HUYGENS RADIO LINK IN-FLIGHT PERFORMANCE

And some science results

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IPPW3, Annavyssos, Greece 26 Jun 05

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OUTLINE of the presentation

1.- HUYGENS data relay link description

2.- Link design flaw discovery and recovery mission

3.- In-flight link reconstruction and performance overview

4.- Some science aspects/results derived from the engineering link parameters

5.- Conclusions

Back-up slides

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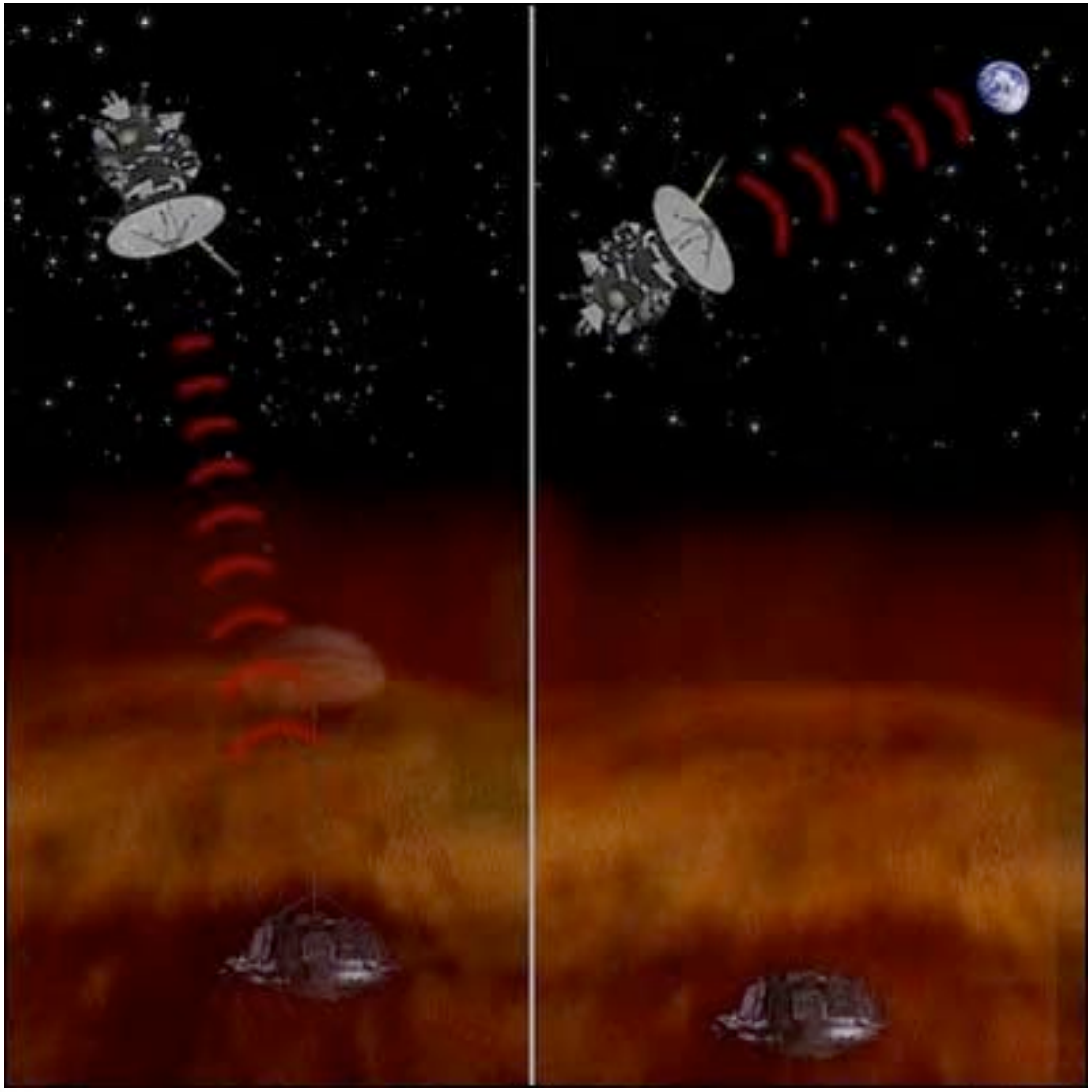
THE HUYGENS DATA RELAY LINK



- 2 CHAINS (redundancy)
- PCM/BPSK/PM ONE-WAY:
  - ChA: 2040 MHz LHCP
  - ChB: 2080 MHz RHCP
- Residual carrier phase modulation (m=1.34, 1.37)
- Subcarrier 131072 Hz, BPSK modulated
- Data PCM-NRZ-M 8kbps, Reed-Solomon + Convolutional CODE (2:1) ➔16ksps
- PTA antenna: resonant quadrifilar helix antenna

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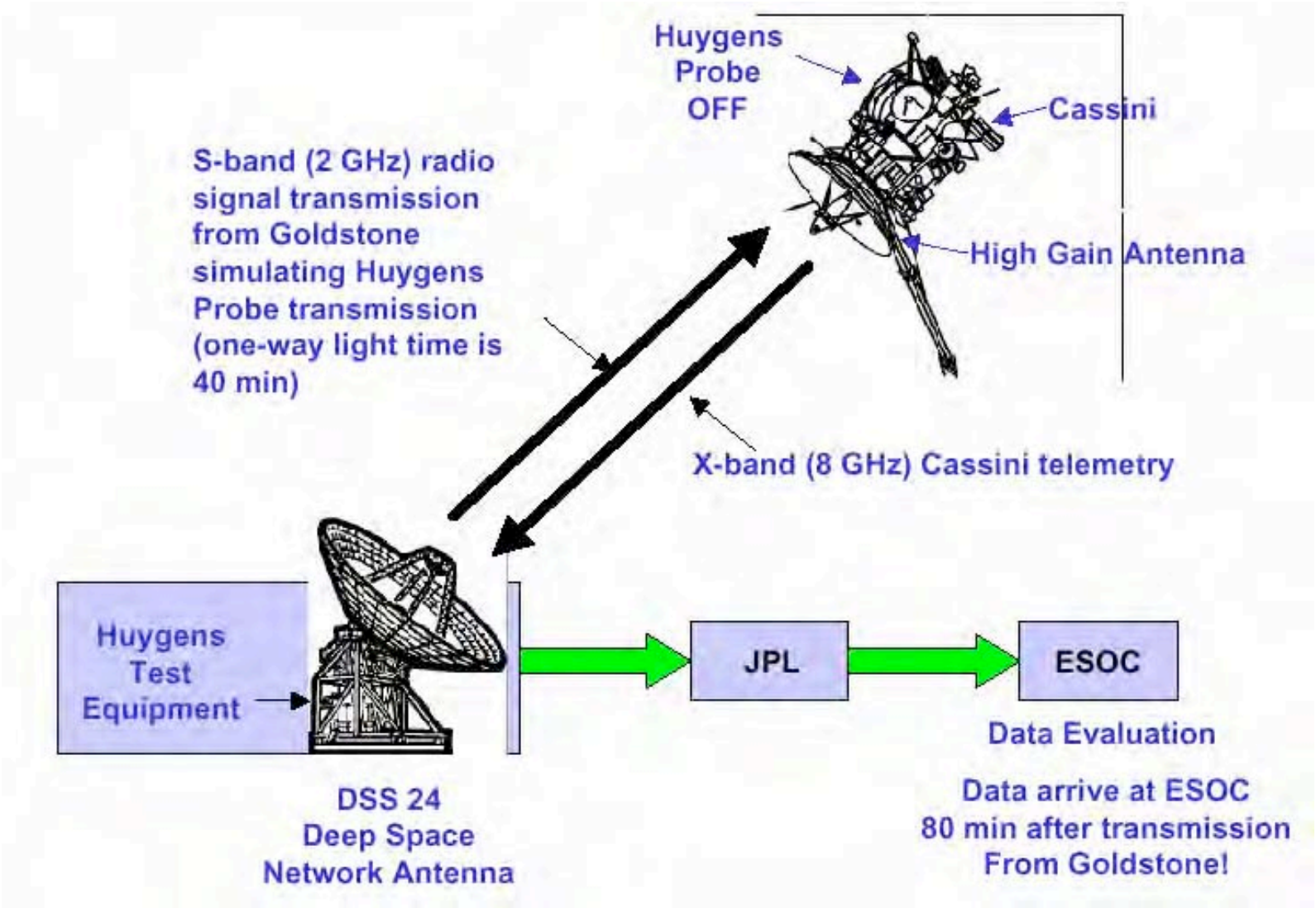
End-to-end test: PROBE RELAY TEST (PRT #1) Feb 2000



PRT#1 RESULT:

For the expected mission frequency Doppler shift, 80-90% of data packets would be rejected on-board!!! On Earth, severe (CRITICAL) science data loss.

HRTF: Huygens Recovery Task Force

~1.5 years, Feb 2000- July 2001

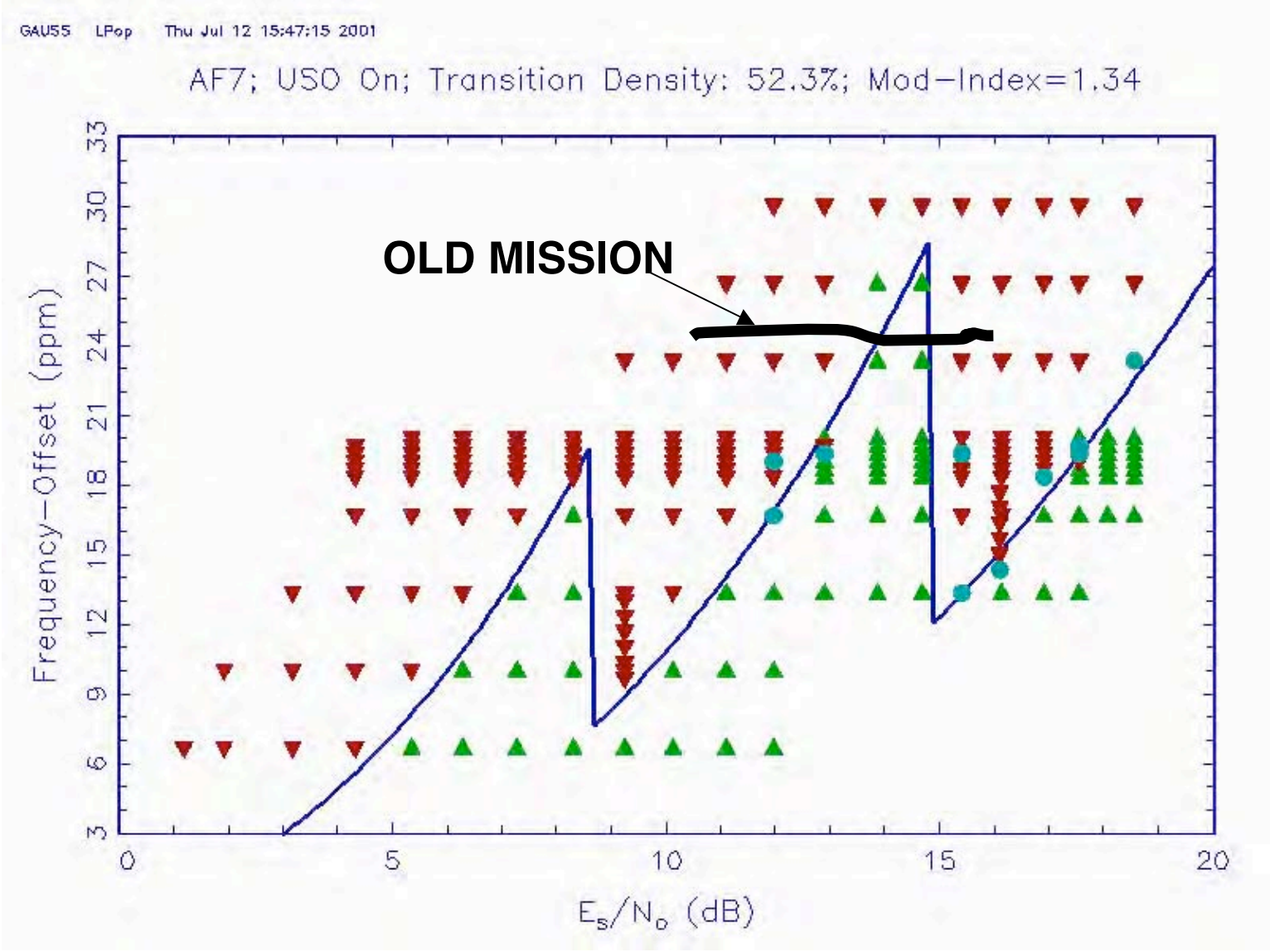
Goal: understand flaw and find solutions

HIT: Huygens Implementation Team

~3 years, July 2001 – mid-2004

Goal: implement the recovery solution

RECEIVER MODEL and IN-FLIGHT TESTING



RECOVERY SCENARIO:

1.- Trajectory change Cassini – Huygens

Objective: reduce relative doppler offset

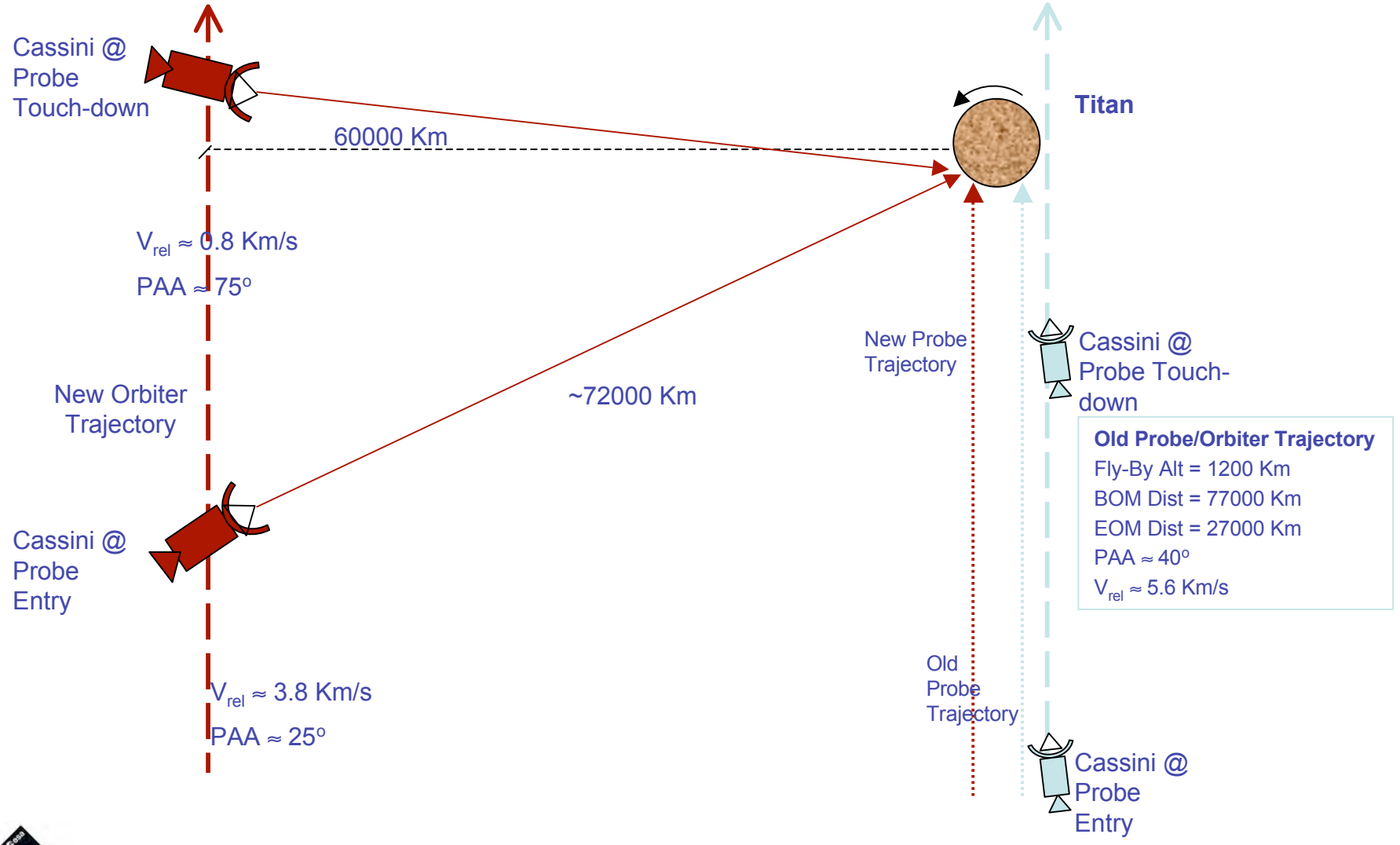
2.- Pre-heating of the probe (4 hours)

Objective: decrease the frequency of the data by warming the data stream clock before entry

