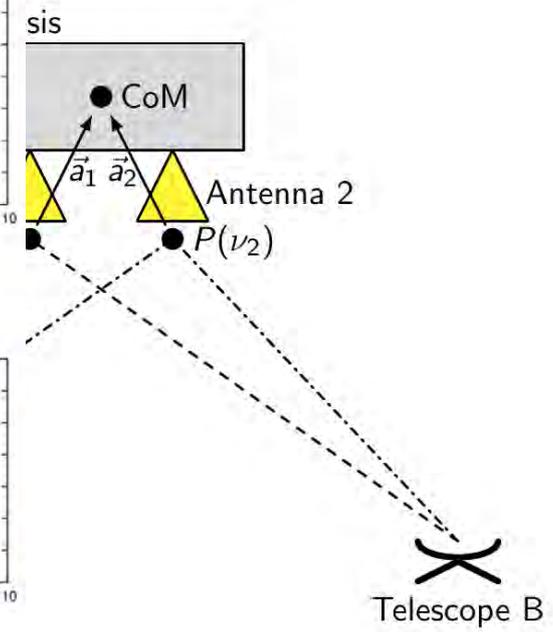
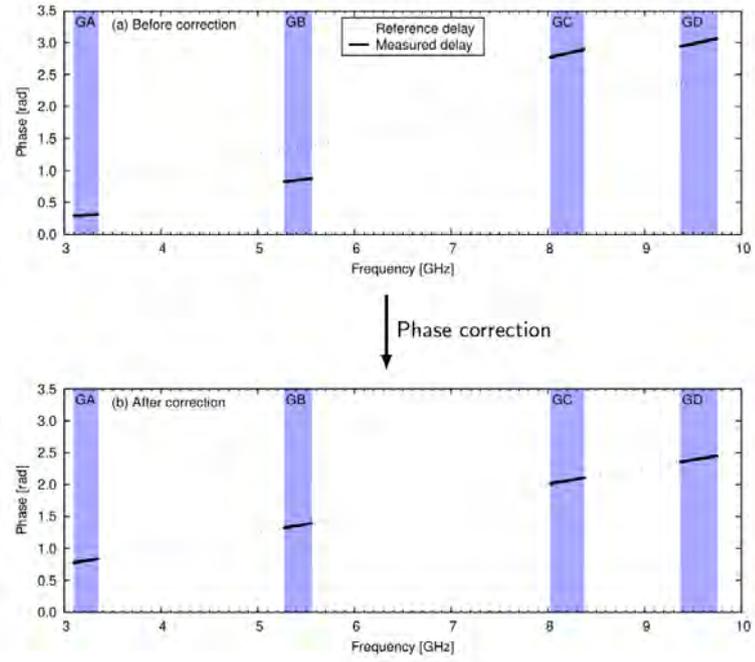
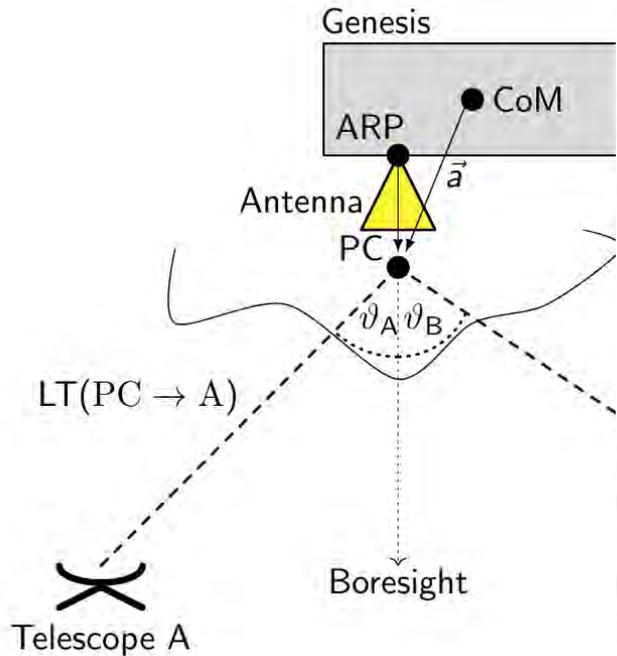
# Phase Center Offsets and Variations



