VLBI observation biases induced by antenna gravitational flexures

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The early "warnings"

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Comparison of Geodetic and Radio Interferometric Measurements of the Haystack-Westford Base Line Vector

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A three-dimensional geodetic measurement of the 1.24-km Haystack-Westford base line vector was performed to verify the accuracy of previously published radio interferometric measurements. The differences between the geodetic and the very long base line interferometry (VLBI) measurements of the base line length, the horizontal X and Y components, and the vertical Z component were −4, 2, 4, and −19 mm, respectively. After a correction was applied to the VLBI determination of the vertical component to

TABLE 1. Results From Geodetic Measurements of Haystack-Westford Base Line Vector

Base Line Characteristic*	Value,† m
X component	−1149.592 ± 0.002
Y component	−462.196 ± 0.003
Z component	−30.024 ± 0.003
Length	1239.390 ± 0.001

TABLE 2. Results From VLBI Measurements of Haystack-Westford Base Line Vector

Base Line Characteristic*	Mean of 11 Determinations,† m [*Rogers et al.*, 1978]	Twelfth Determination,‡ m (See Text)	Difference, §
X component	−1149.594 ± 0.003	−1149.597 ± 0.001	0.003
Y component	−462.200 ± 0.005	−462.196 ± 0.001	−0.004
Z component	−30.005 ± 0.007	−30.002 ± 0.003	−0.003
Length	1239.394 ± 0.003	1239.394 ± 0.001	0.000

TABLE 3. Comparison of the Geodetic and VLBI Measurements of the Haystack-Westford Base Line Vector

Base Line Characteristic*	Difference Between Geodetic Value and Mean VLBI Value, m	
	Uncorrected†	Partially Corrected‡
X component	0.002	0.002
Y component	0.004	0.004
Z component	−0.019	−0.006
Length	−0.004	−0.004

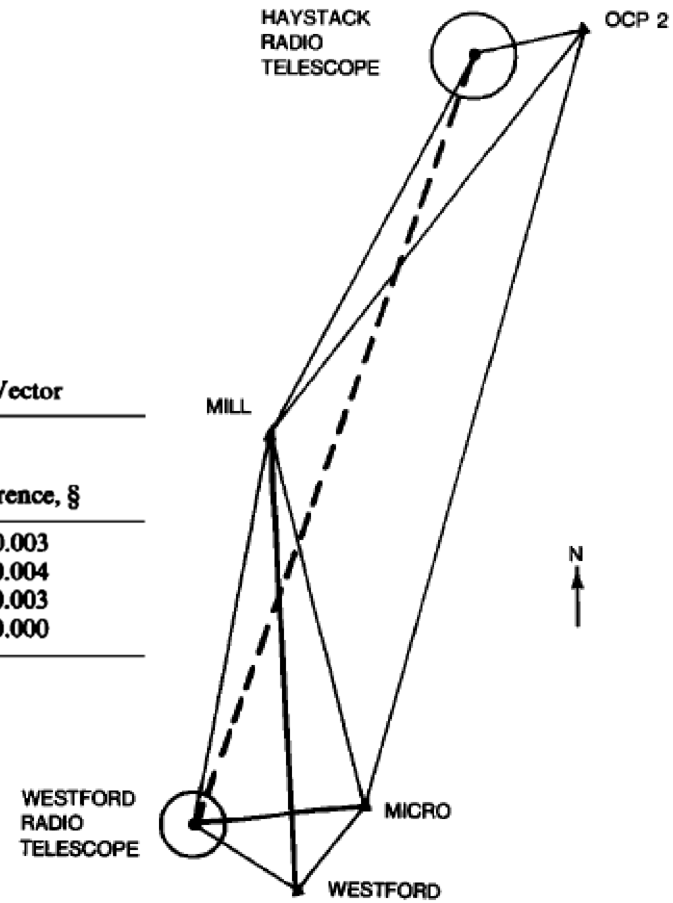

Fig. 3. Sketch of the geodetic network. The dashed line represents the 1.24-km Haystack-Westford base line vector.