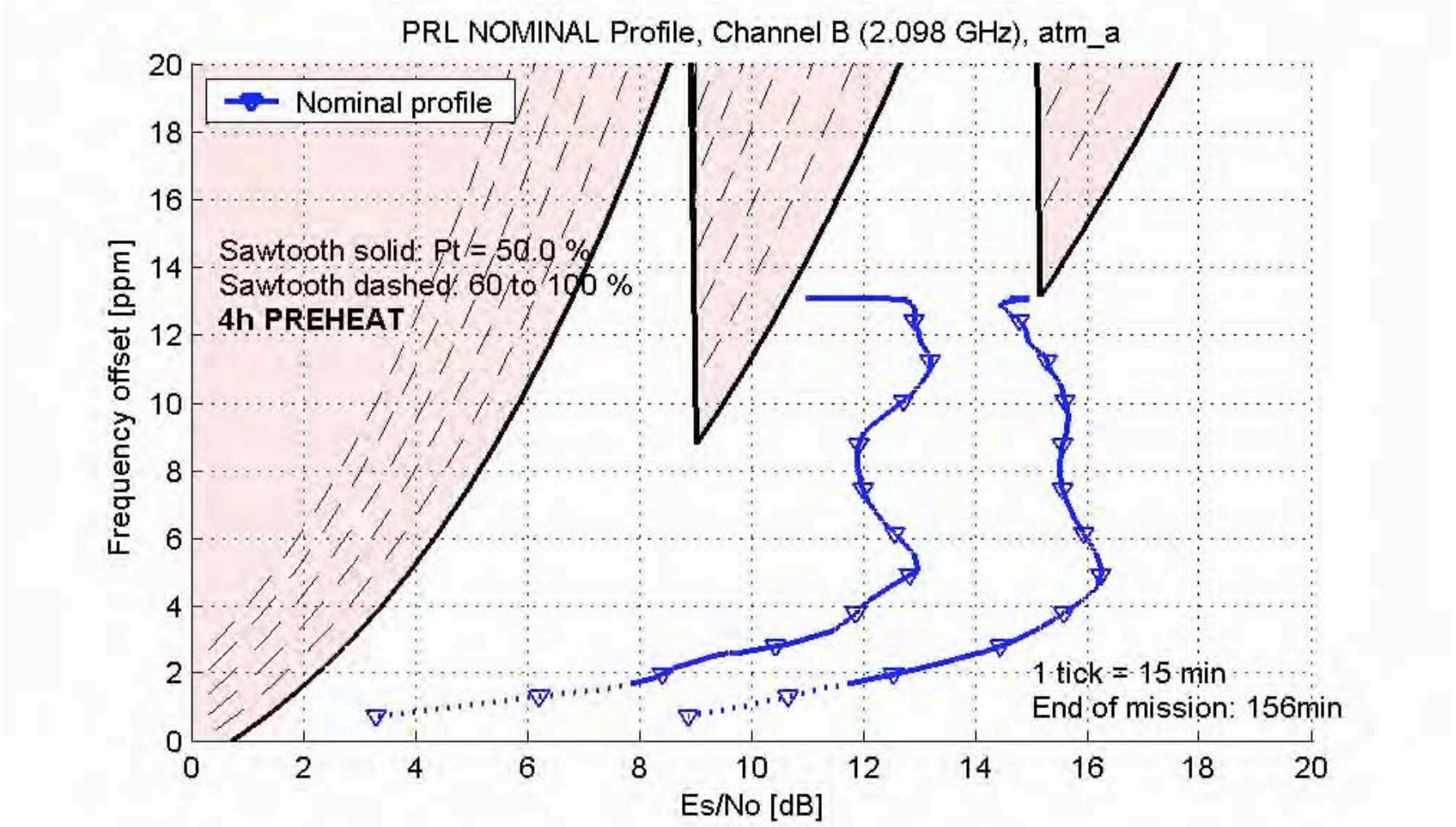
(3.-) Data post-processing on Earth

Further use of Reed-Solomon capability

Geometry change



Predicted performance of the recovery scenario



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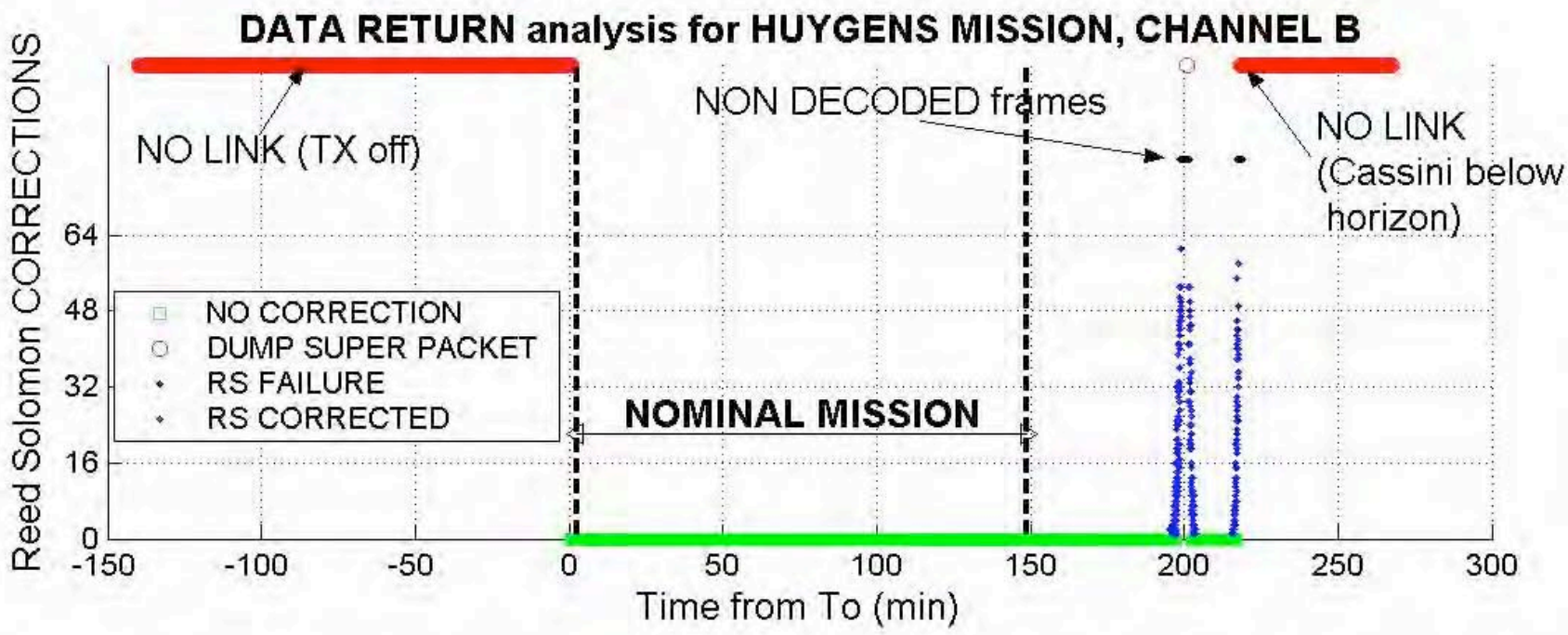
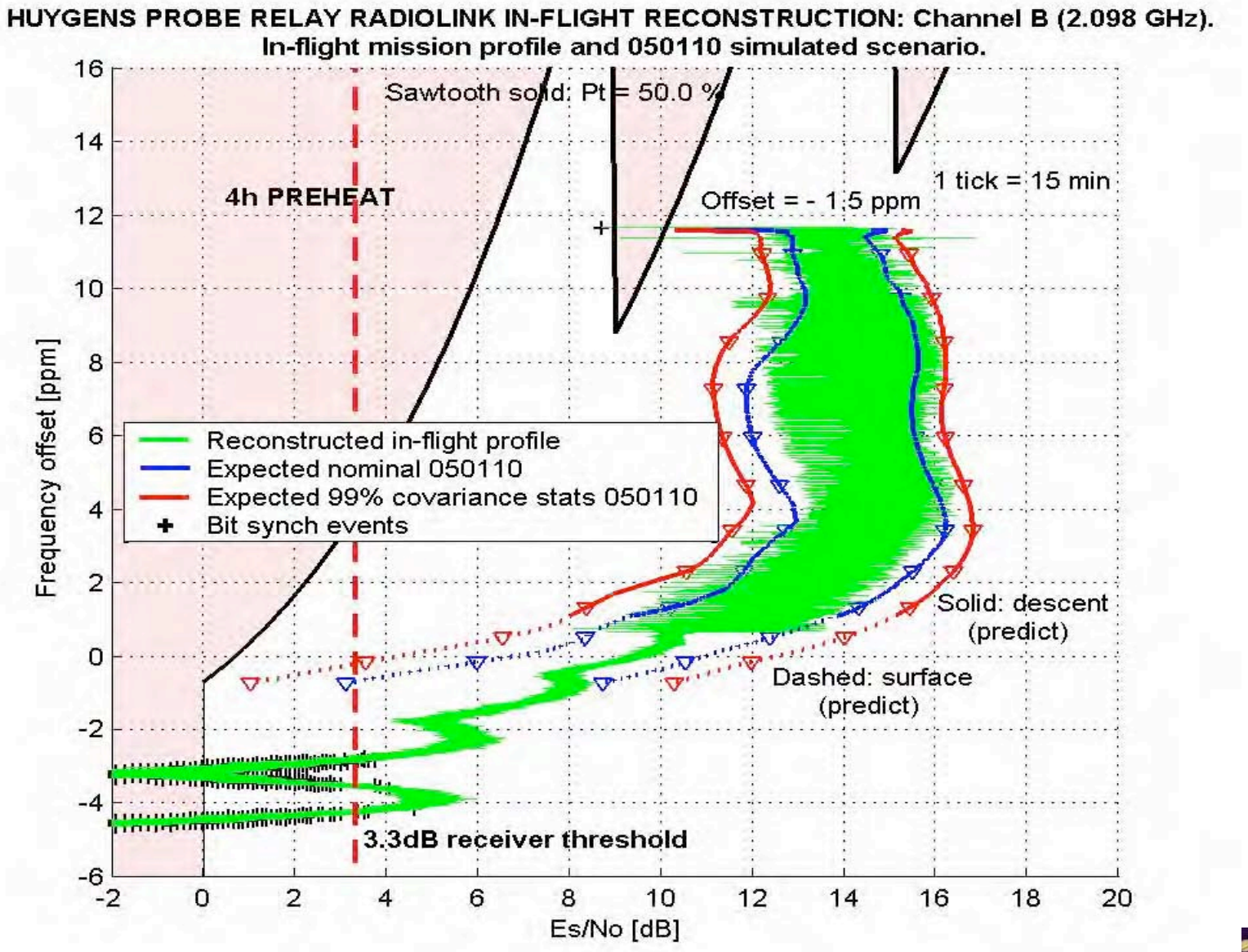
Data Link PERFORMANCE overview

100 % DATA RETURN for CH B ! ! GREAT SUCCESS
+71 min on SURFACE !



Finger Plot RECONSTRUCTION



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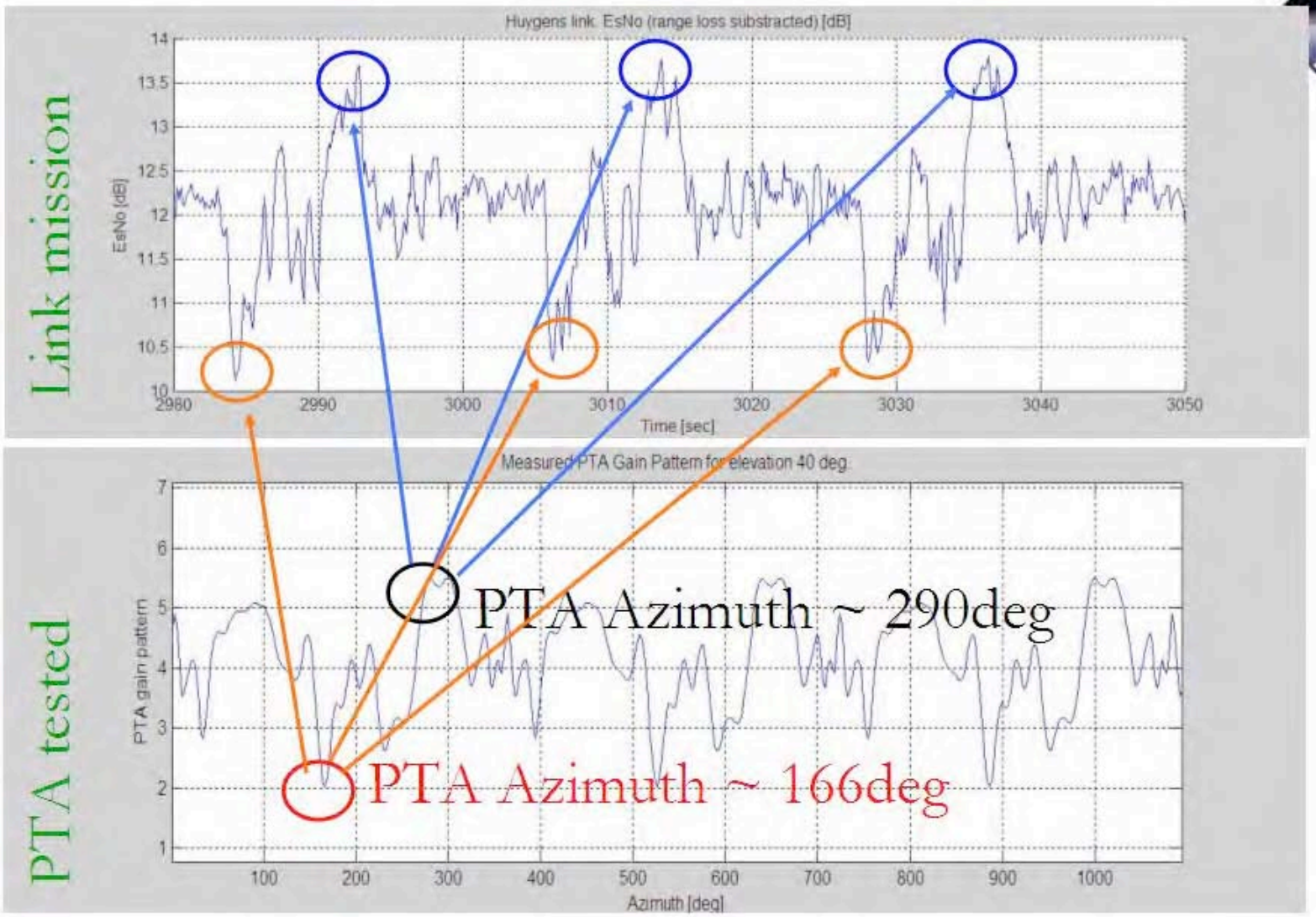
- (a) Azimuth reconstruction
- (b) Spin rate reconstruction
- (c) Link on the surface: radio science

5.- Conclusions

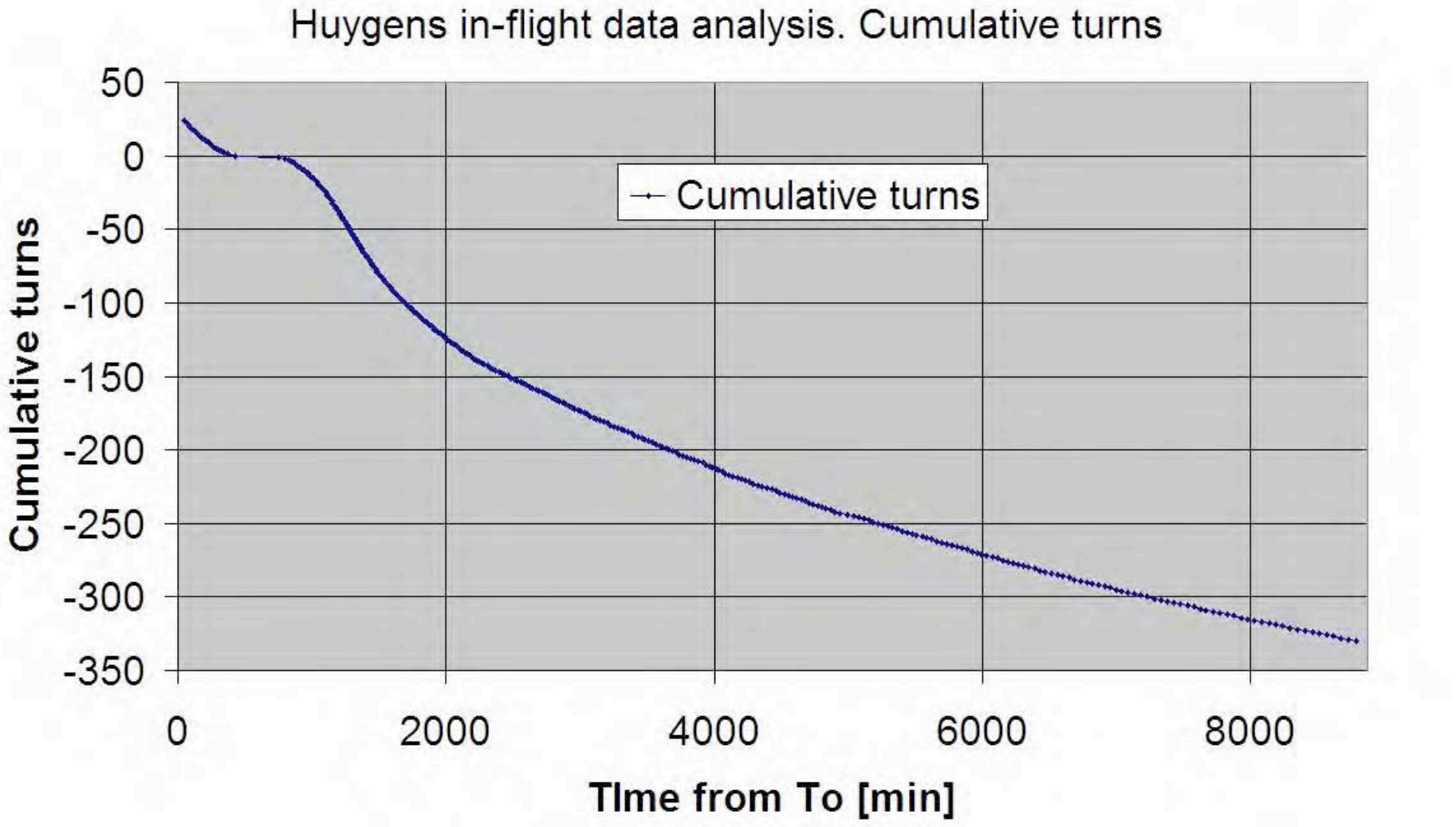
Back-up slides

(a) Absolute AZIMUTH reconstruction:

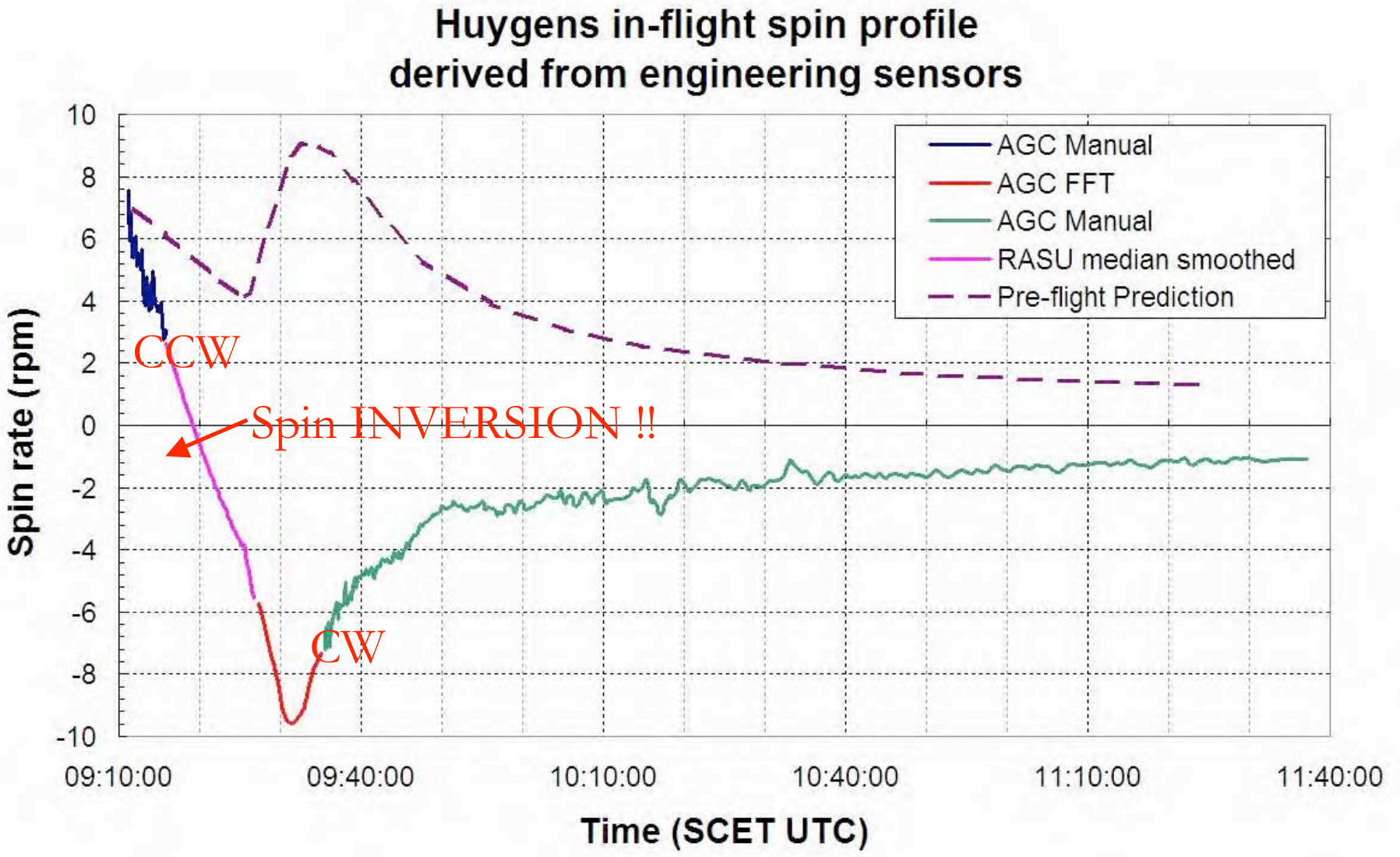
based on matching the PTA test pattern and the AGC in-flight signal