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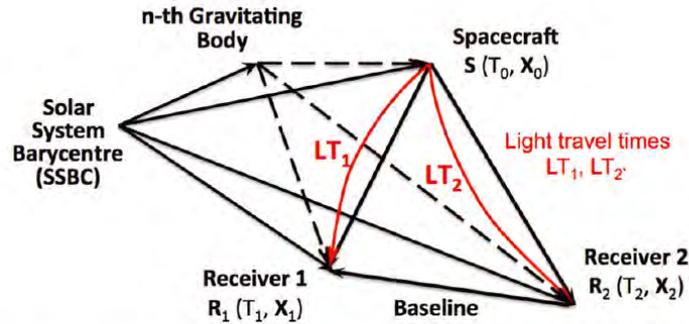


# Phase Center Offsets and Variations



# Phase Center Offset and Variations

## Computation of the VLBI near-field delay



**Fig. 2.** Geometry of VLBI observations of spacecraft in the barycentric celestial reference frame.

Duev *et al.* 2012, *A&A*, 541, A43

### Correction of the interferometer phases

Interferometer phase:  $\phi(\nu) = \omega\tau_{PC}(\nu) + \phi_{PCV}(\nu, A, \vartheta)$

Correction:  $\phi \mapsto \phi + \Delta\phi_{PCO} + \Delta\phi_{PCV}$

### Light-time equations

$$LT_1 : T_0 = T_1 - \frac{|\mathbf{X}_1(T_1) - \mathbf{X}_0(T_0)|}{c}$$

$$LT_2 : T_0 = T_2 - \frac{|\mathbf{X}_2(T_2) - \mathbf{X}_0(T_0)|}{c}$$

$$\tau = T_2 - T_1 \quad (\text{TCG} \rightarrow \text{TT})$$

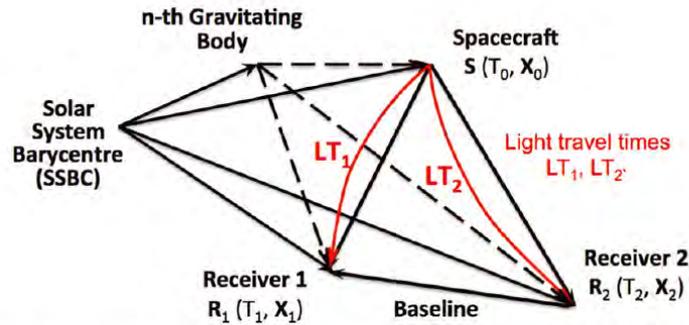
### Correction terms

$$\Delta\phi_{PCO} = 2\pi\nu (\tau_{CoM} - \tau_{PC}(\nu))$$

$$\Delta\phi_{PCV} = -[\phi_{PCV,B} - \phi_{PCV,A}]$$

# Phase Center Offset and Variations

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### Light-time equations

$$LT_1 : T_0 = T_1 - \frac{|\mathbf{X}_1(T_1) - \mathbf{X}_0(T_0)|}{c}$$

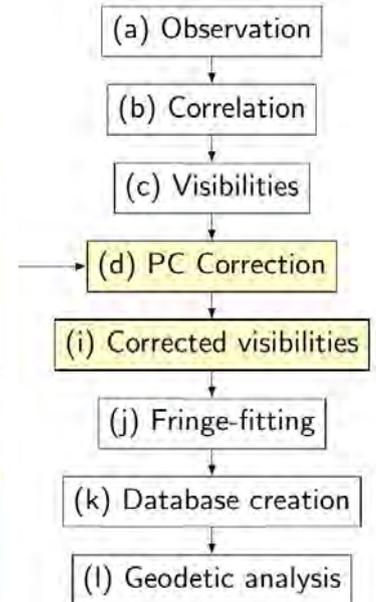
$$LT_2 : T_2 = T_0 + \frac{|\mathbf{X}_2(T_2) - \mathbf{X}_0(T_0)|}{c}$$

$$\tau = T_2 - T_1 \quad (\text{TCG} \rightarrow \text{TT})$$

### Correction terms

$$\Delta\phi_{PCO} = 2\pi\nu (\tau_{CoM} - \tau_{PC}(\nu))$$

$$\Delta\phi_{PCV} = -[\phi_{PCV,B} - \phi_{PCV,A}]$$



# Phase Center Correction



## Requirements:

- Well-defined reference point on GENESIS to tie the different observing techniques
- Phase-center offsets per antenna
- Antenna parameters (PC variation)
- GENESIS Ephemeris
- Attitude

→ Apply information to a near-field delay model and implement phase center corrections at data level 1