Comparison of Geodetic and Radio Interferometric Measurements of the Haystack-Westford Base Line Vector

NASA Technical Memorandum 100696

Deformations in VLBI Antennas

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and

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Vienna, Virginia

NASA
National Aeronautics and
Space Administration

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Greenbelt, Maryland 20771

1988

Signal path variation (SPV)

(Clark & Thomsen, 1988)

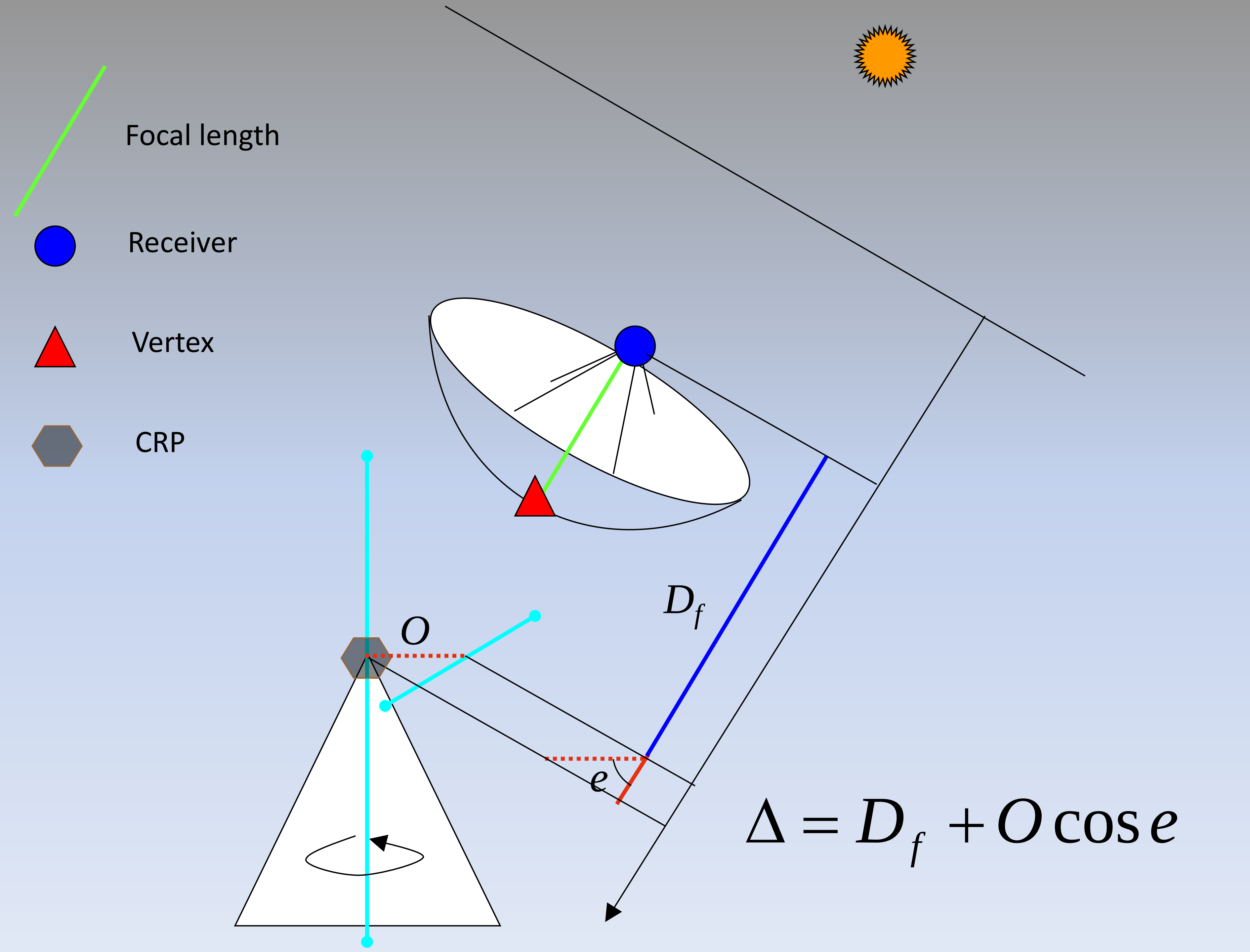
$$\Delta L(e) = \alpha_R \Delta R(e) + \alpha_F \Delta F(e) + \alpha_V \Delta V(e)$$