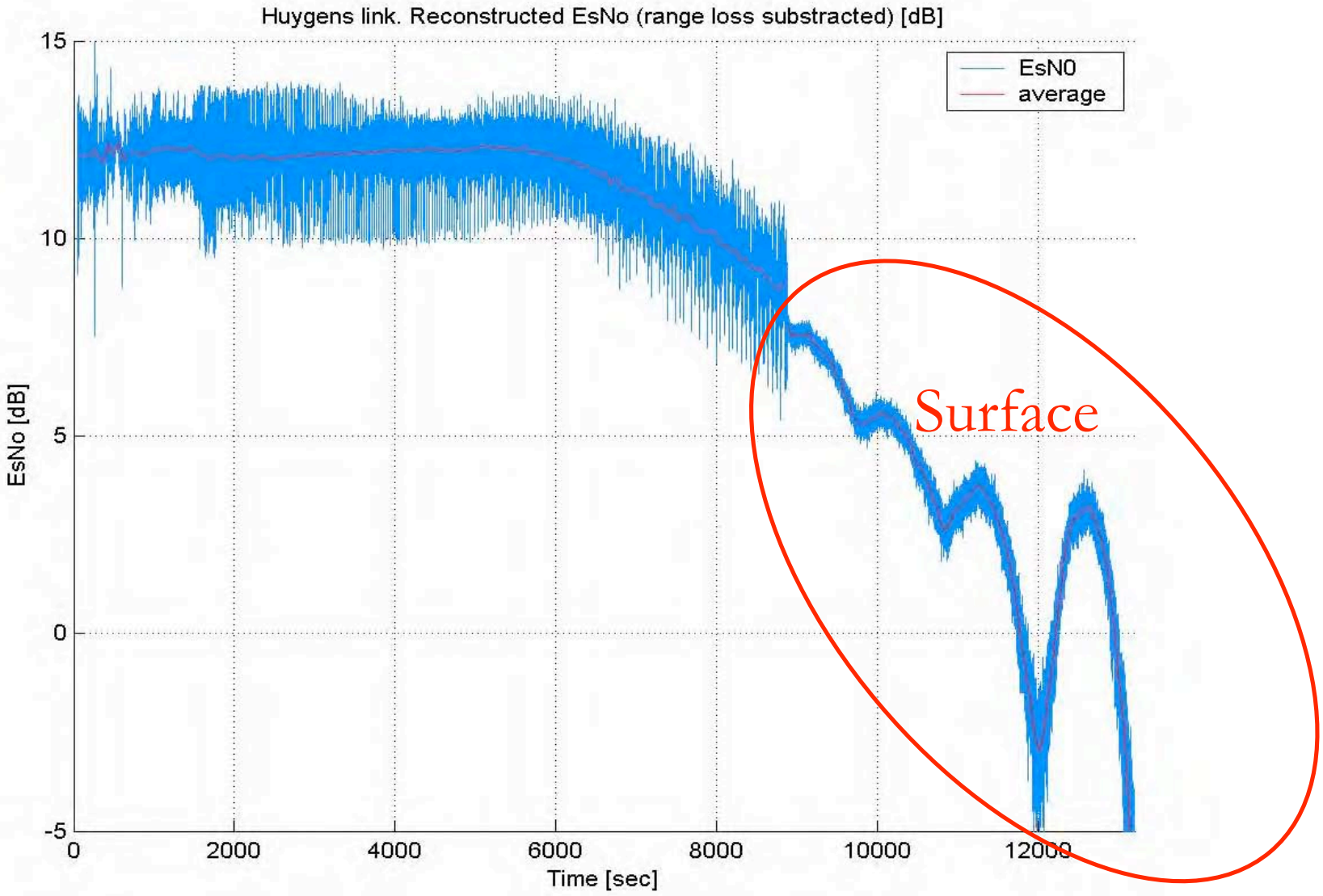
(a) Absolute AZIMUTH reconstruction

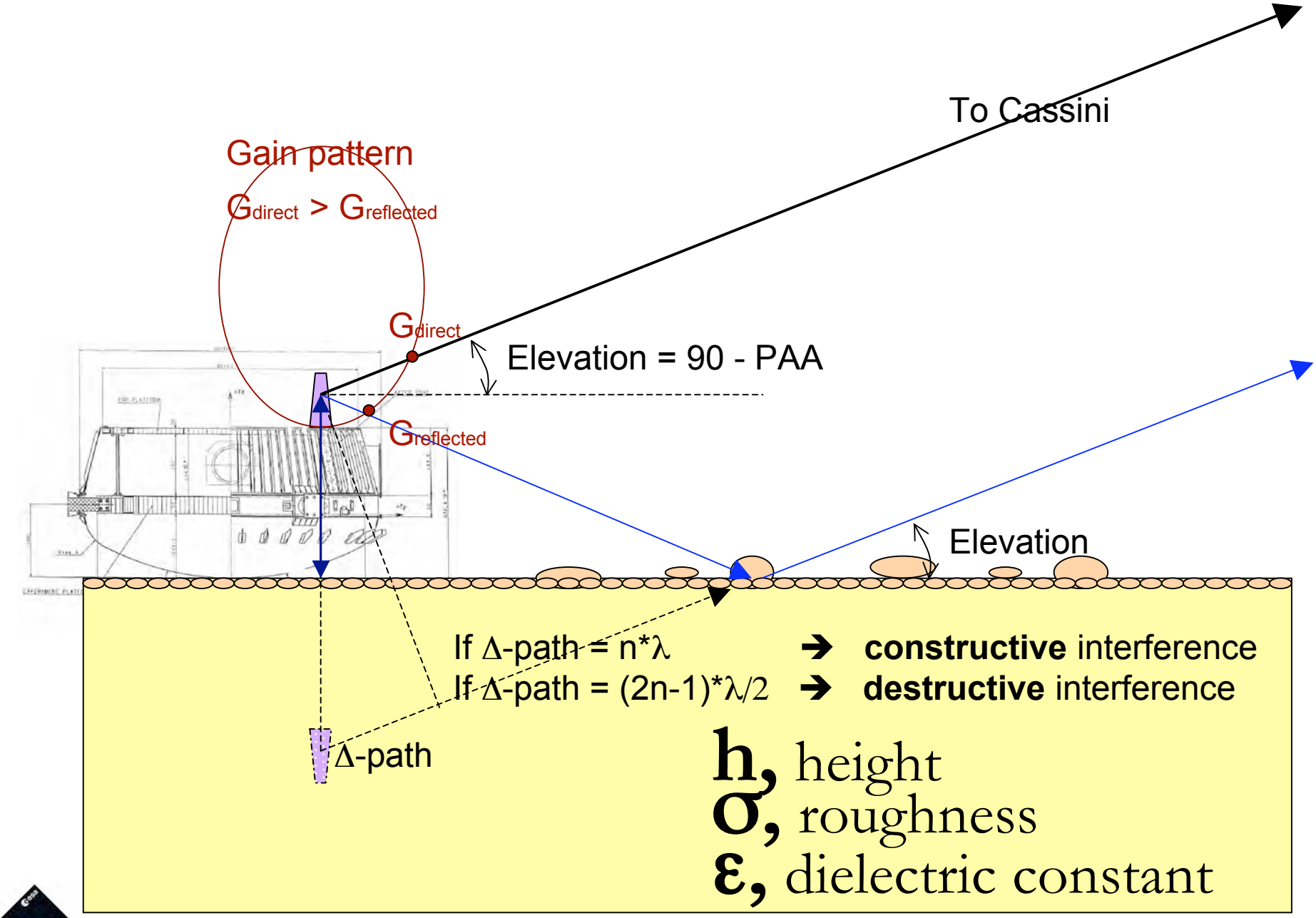


(b) Spin profile reconstruction

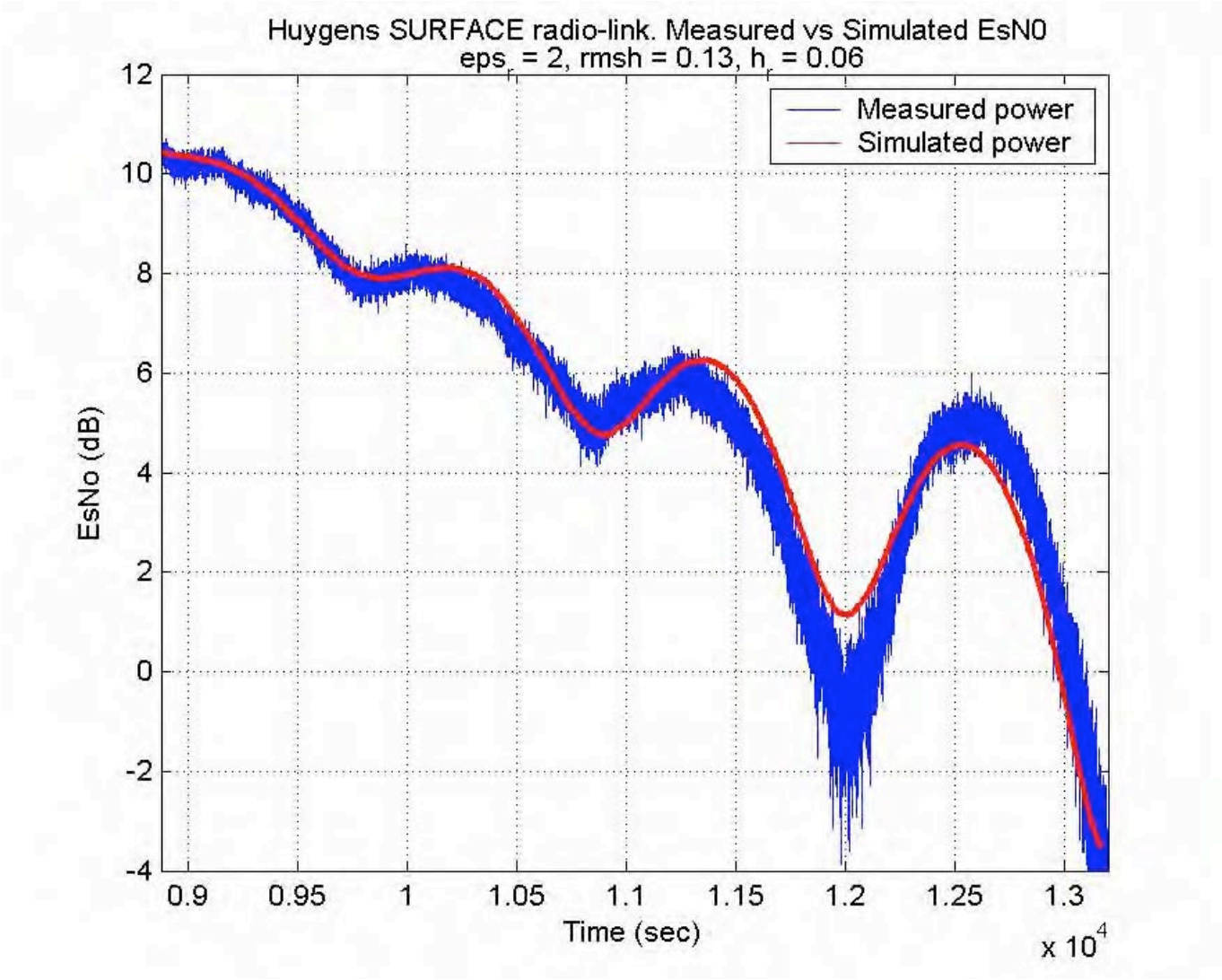


(c) Link on the Surface




To Cassini
Gain pattern
Gdirect > Greflected
Gdirect
Elevation = 90 - PAA
Greflected
Elevation
If Δ-path = n*λ → constructive interference
If Δ-path = (2n-1)*λ/2 → destructive interference
Δ-path
h, height
σ, roughness
ε, dielectric constant

Simulations



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CONCLUSIONS

1.- **Excellent engineering performance** of the Huygens ChB radio link:

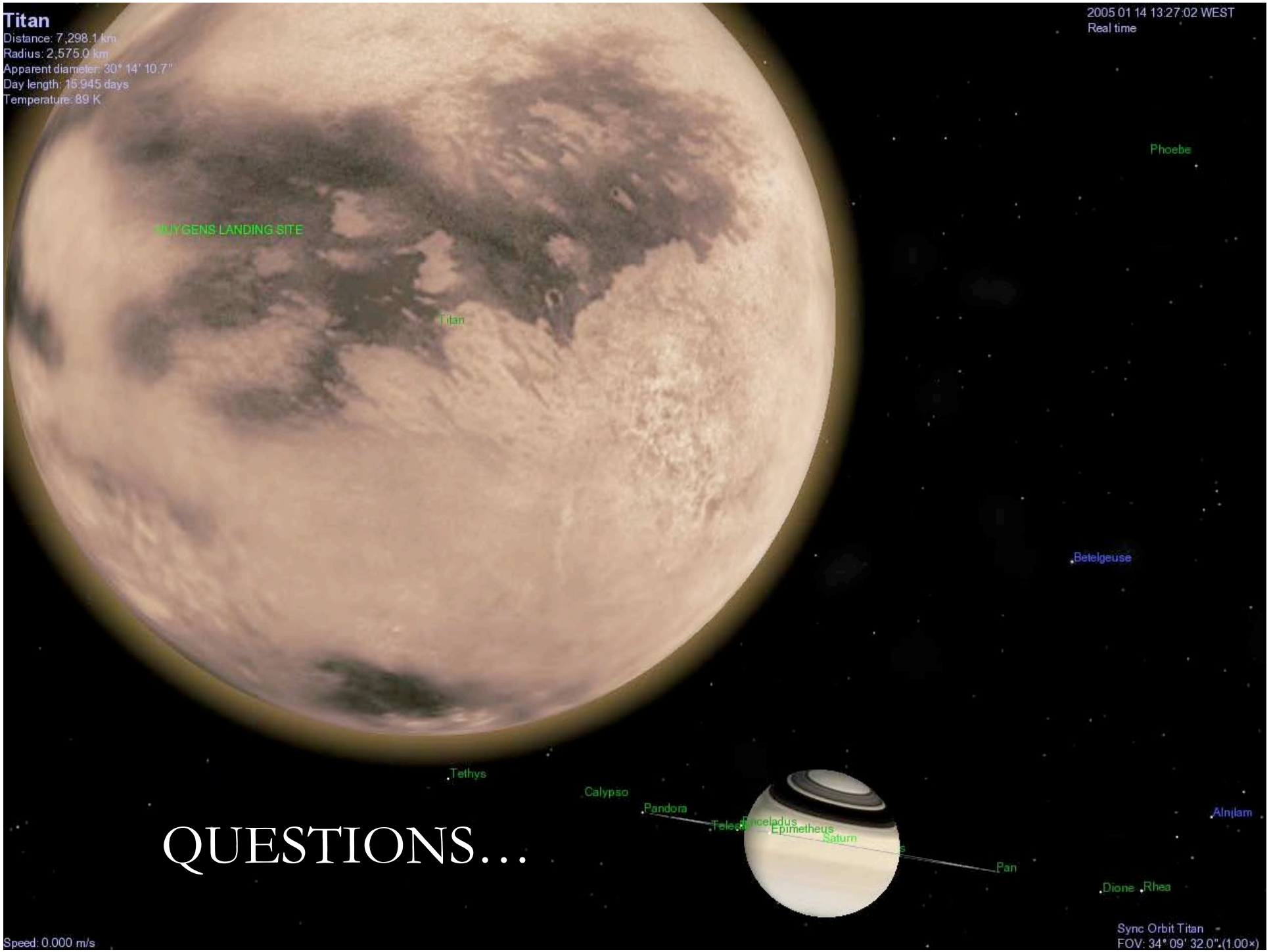
- full **100% data returned** back to Earth
- **71 min** 'bonus' on the **surface**, until Cassini set beneath horizon.

Recovery Mission efforts paid off. THANKS HRTF and HIT !! SCIENTISTS have their data to analyse TITAN.

2.- Engineering telemetries CAN be used for **scientific purposes**, beyond the regular engineering service intended for. BUT need an intelligent planning. Examples:

- The **spin reversal** anomaly has been confirmed and **characterized**.
- **Azimuth and spin rate** profiles have been generated and will help the instrument teams to better interpret their measurements.
- The **multi-path radio-science** behaviour **on the surface** will also provide a local characterization of the **soil properties** (dielectric constant, roughness) for synergies with the lower res Cassini radar mapping of Titan.

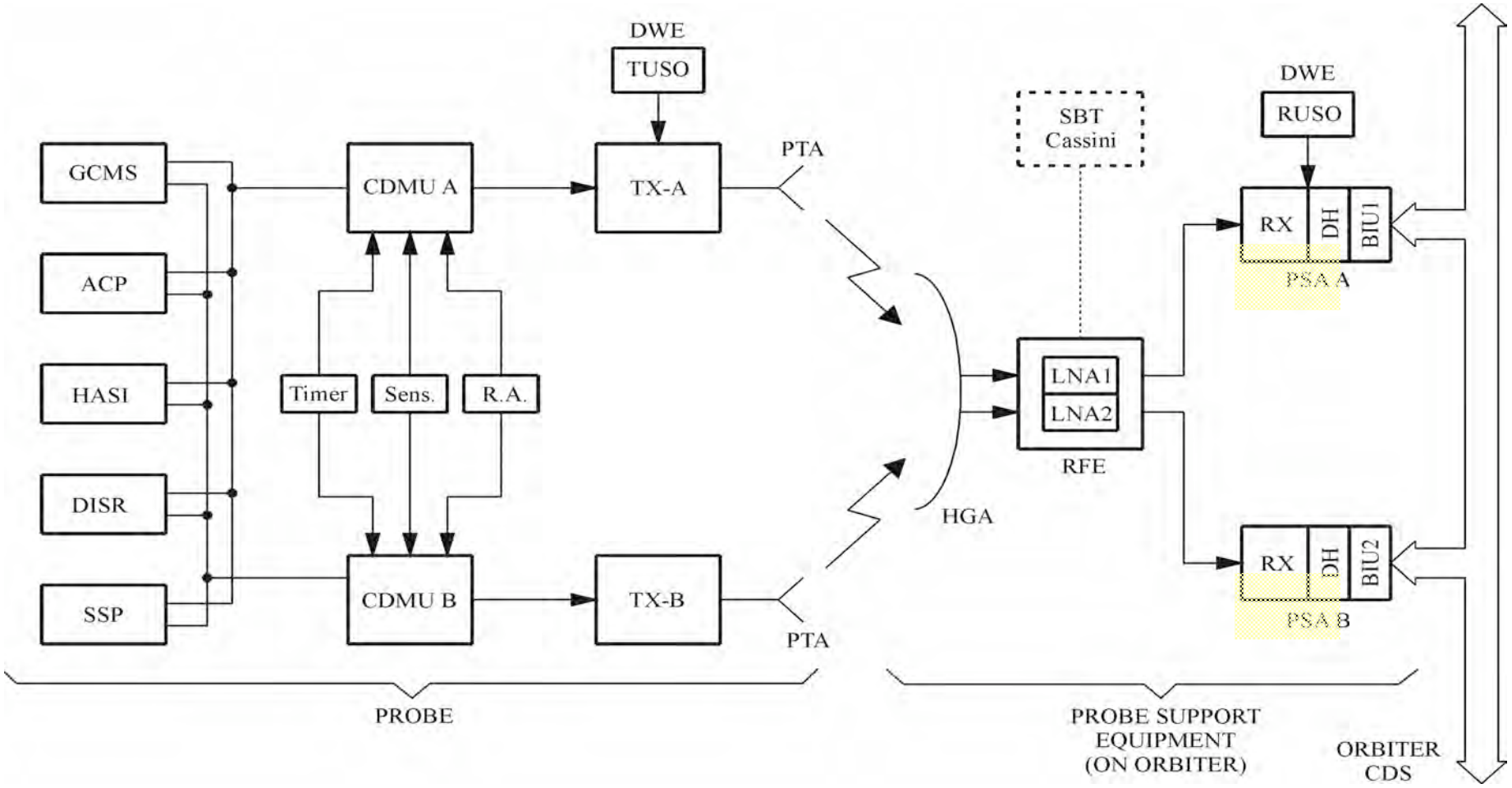
3.- CONGRATULATIONS to all HUYGENS and CASSINI TEAMS for the recovery efforts, and such an awesome mission


Titan
Distance: 7,298.1 km
Radius: 2,575.0 km
Apparent diameter: 30° 14' 10.7"
Day length: 15.945 days
Temperature: 89 K
2005 01 14 13:27:02 WEST
Real time
HUYGENS LANDING SITE
Titan
Phoebe
Betelgeuse
Tethys
Calypso
Pandora
Telesto
Prometheus
Epimetheus
Saturn
Pan
Dione
Rhea
Alnilam
Sync Orbit Titan
FOV: 34° 09' 32.0" (1.00×)
Speed: 0.000 m/s

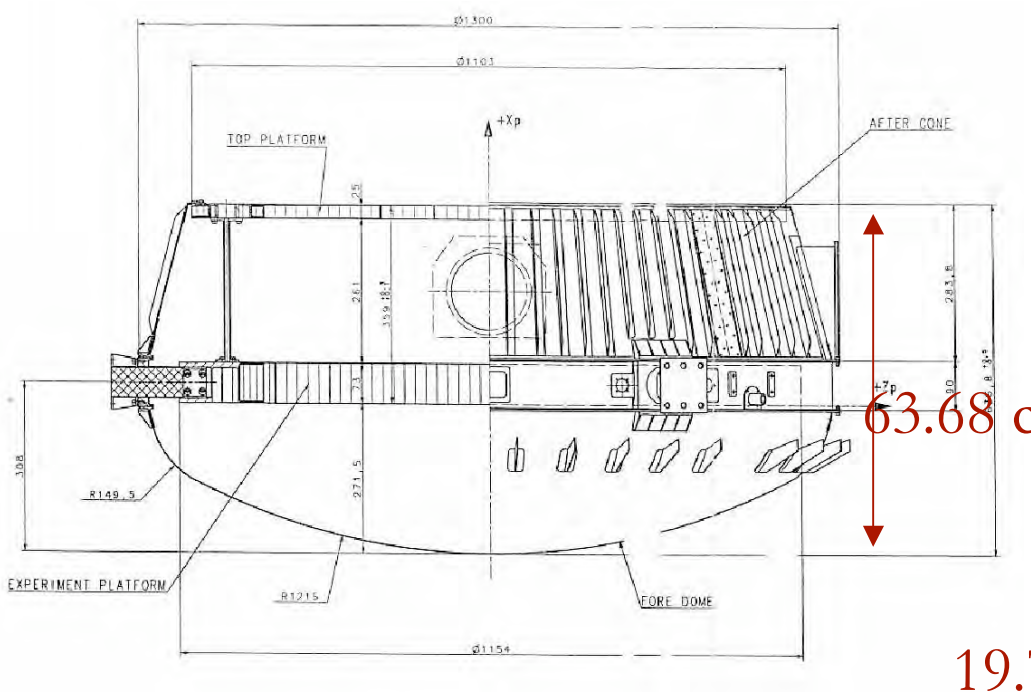
QUESTIONS…

BACK-UP SLIDES

Probe Data Relay Subsystem (PDRS)

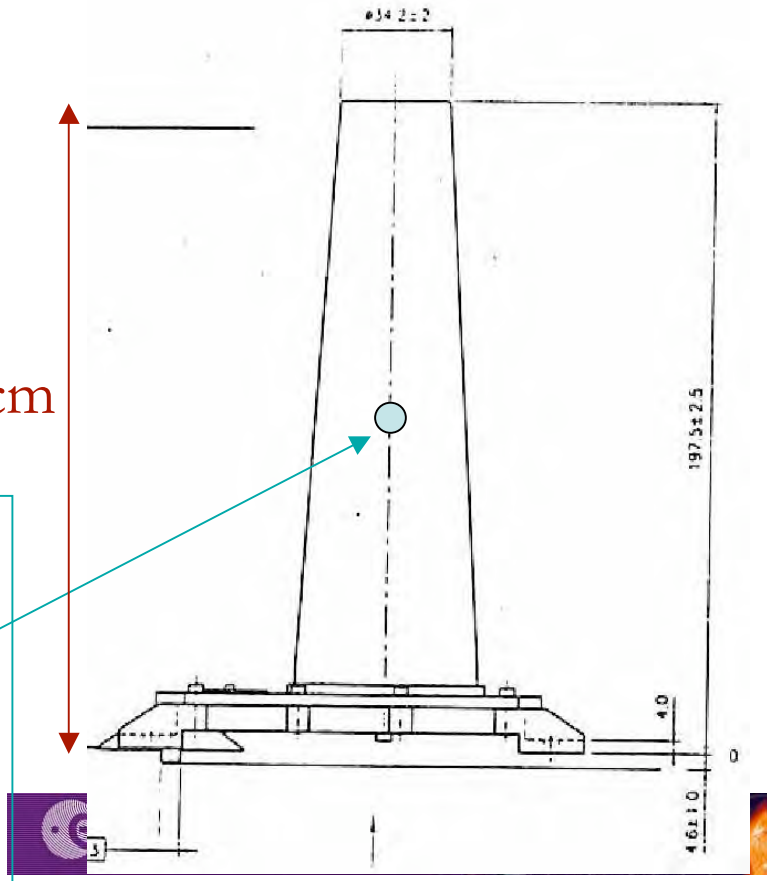


PTA heigth = DM height + PTA phase center =
63.68 + 19.75/2 = 73.555 cm



63.68 cm

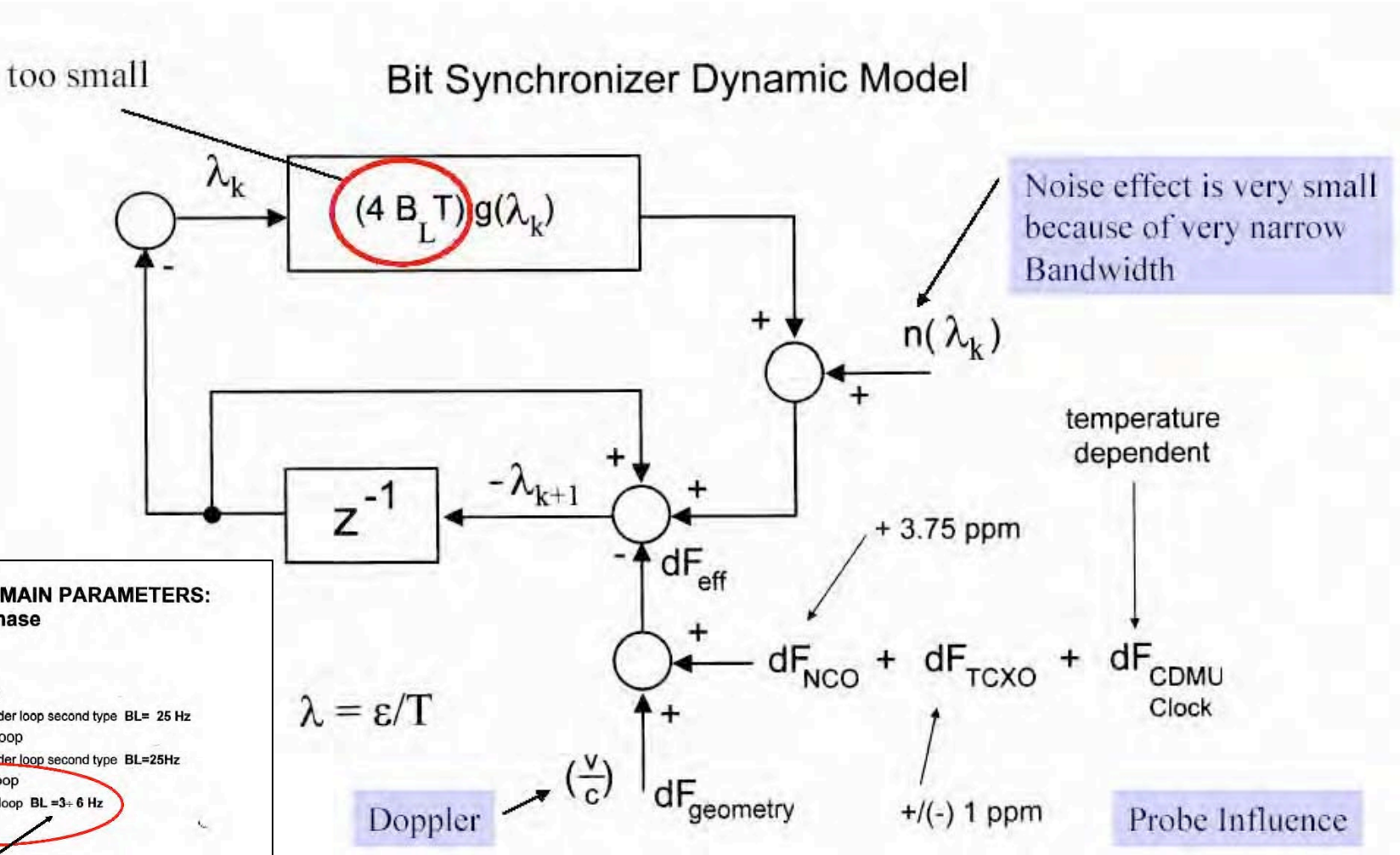
19.75 cm



PTA phase center:

Assumed in the middle of the radome for a 4 wires helical antenna (Klooster, ESTEC).