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# WP-6 - Test observations



- First test observation with GENESIS frequency setup on 2025-07-31
- Participating stations:
  - Hb Is K2 Ke S6 T1 Um Yg
  - Hv Mb Nn Ns Oe Ow Ws Yj
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- Next step will be a 24-hour session scheduled for 20 May 2026  
(VR2603, Fz Gs Hv Is K2 Ke Mb Mg Nn Ns Oe Ow S6 Sa T1 Um Wf Wn Ws Yg Yj)

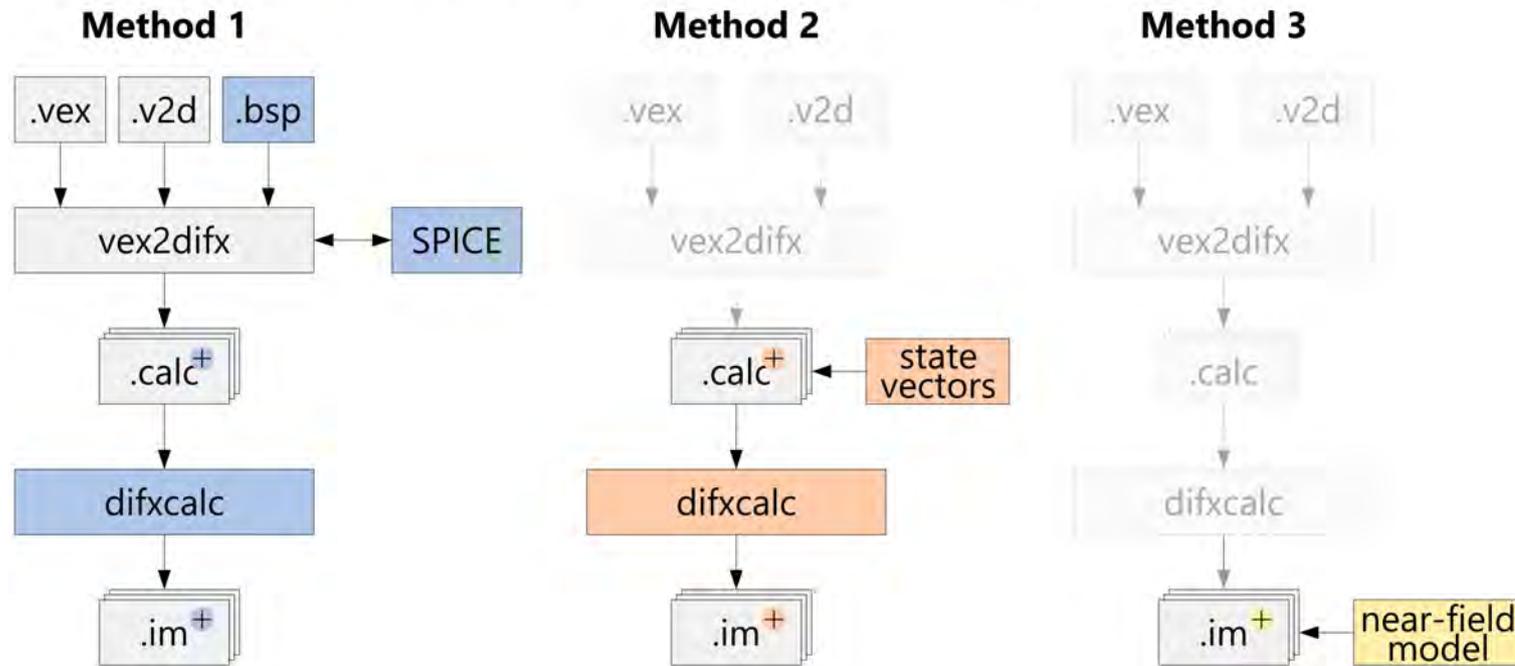
# Near-field Correlation



- AUSCOPE test observations of Galileo satellites in L-band in 2025 presented in IVS WG-7 meeting
- Spacecraft support available for correlation with DiFX via SPICE toolkit:
  - Supports SPICE kernel files, contain ephemeris data located in .bsp (= Binary SPice kernel) files
  - .bsp files can be made from, e.g., TLE (Two-Line Element) files or state vector data
  - TLEs less accurate than SP3 (Standard Product 3), but the latter is not supported by SPICE
    - higher residual delays and variations from scan to scan
    - generate more accurate .im files

# Near-field Correlation

## Generation of .im Files for Near-Field Targets





Thank you!

Questions/comments?