Bit Synchronizer Dynamic Model



RECEIVER MAIN PARAMETERS:
Tracking Phase

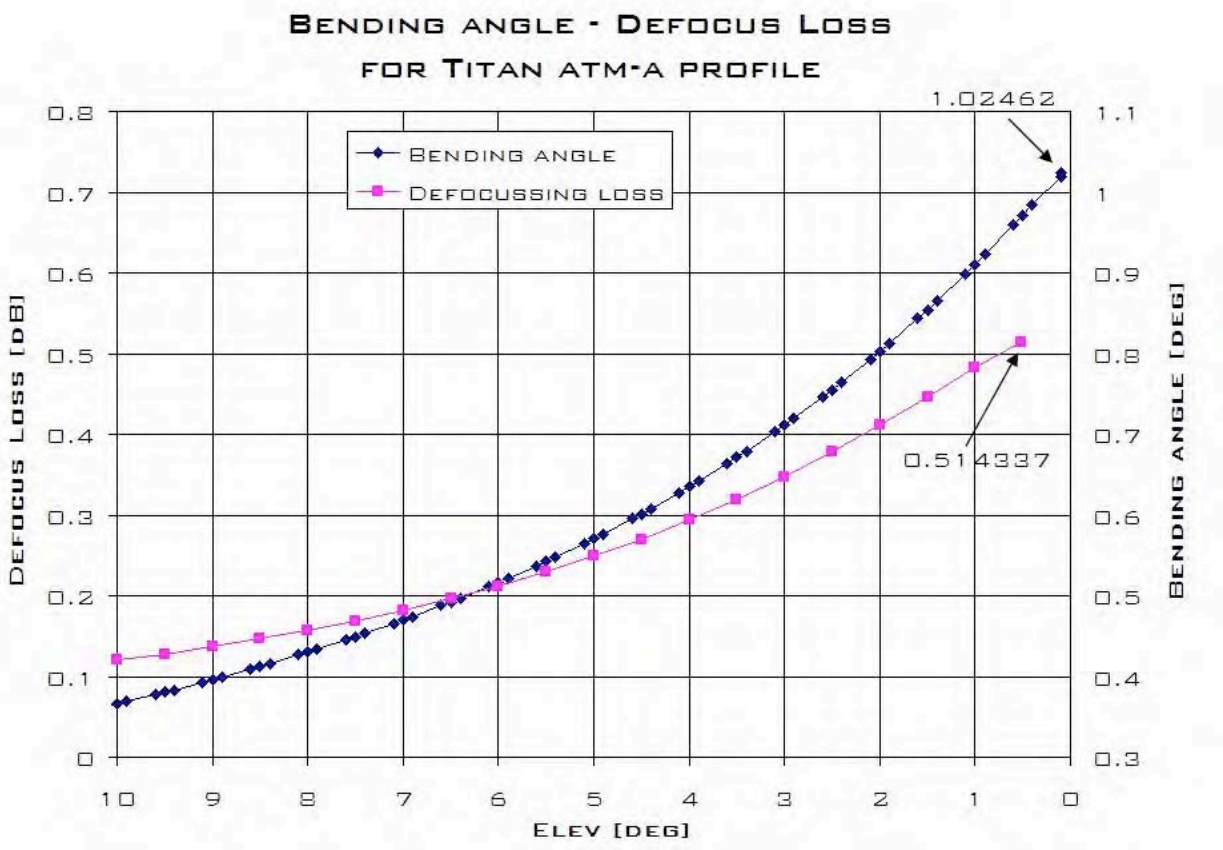
- Carrier Loop
  - second order loop second type **BL= 25 Hz**
- Subcarrier Loop
  - second order loop second type **BL=25Hz**
- Bit synch. Loop
  - first order loop **BL =3÷ 6 Hz**

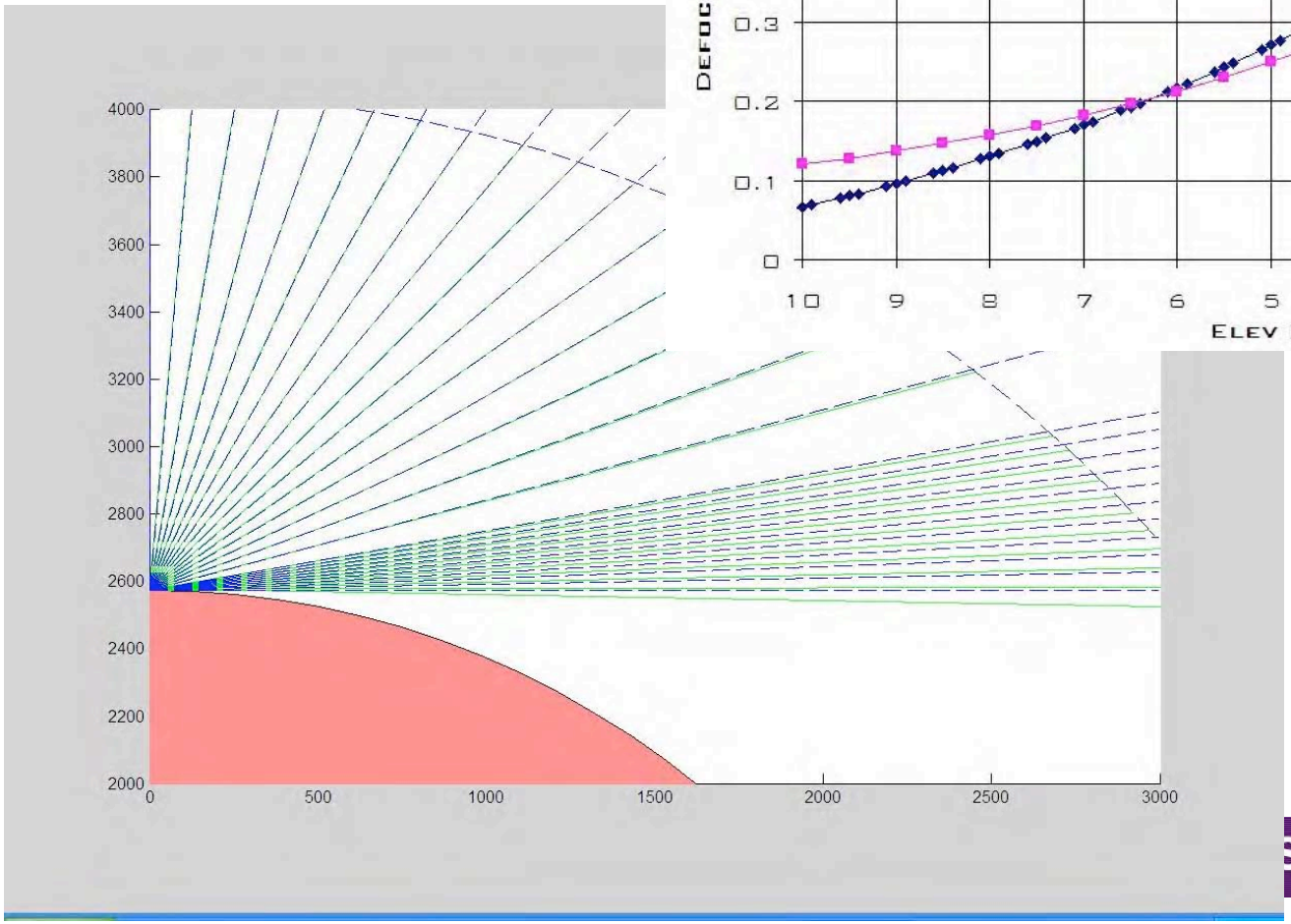
Intention, but not satisfied in actual implementation

HUY ROME March, 2000

RAY BENDING

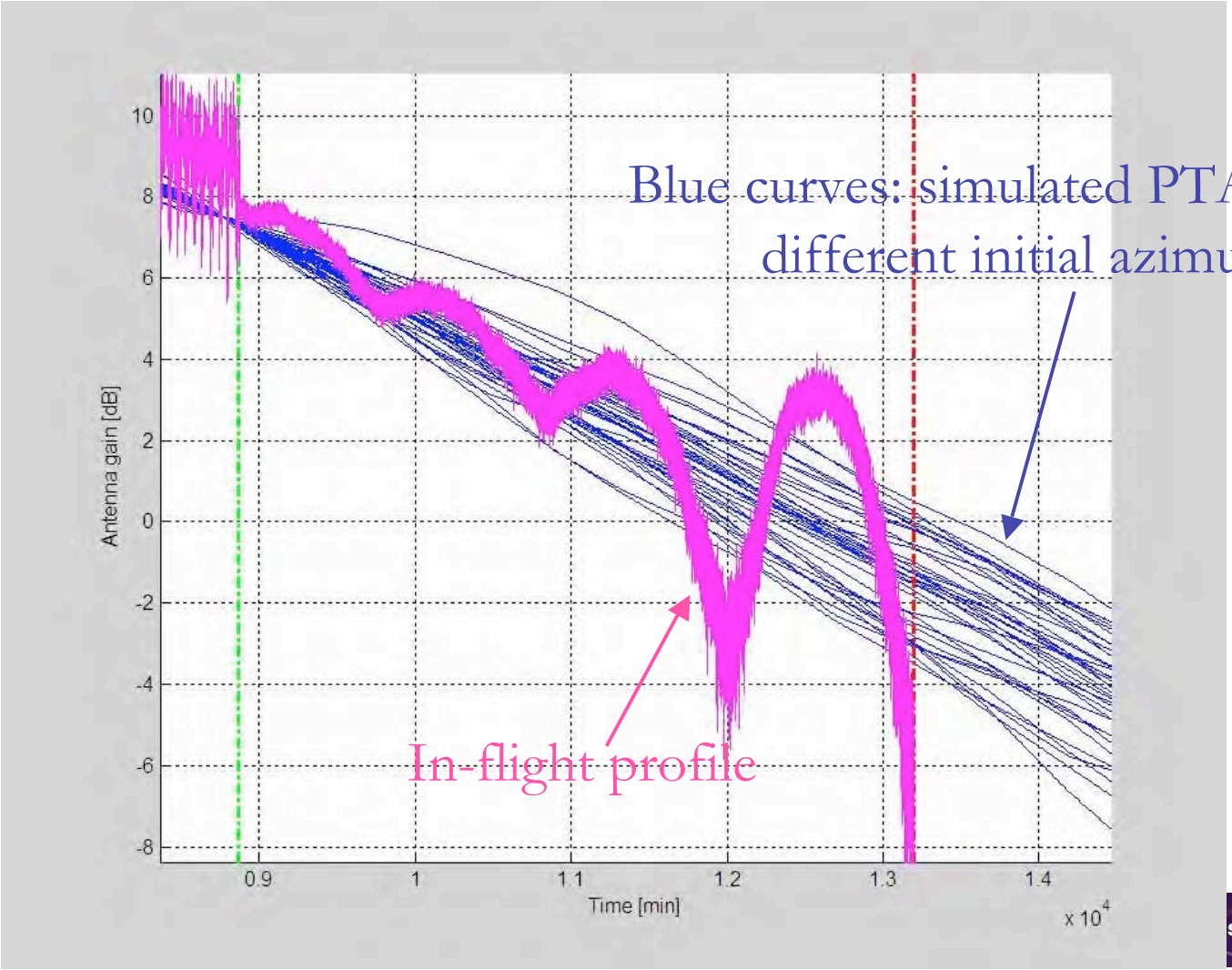
effect



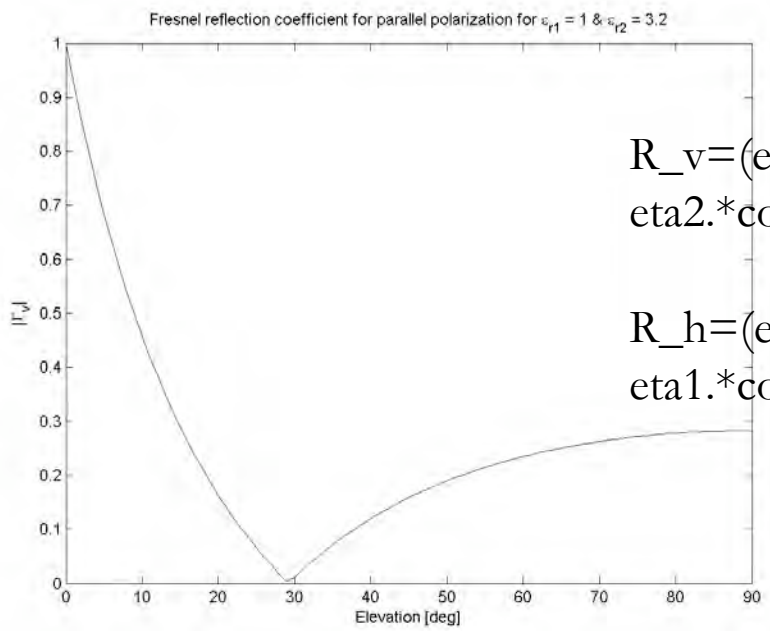


Oscillation not explained by 'SCANNING of the PTA pattern' (due to azimuth-elevation variation of orbiter position):

- too fast in time
- too large in power variation

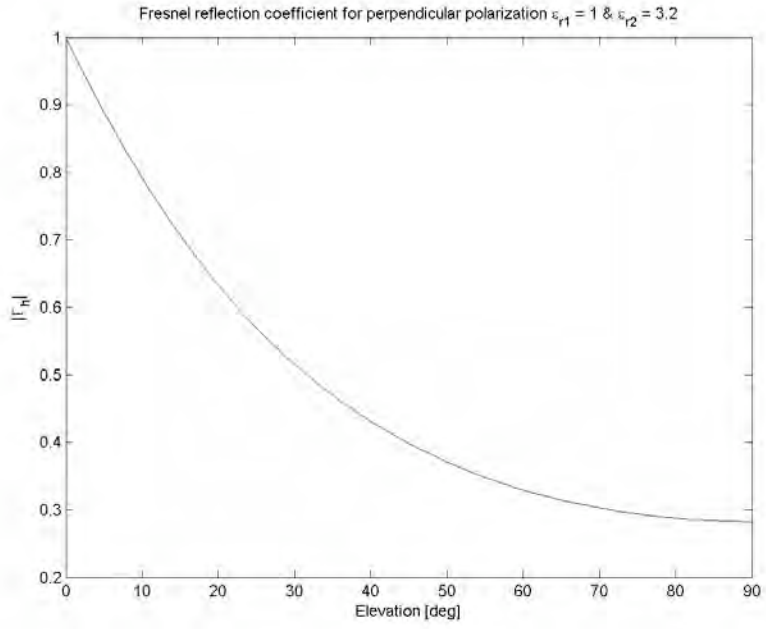


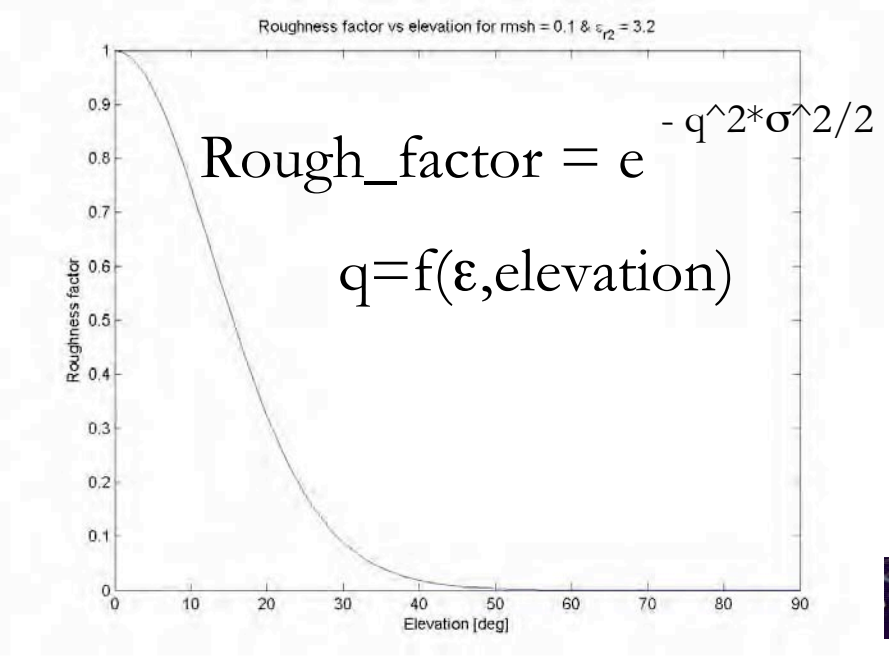
Coefficients



R_v=(eta1.*cos(theta1)-
eta2.*cos(theta2))./(eta1.*cos(theta1)+eta2.*cos(theta2));

R_h=(eta2.*cos(theta1)-
eta1.*cos(theta2))./(eta2.*cos(theta1)+eta1.*cos(theta2));

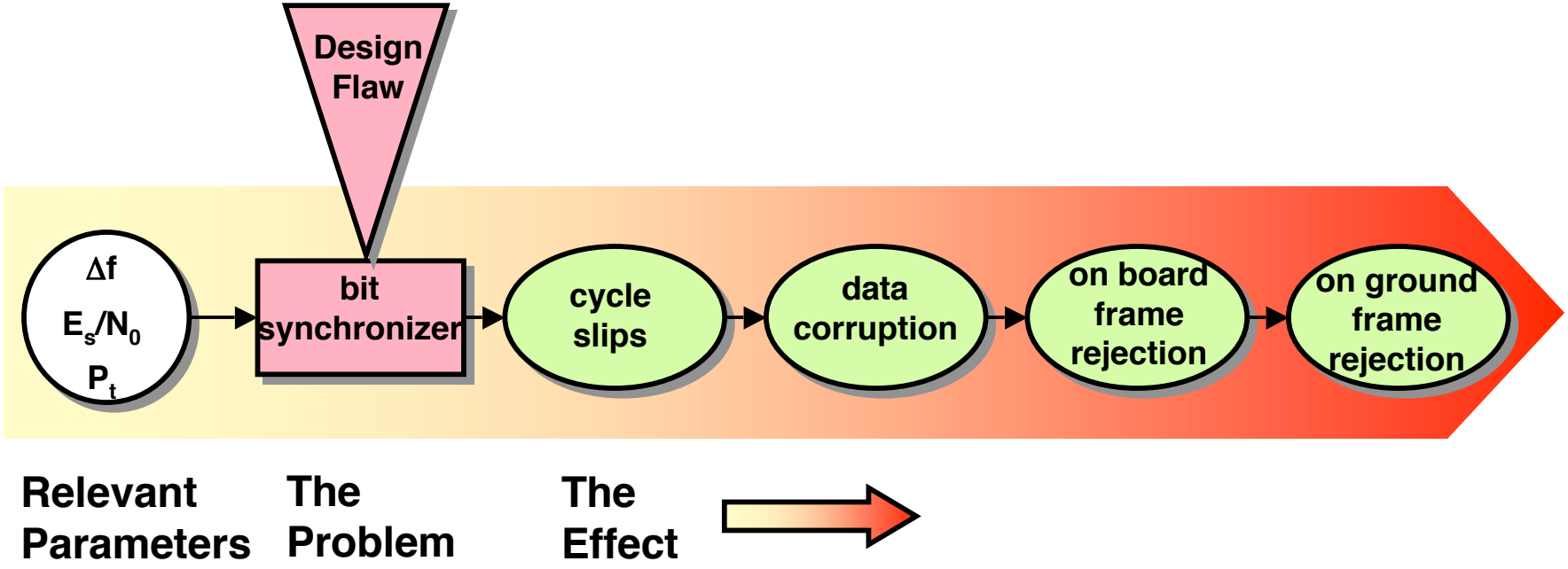




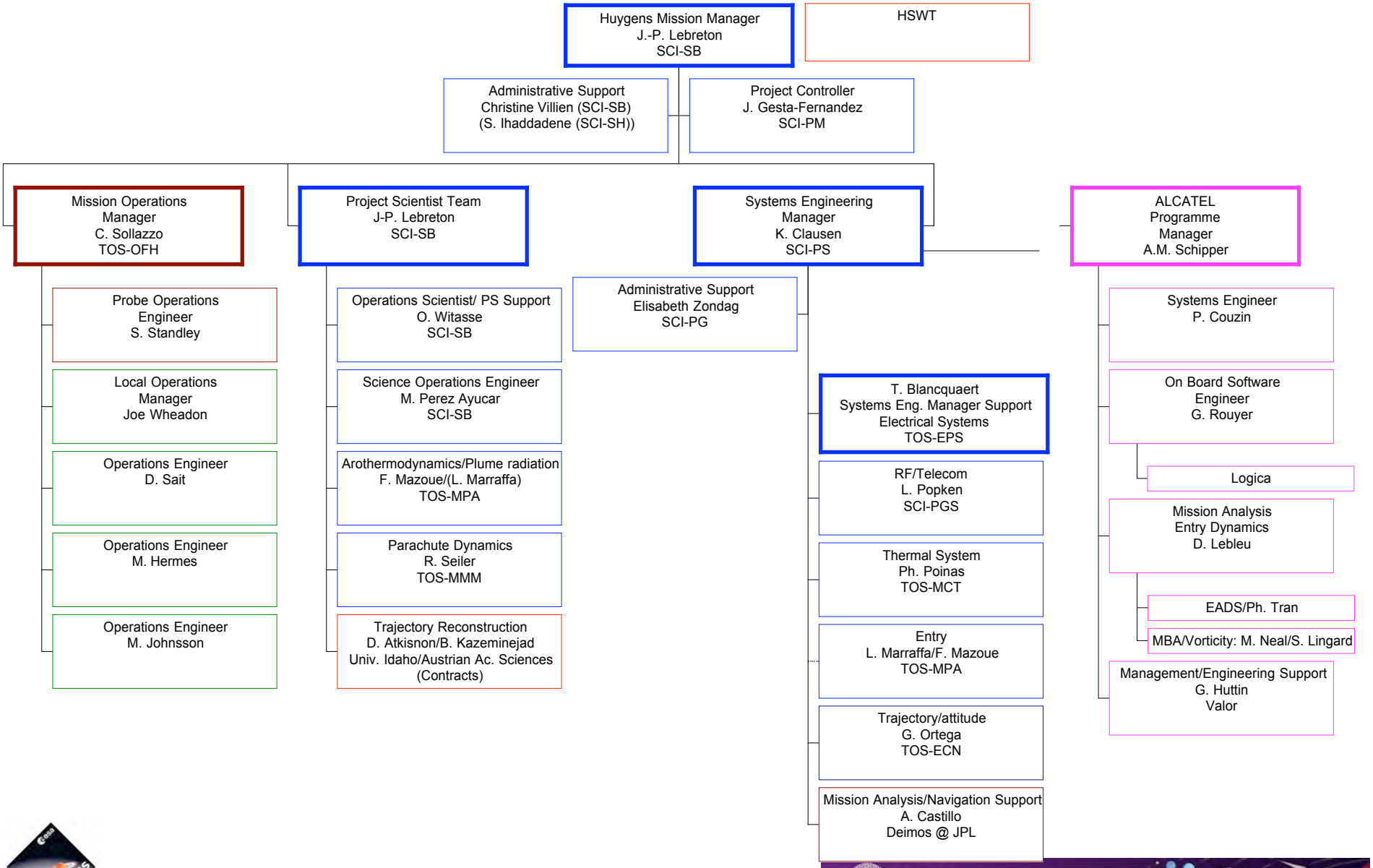
$$\text{Rough\_factor} = e^{-q^2*\sigma^2/2}$$

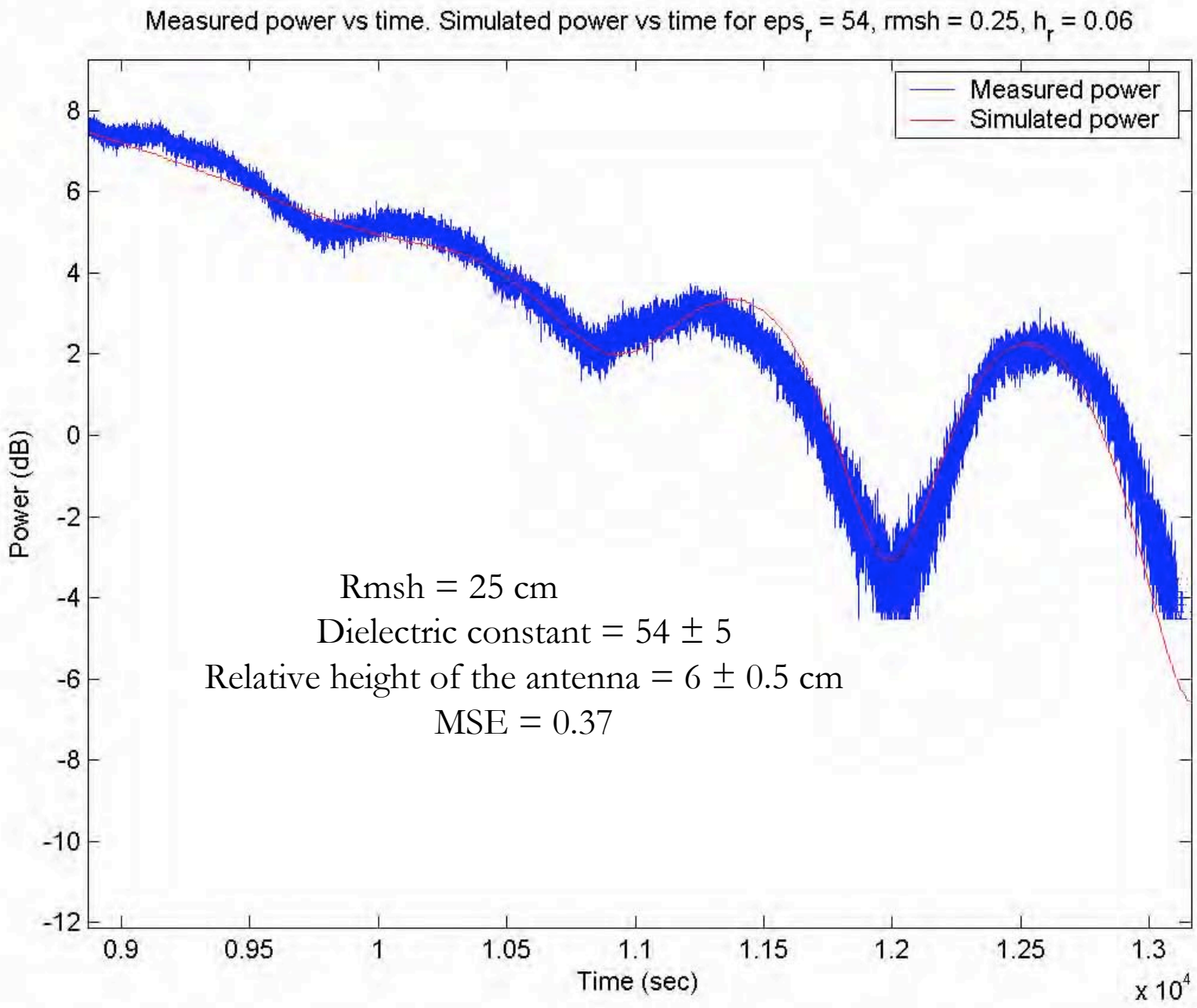
q=f(ε,elevation)

Frame loss mechanism



ESA Huygens Mission Team: HMT



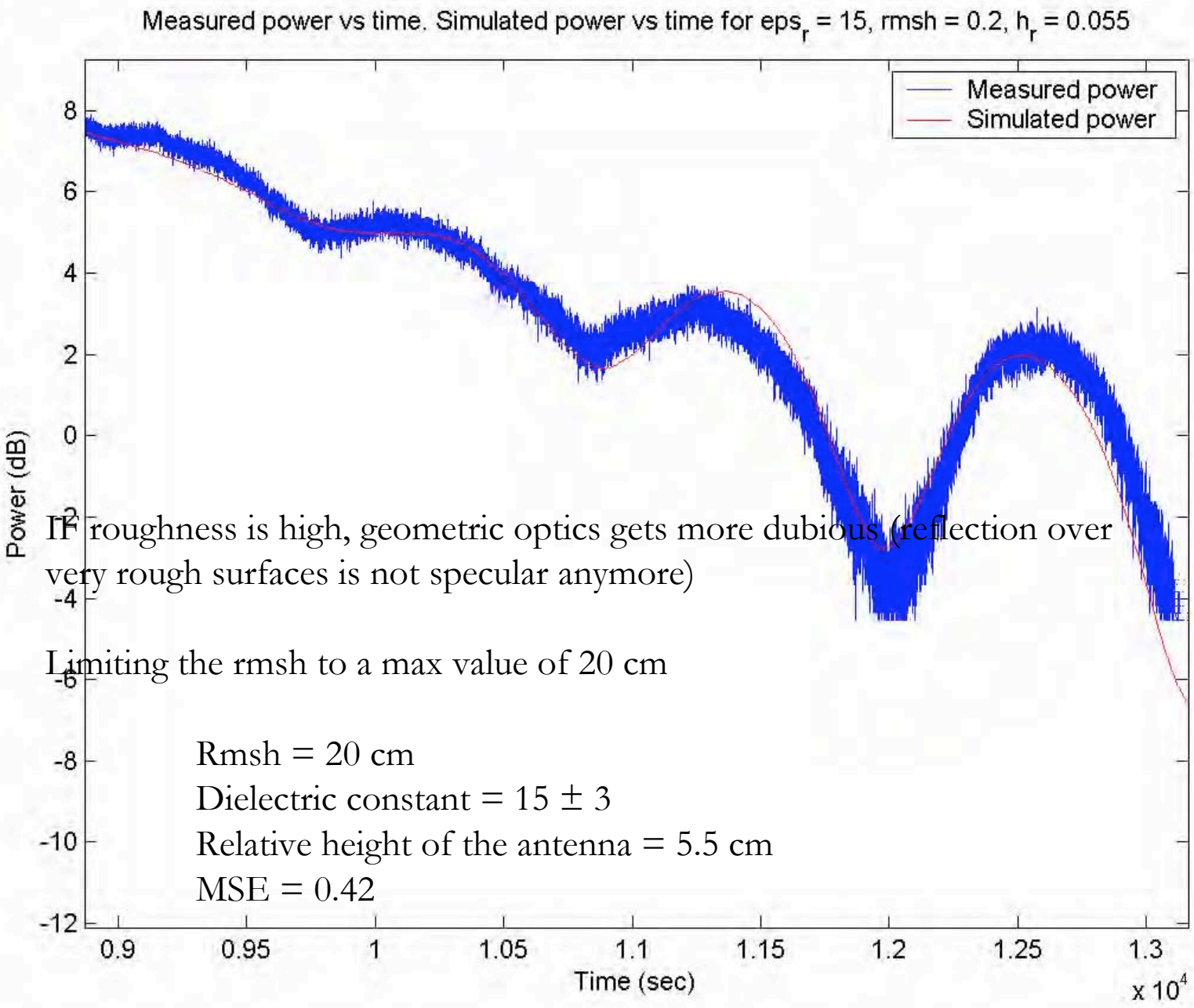


Rmsh = 25 cm

Dielectric constant = 54 ± 5

Relative height of the antenna = 6 ± 0.5 cm

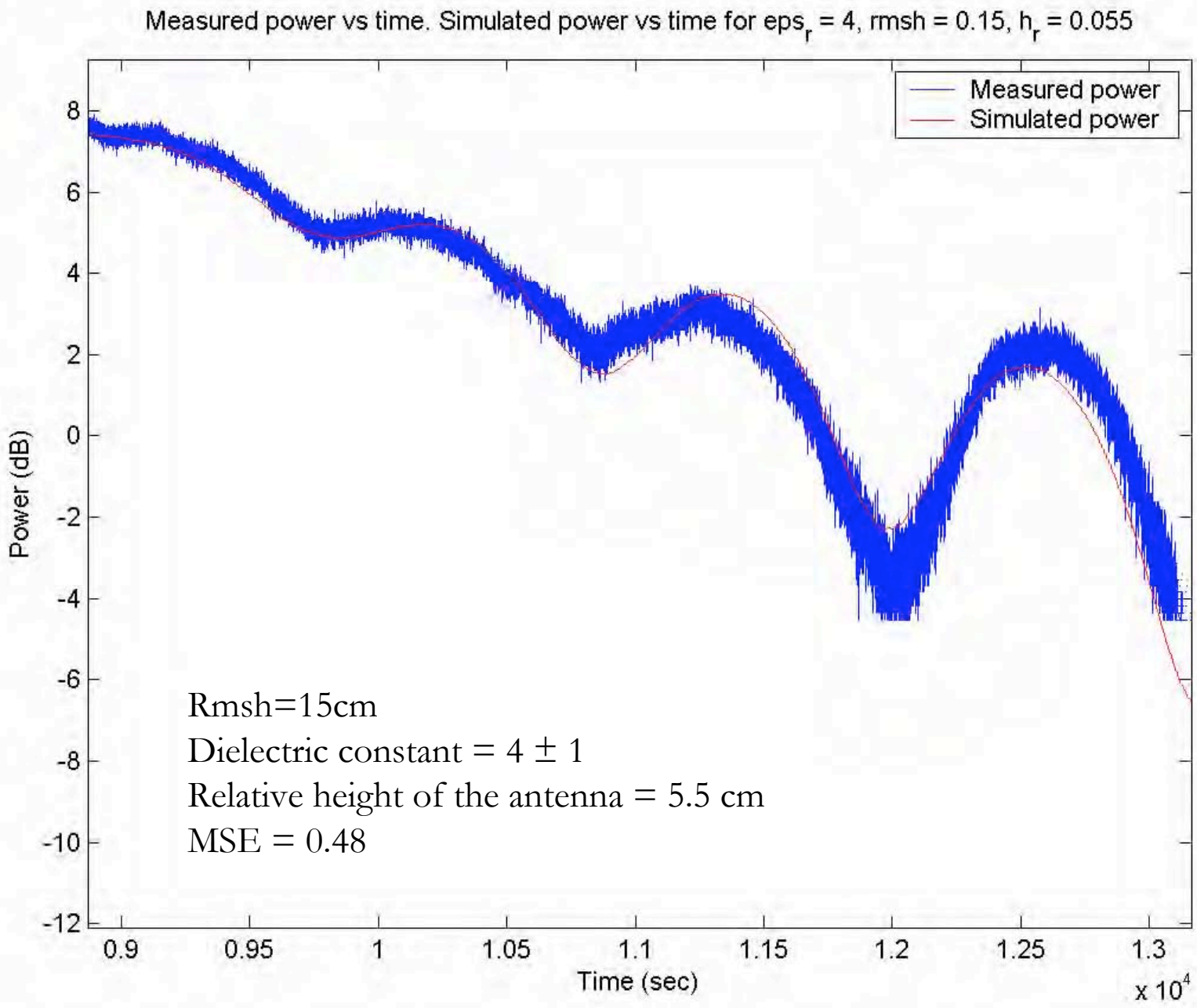
MSE = 0.37



IF roughness is high, geometric optics gets more dubious (reflection over very rough surfaces is not specular anymore)

Limiting the rmsh to a max value of 20 cm

Rmsh = 20 cm
Dielectric constant = 15 ± 3
Relative height of the antenna = 5.5 cm
MSE = 0.42

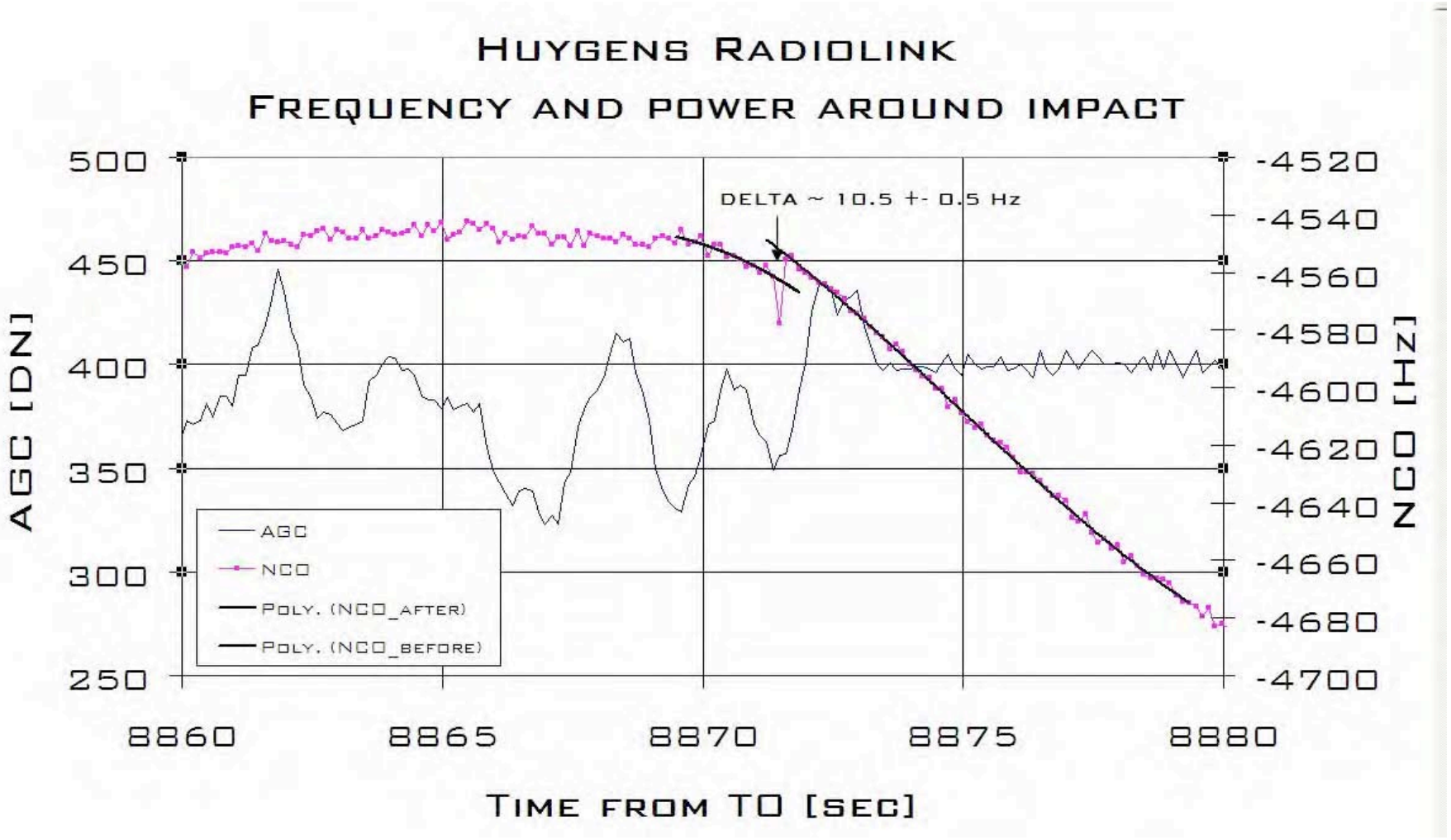


Rmsh=15cm

Dielectric constant = 4 ± 1

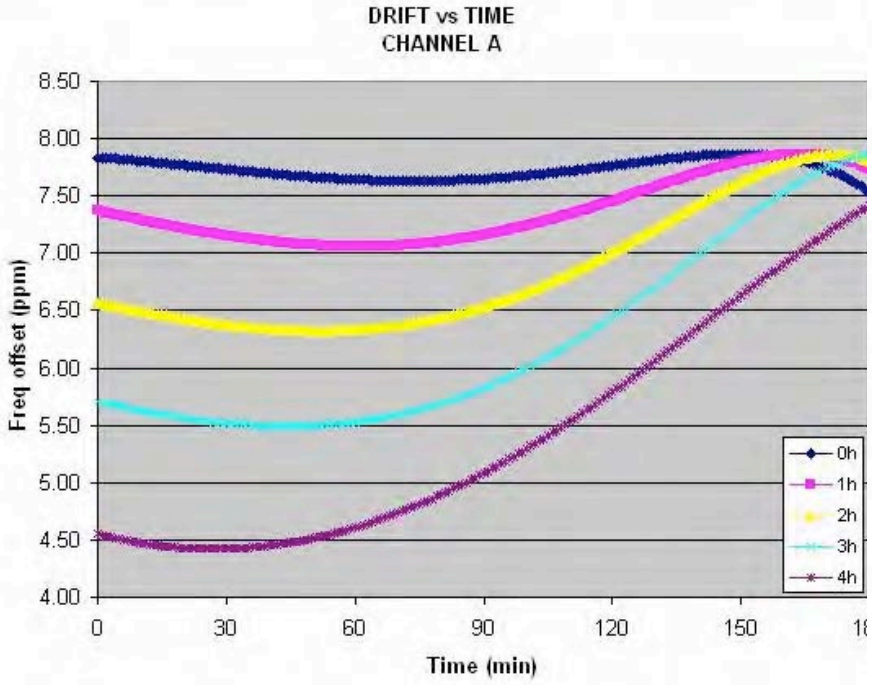
Relative height of the antenna = 5.5 cm

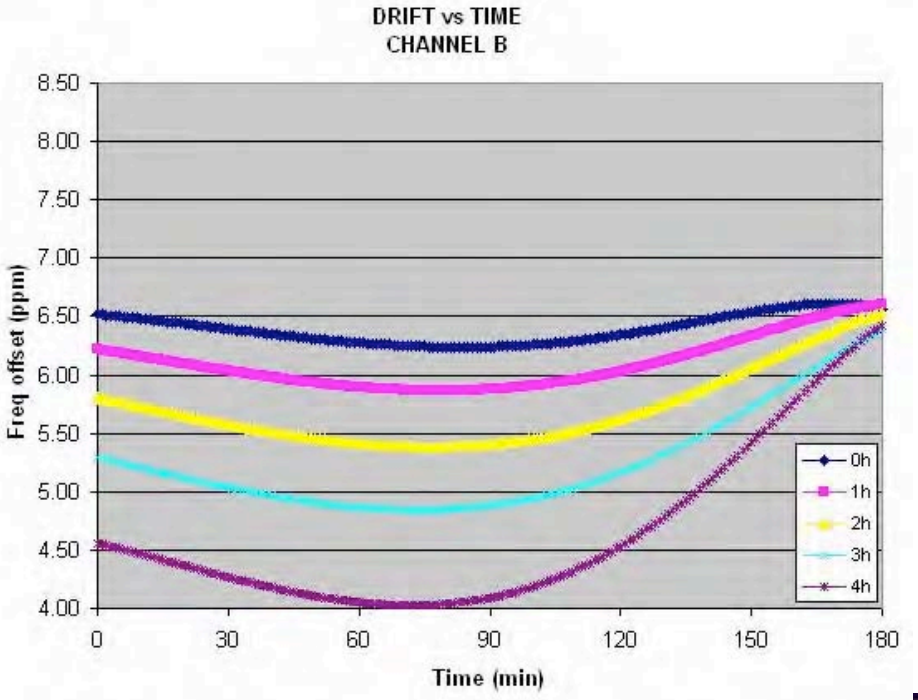
MSE = 0.48


HUYGENS RADIOLINK
FREQUENCY AND POWER AROUND IMPACT
DELTA ~ 10.5 +- 0.5 Hz
AGC
NCO
POLY. (NCO_AFTER)
POLY. (NCO_BEFORE)
AGC [DN]
NCO [HZ]
TIME FROM TO [SEC]
500
450
400
350
300
250
-4520
-4540
-4560
-4580
-4600
-4620
-4640
-4660
-4680
-4700
8860
8865
8870
8875
8880

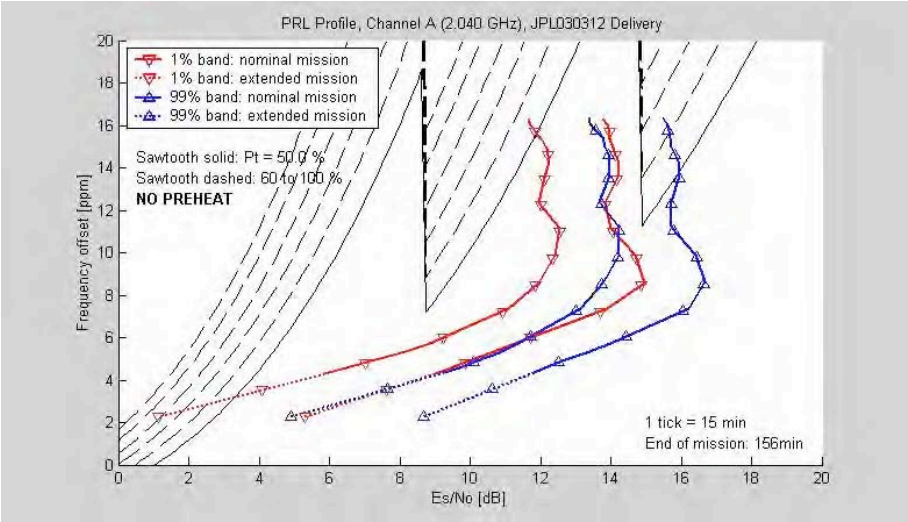
PRE-HEATING 4 hours:

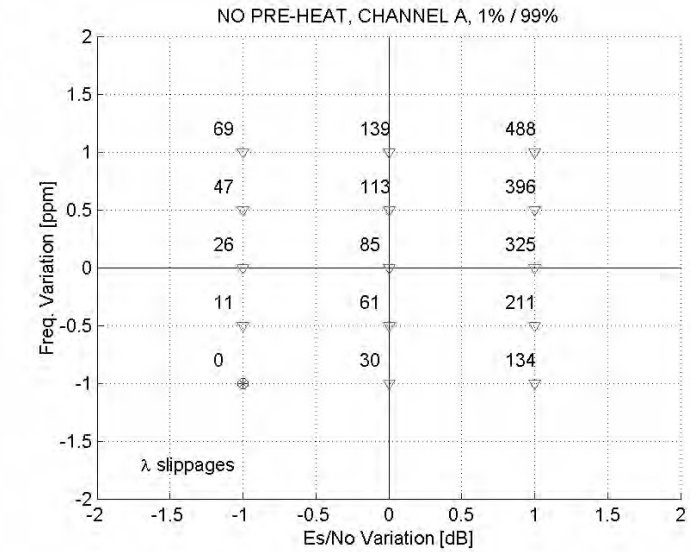
Warm-up the quartz oscillator generating the frequency for the transmitted data frequency, to shift it and compensate the Doppler

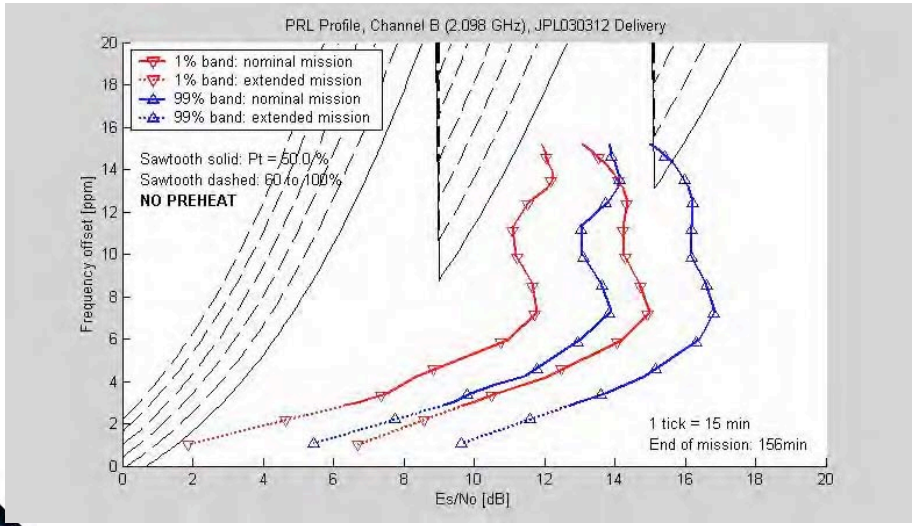


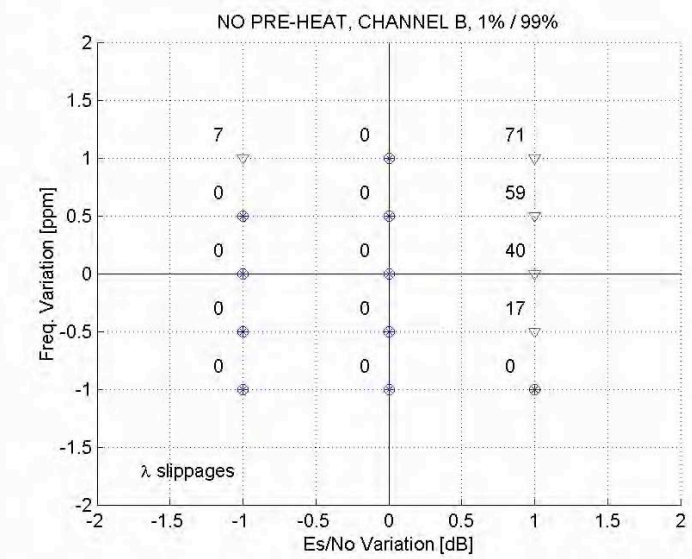


Robustness: NO PRE-HEAT

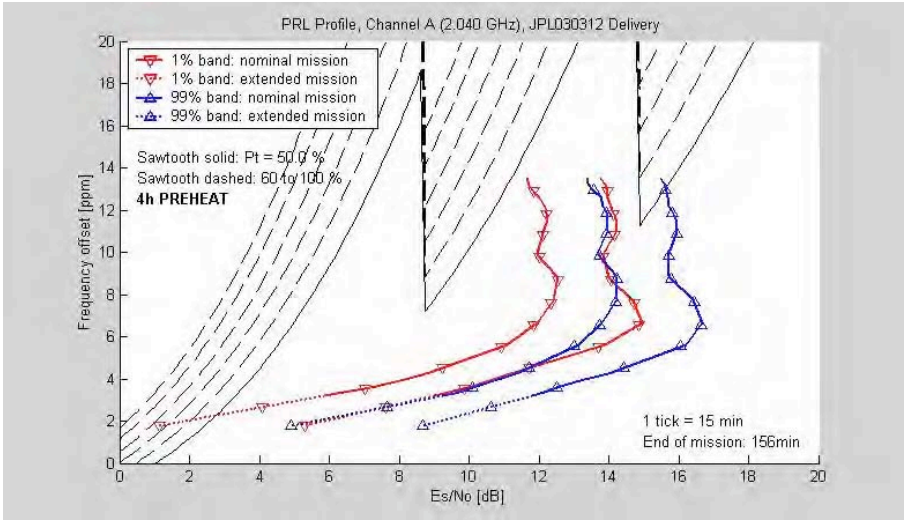


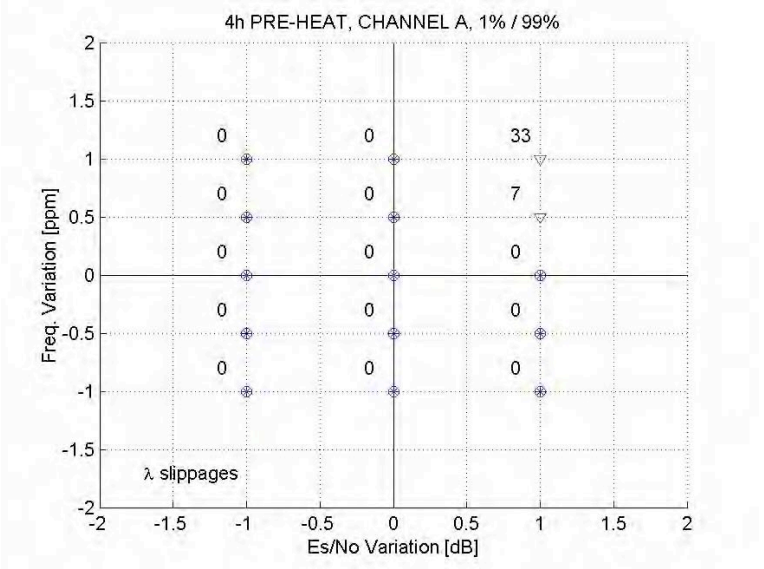


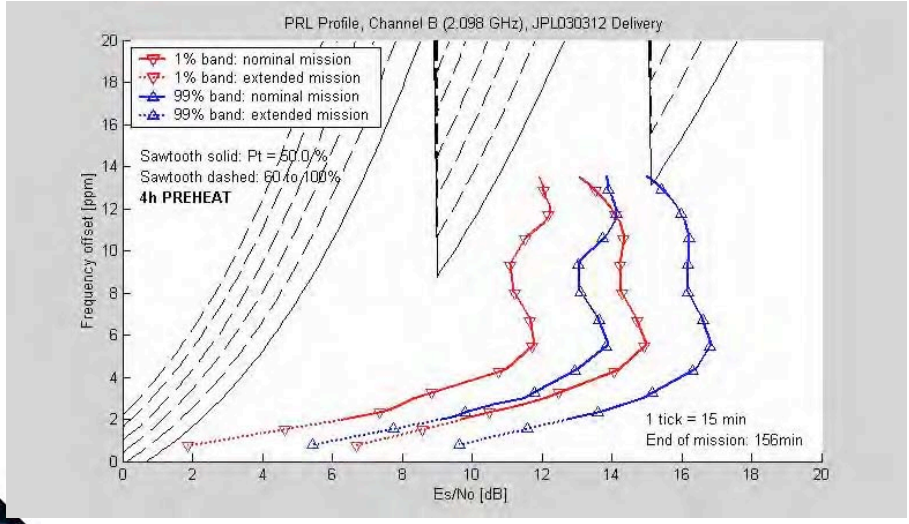


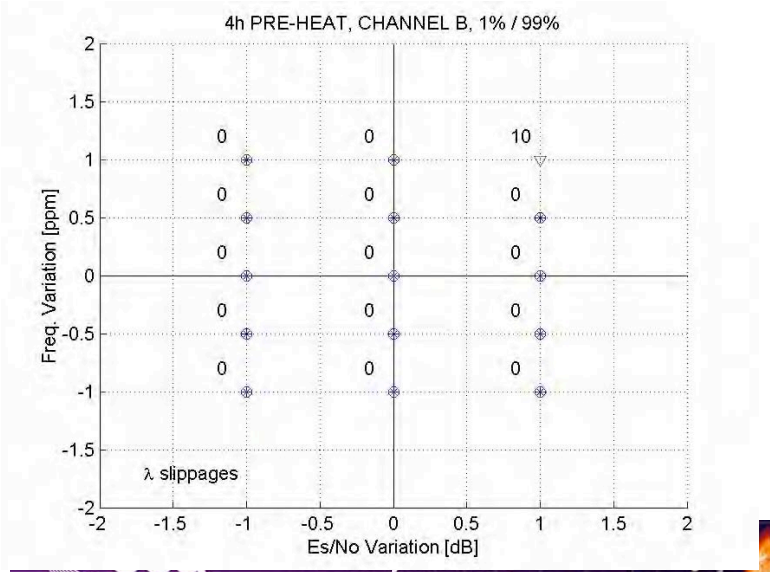


Robustness: 4h PRE-HEAT (implemented option)

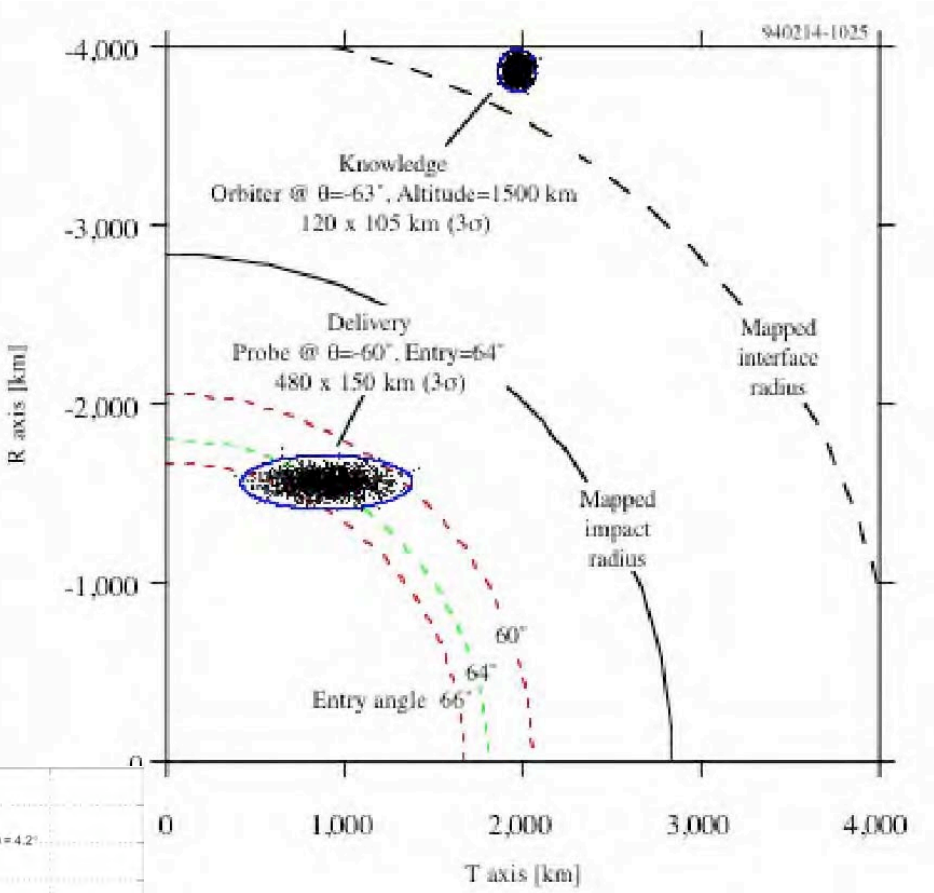


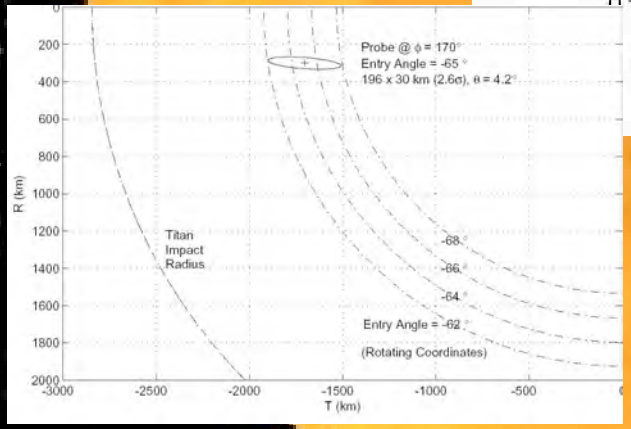






TARGETING



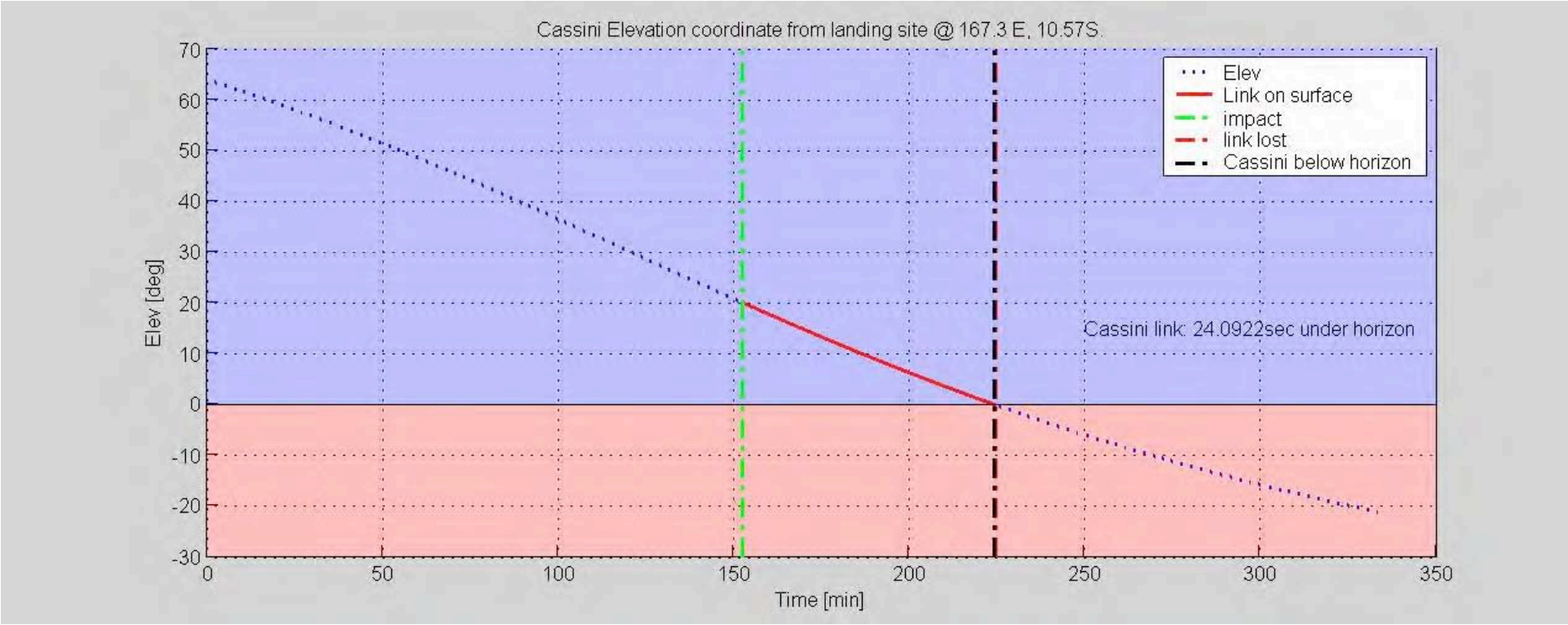


NUEVA GEOMETRIA

VIEJA GEOMETRIA

END OF LINK: Cassini ELEV vs TIME

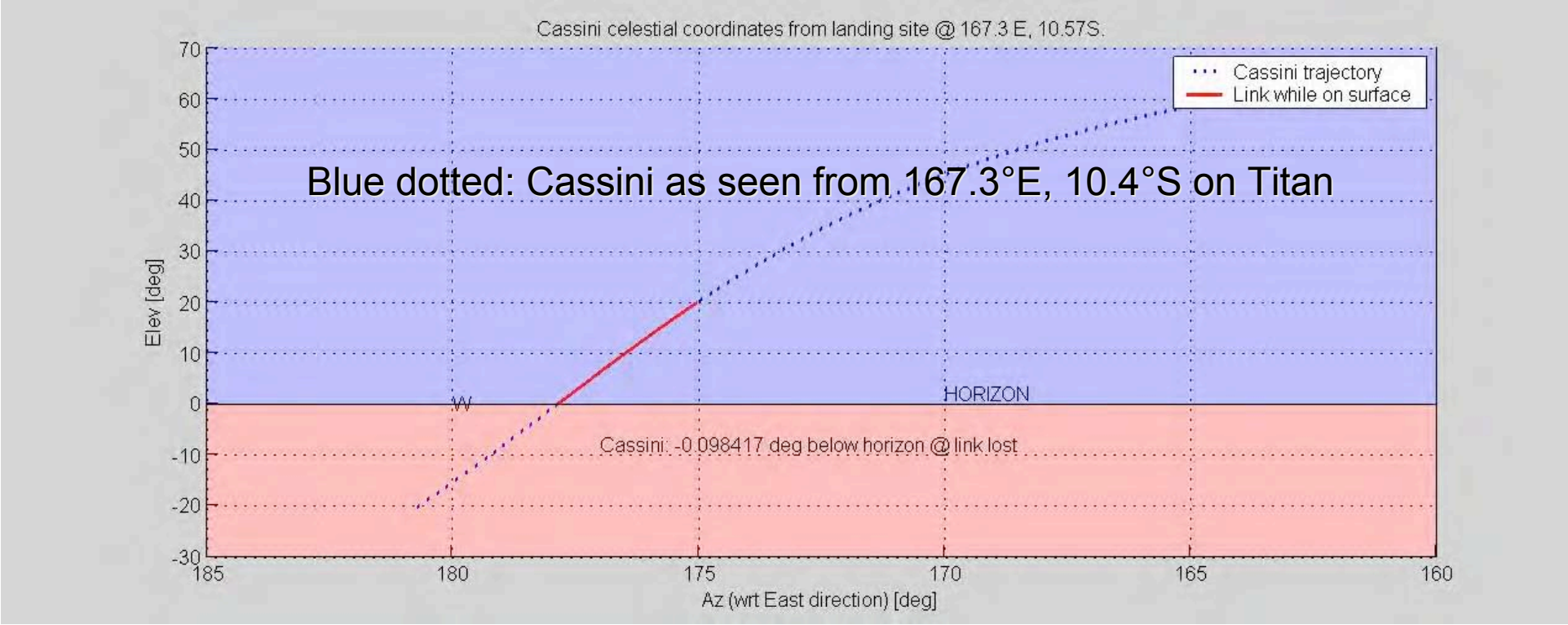
- Cassini very close to disappear under the horizon at the time of loss of link (**24 seconds**) !!



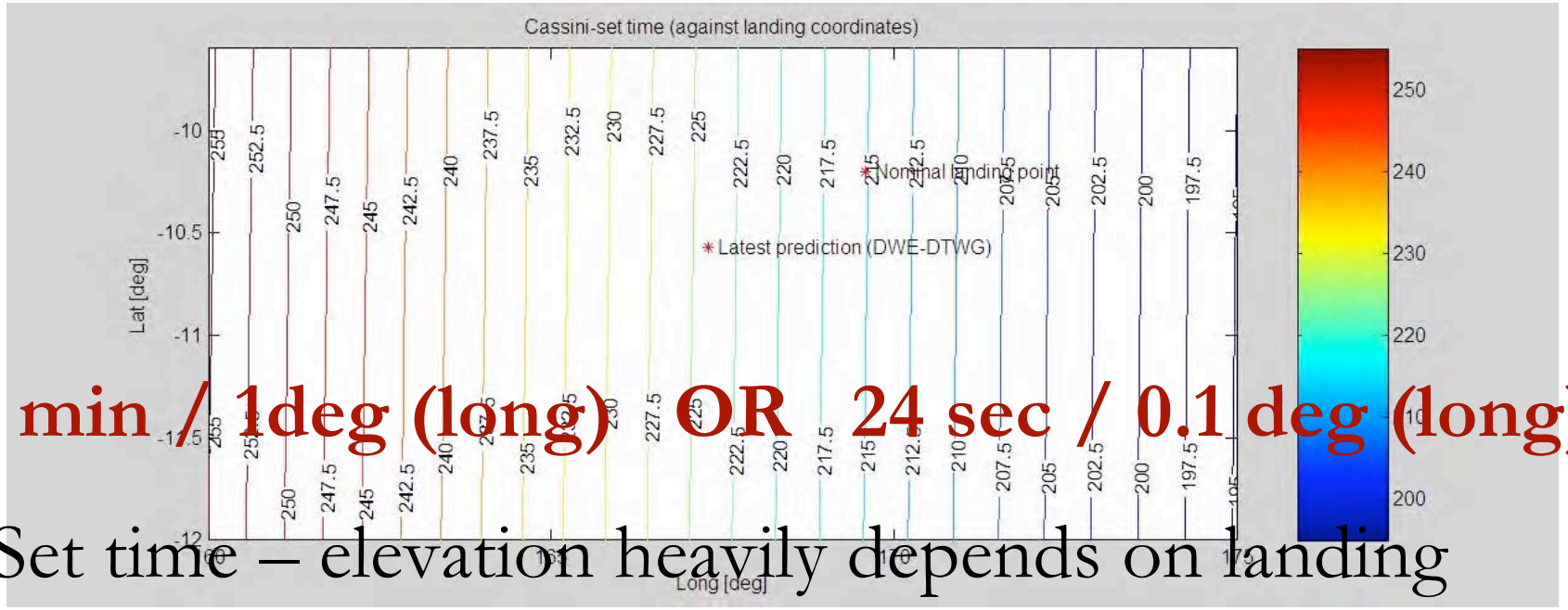
Blue dotted: Cassini ELEV as seen from 167.3° -10.4° on Titan
RED: Link ON SURFACE

END OF LINK: CASSINI AZ-ELEV FROM LANDING SITE

Heavily depending on landing coordinates
Waiting for update of HUYGENS landing site

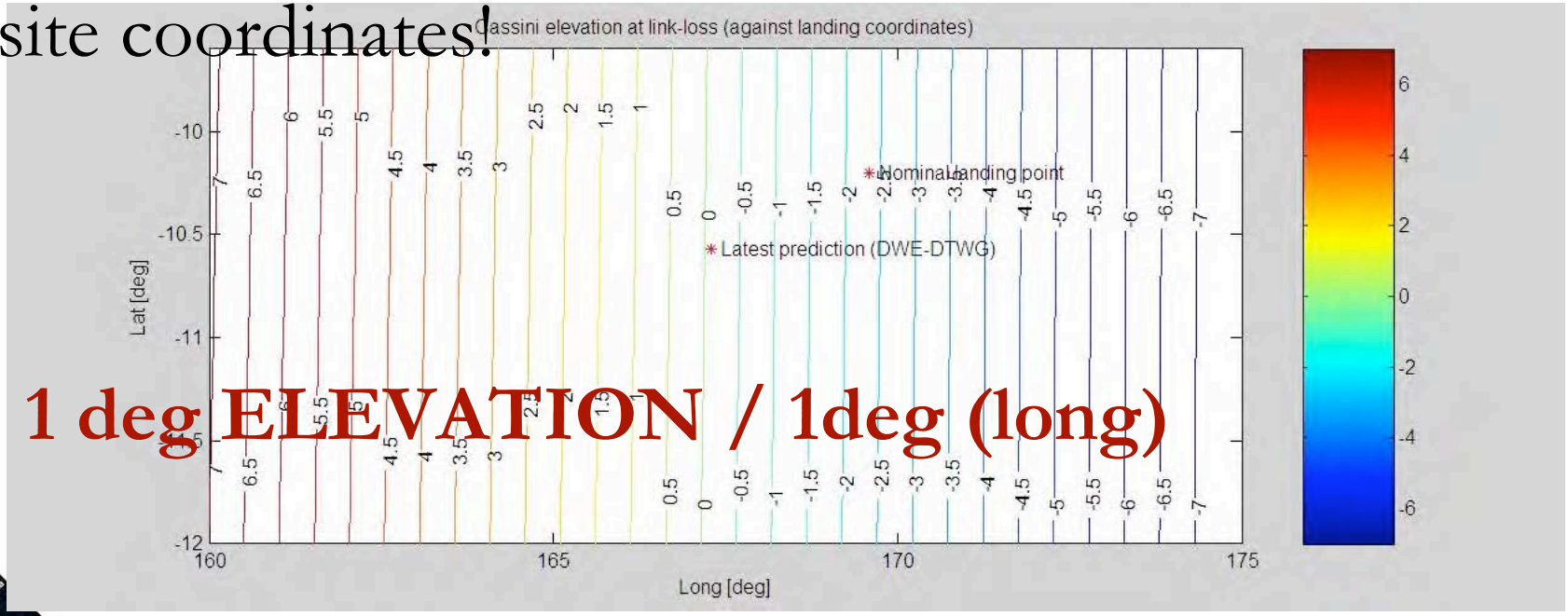


Grazing bending of ray ~ 1deg max
Defocussing loss ~ 10%

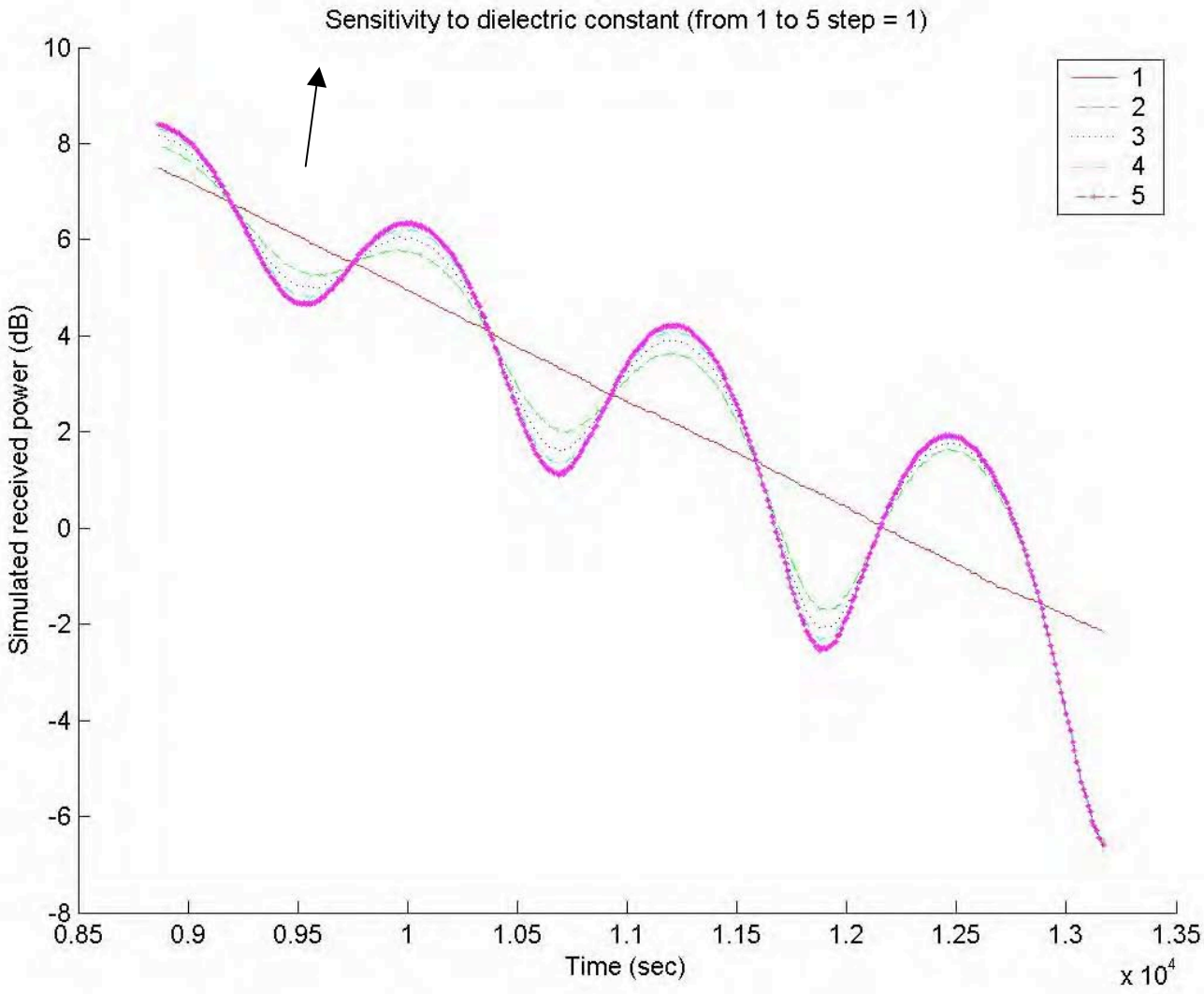


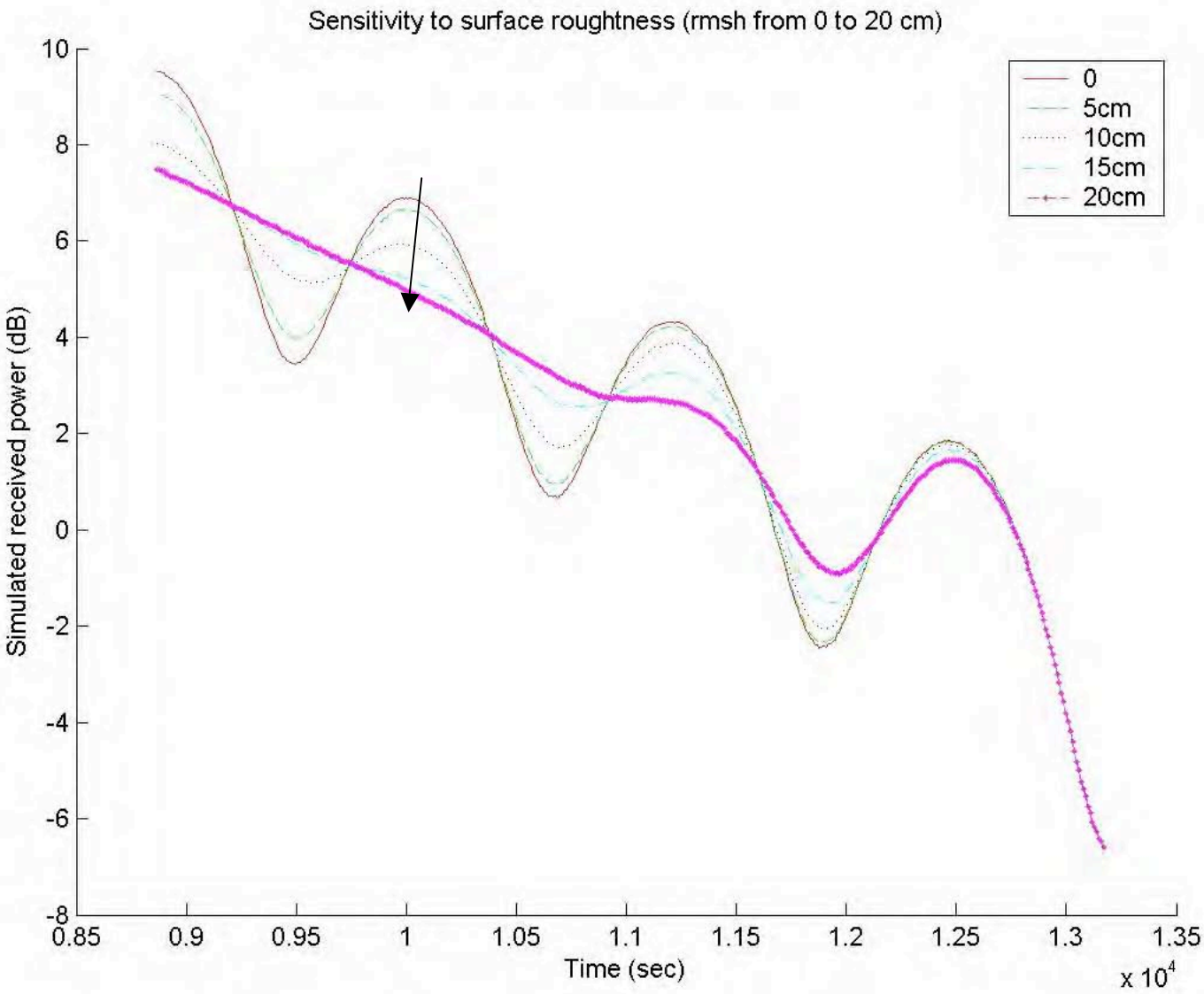
4 min / 1deg (long) OR 24 sec / 0.1 deg (long)

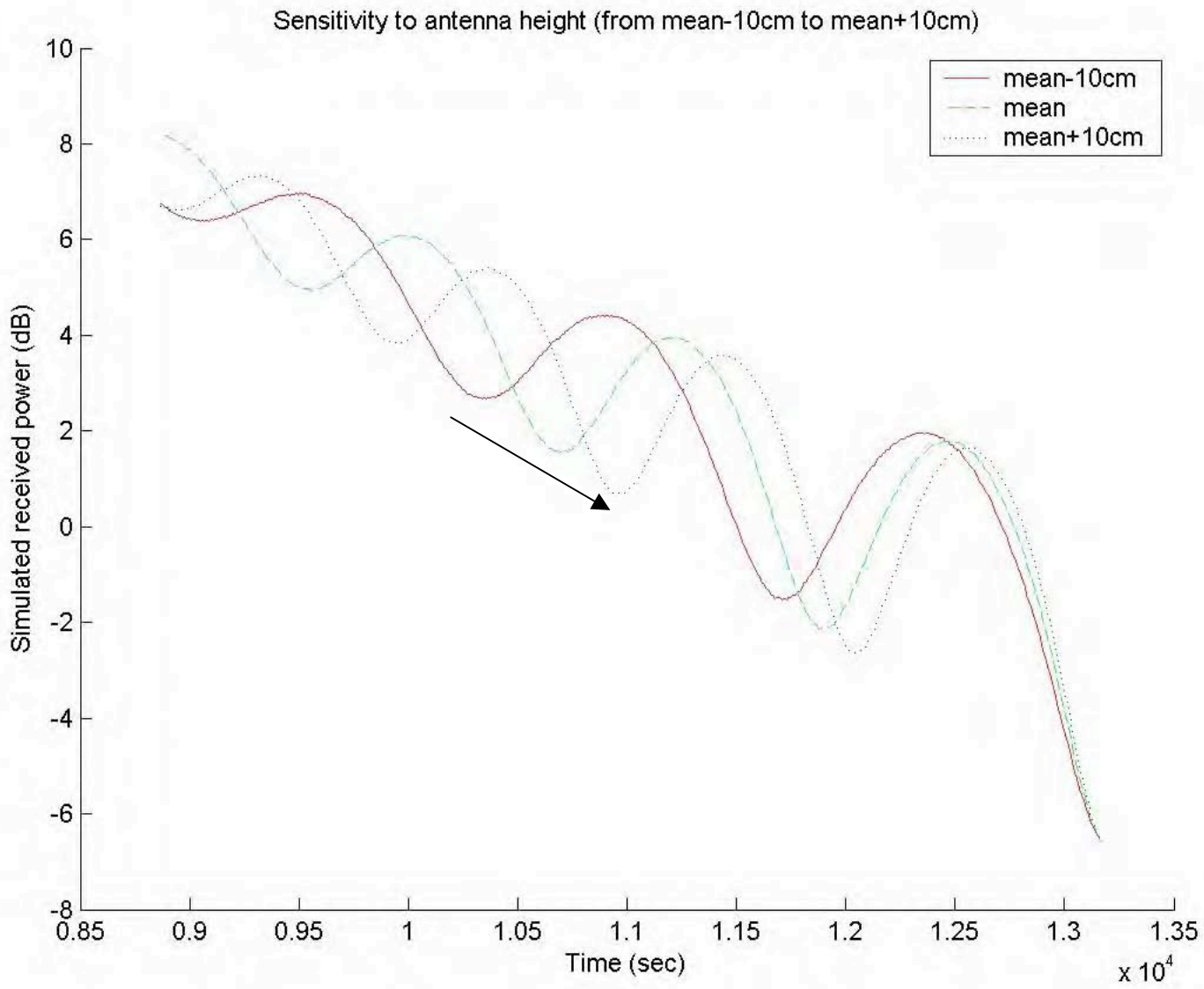
Set time – elevation heavily depends on landing site coordinates!



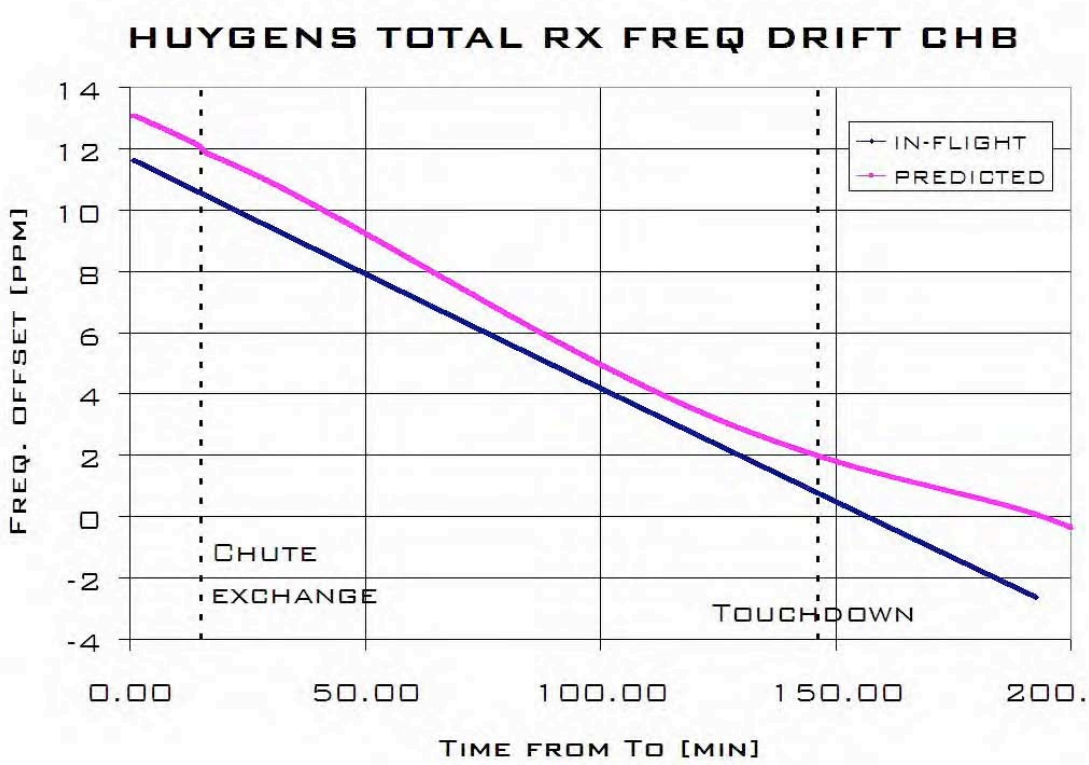
1 deg ELEVATION / 1deg (long)

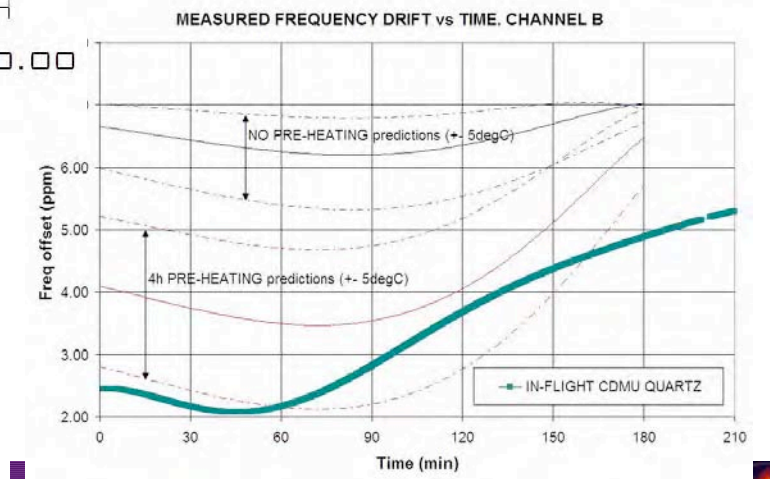

Sensitivity to dielectric constant (from 1 to 5 step = 1)
Simulated received power (dB)
Time (sec)
x 10^4
1
2
3
4
5
10
8
6
4
2
0
-2
-4
-6
-8
0.85
0.9
0.95
1
1.05
1.1
1.15
1.2
1.25
1.3
1.35


Sensitivity to surface roughtness (rmsh from 0 to 20 cm)
0
5cm
10cm
15cm
20cm
Simulated received power (dB)
10
8
6
4
2
0
-2
-4
-6
-8
0.85
0.9
0.95
1
1.05
1.1
1.15
1.2
1.25
1.3
1.35
Time (sec)
x 10^4

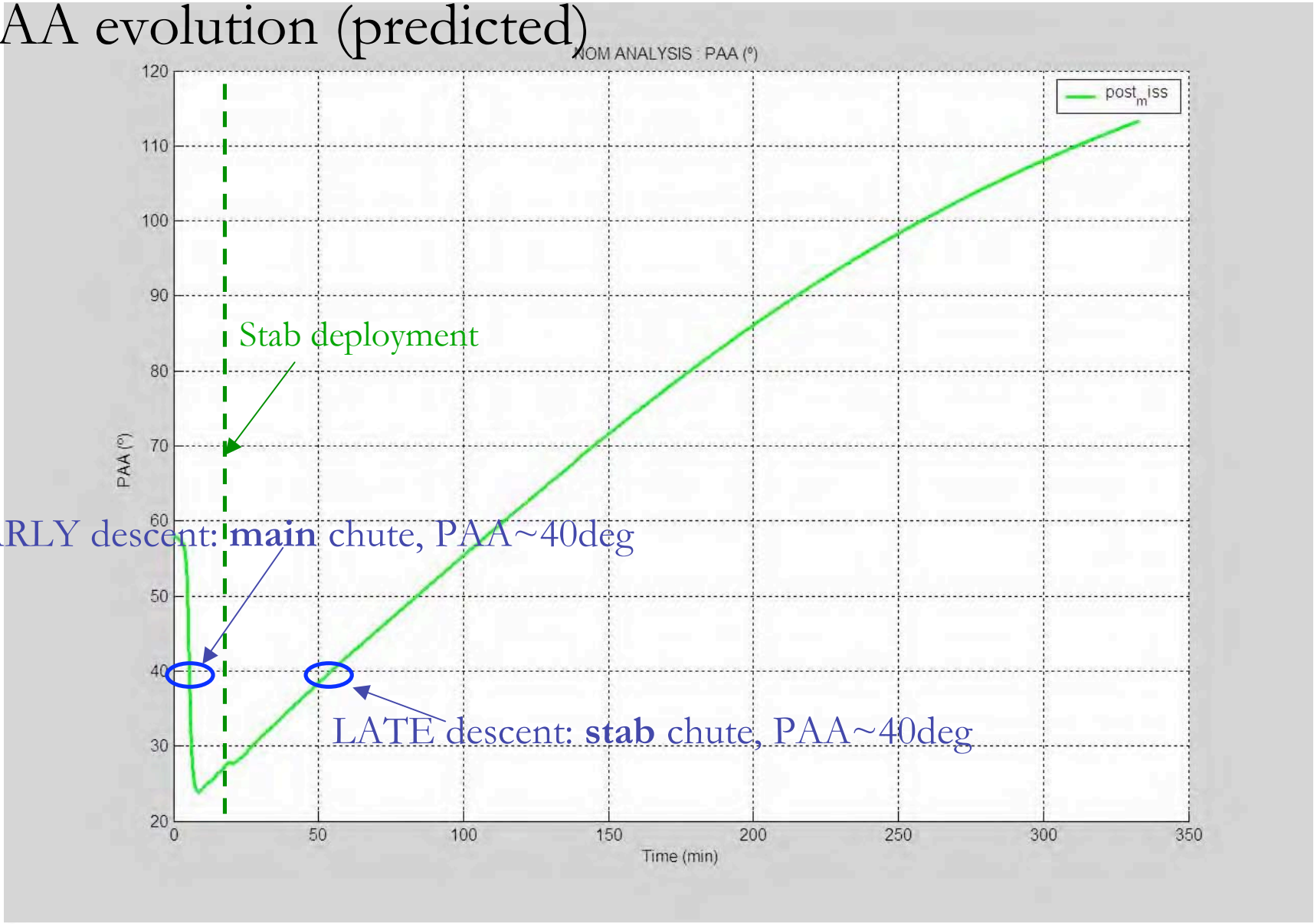

Sensitivity to antenna height (from mean-10cm to mean+10cm)
mean-10cm
mean
mean+10cm
Simulated received power (dB)
10
8
6
4
2
0
-2
-4
-6
-8
0.85
0.9
0.95
1
1.05
1.1
1.15
1.2
1.25
1.3
1.35
Time (sec)
x 10^4

The reconstructed received frequency profile





PAA evolution (predicted)

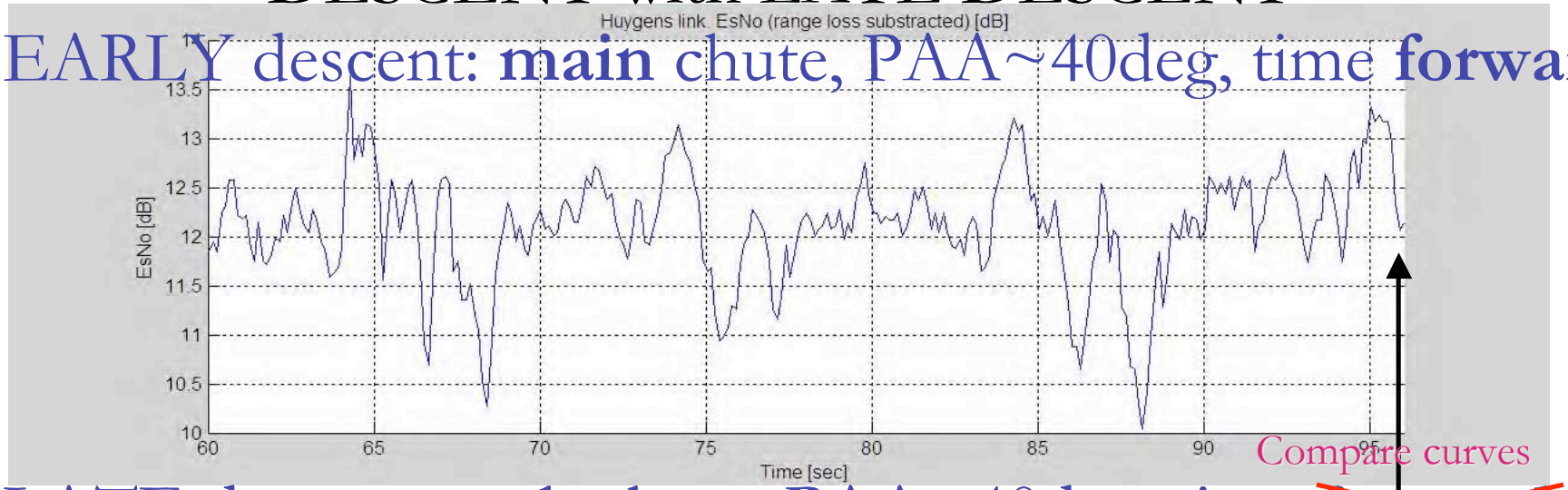


EARLY descent: **main** chute, PAA~40deg

LATE descent: **stab** chute, PAA~40deg

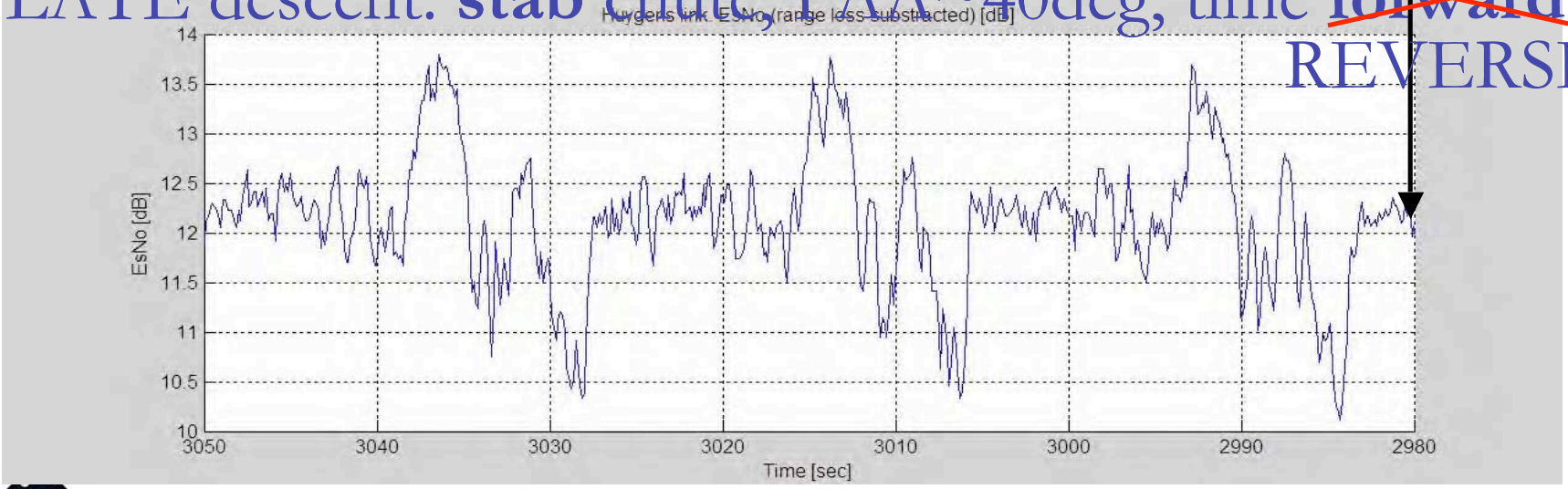
SPIN REVERSAL – MATCHING EARLY DESCENT with LATE DESCENT

EARLY descent: **main** chute, PAA~40deg, time **forward**



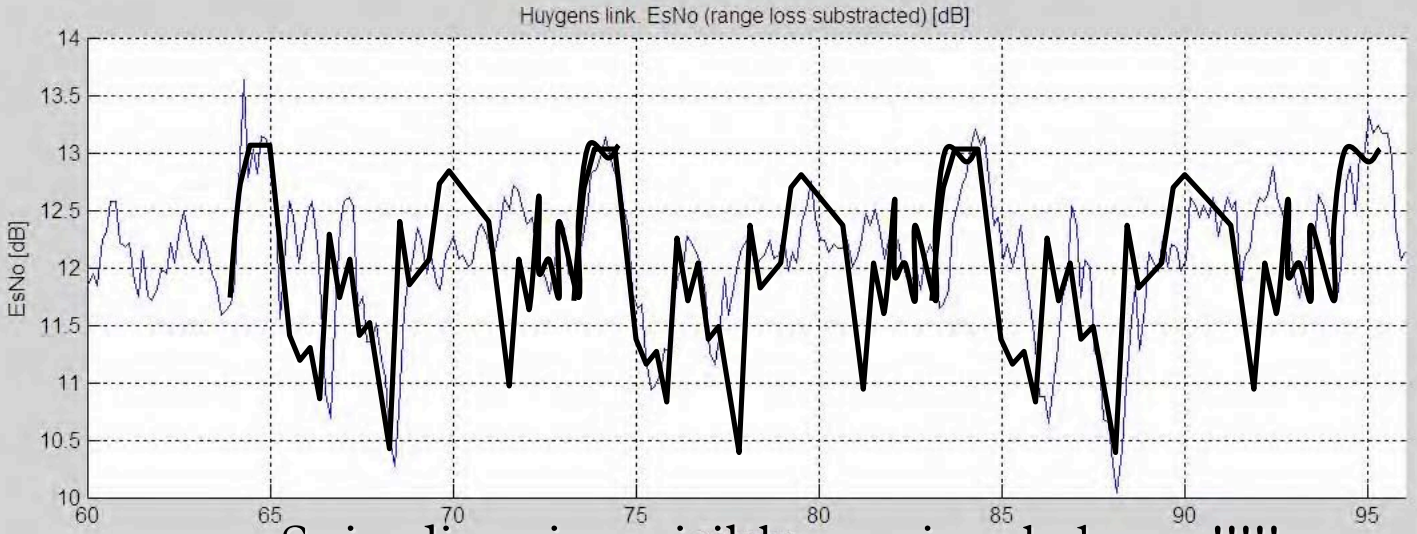
Compare curves

LATE descent: **stab** chute, PAA~40deg, time ~~**forward**~~ REVERSED



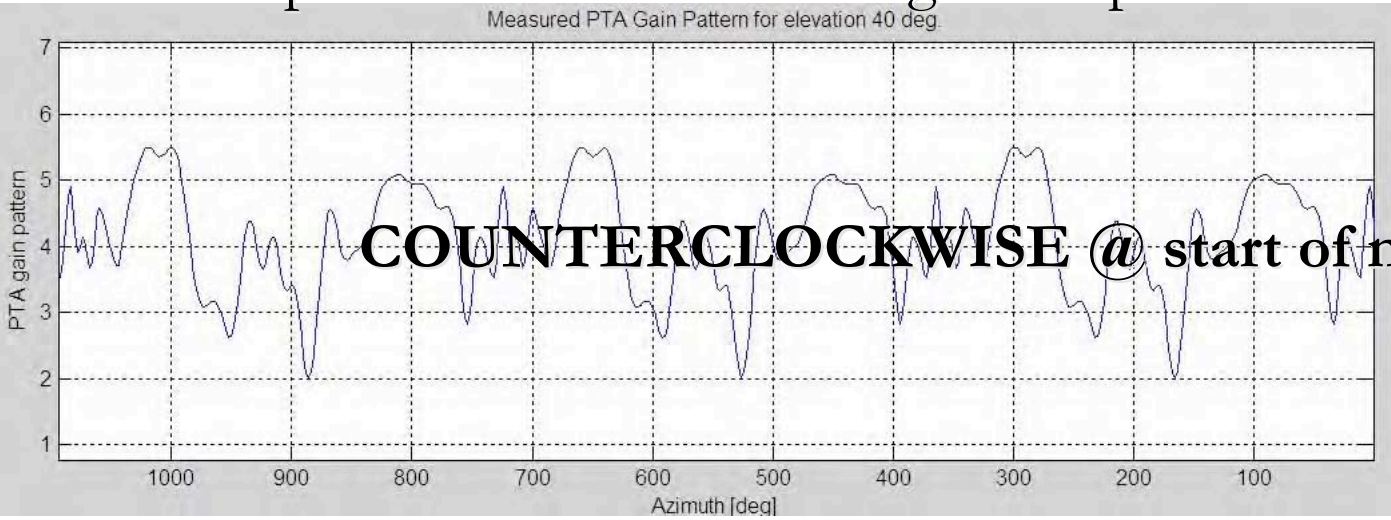
SPIN REVERSAL – MATCHING THE TESTED PTA PATTERNS

Link mission



Spin direction visible on signal shape !!!!!

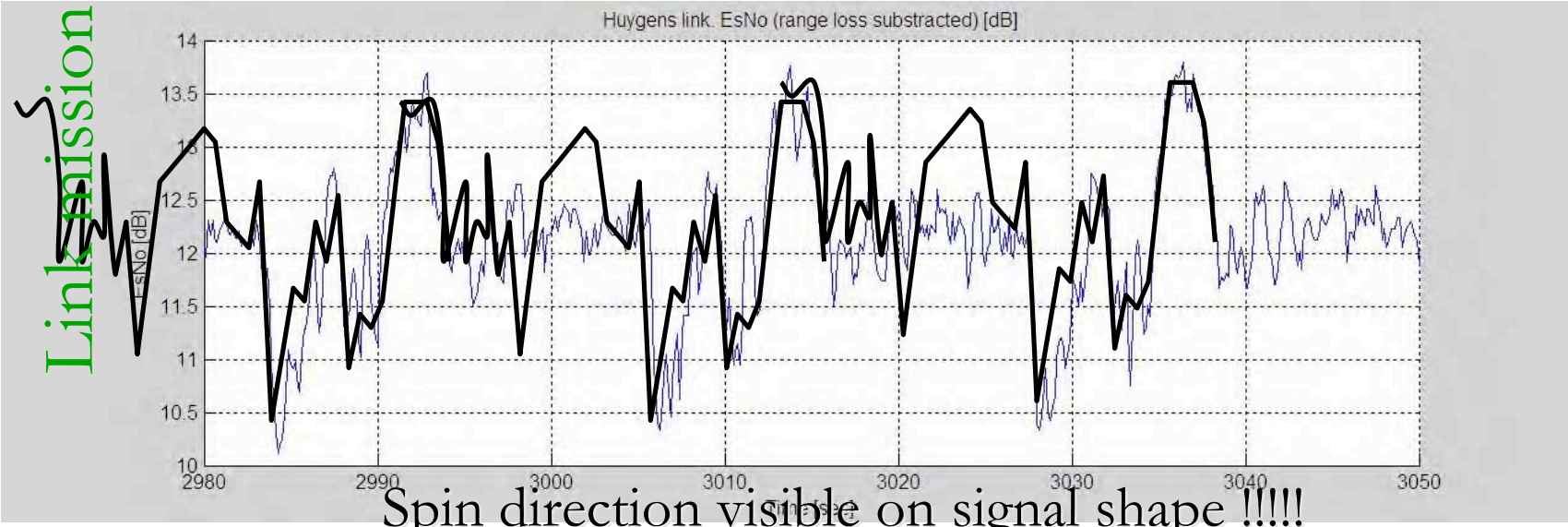
PTA tested



COUNTERCLOCKWISE @ start of mission

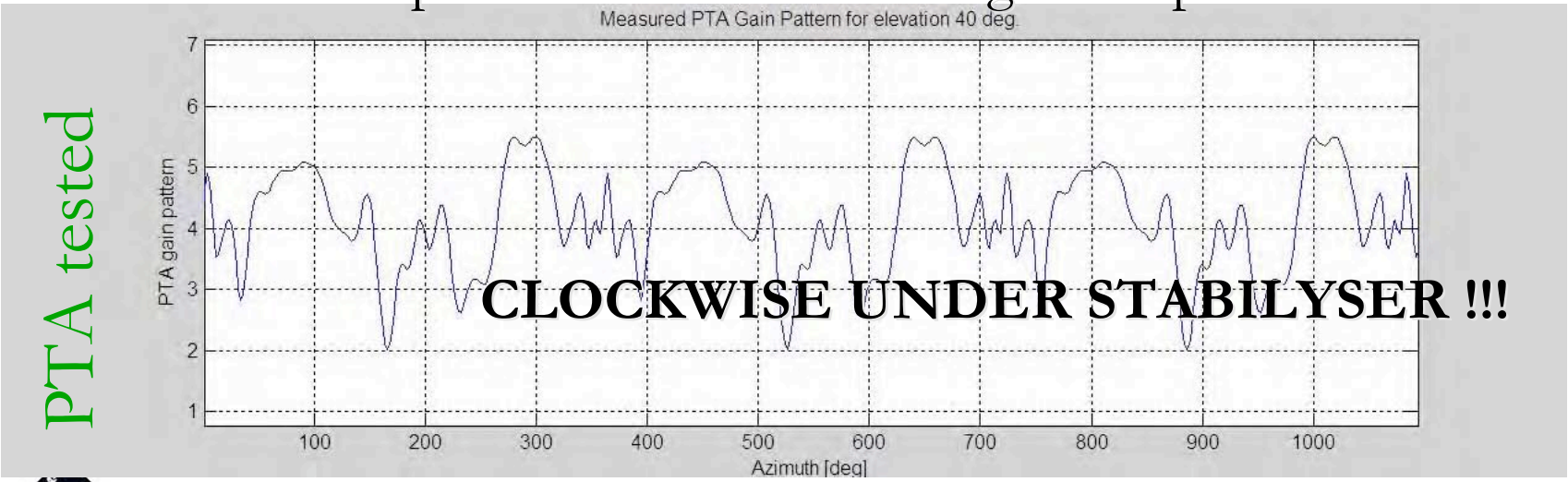
SPIN REVERSAL – MATCHING THE TESTED PTA PATTERNS

Link mission



Spin direction visible on signal shape !!!!!

PTA tested



CLOCKWISE UNDER STABILYSER !!!

Oscillation not explained by 'SCANNING of the PTA pattern' (due to azimuth-elevation variation of orbiter position):

- too fast in time
- too large in power variation