- Originated by gravity-induced flexure of radio telescopes
  - It is a linear combination of three contributing terms:
    - Displacement of the receiver along the line of sight
    - Deformation of the primary reflector
    - Displacement of the reflecting system along the line of sight
  - *SPV depends on the pointing elevation!*

Clark & Thomsen (1988)

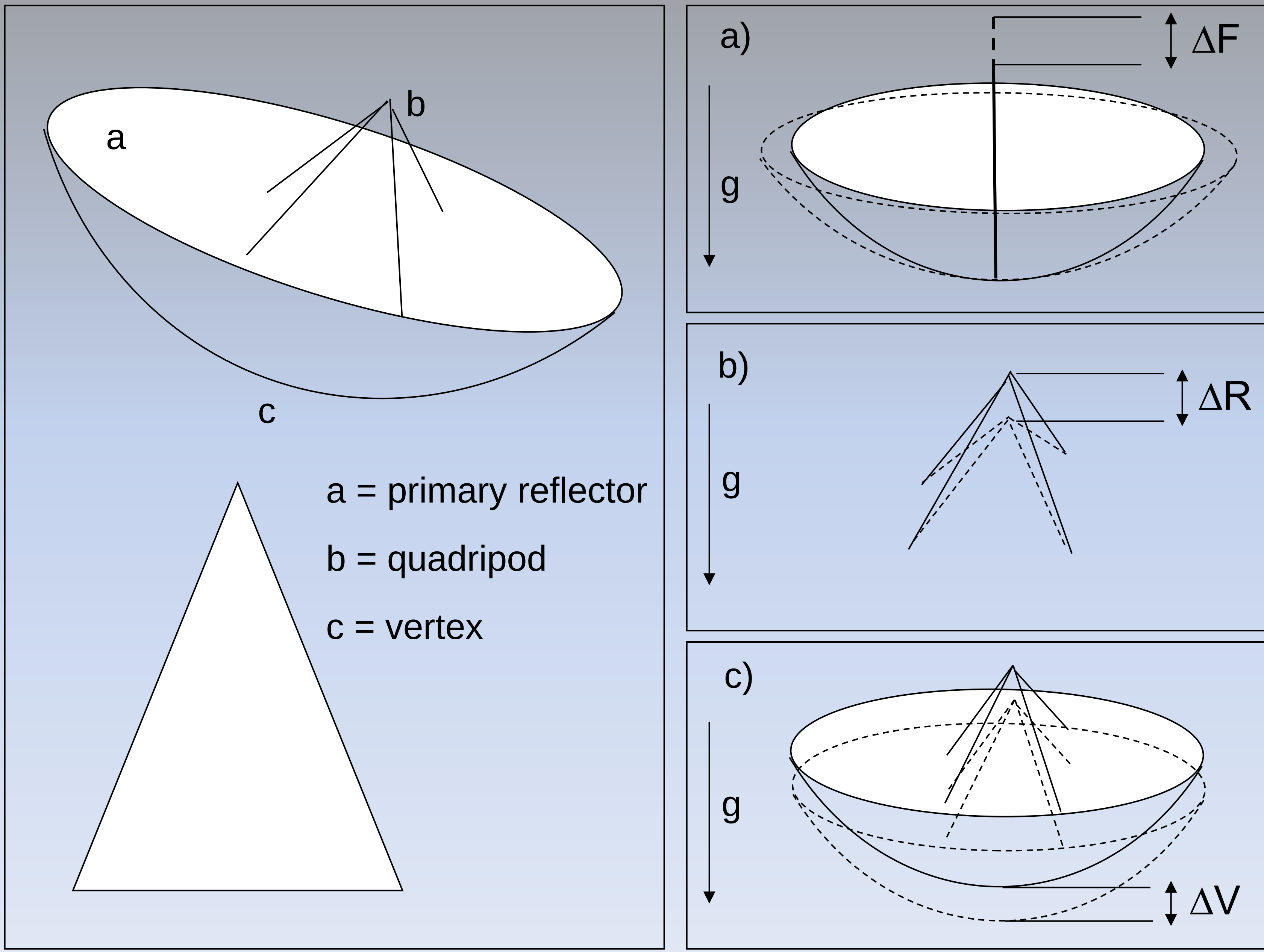
- Focused on the Fairbanks antenna (Alaska):
  - 26 m dish
  - X-Y mount
  - S/X receiver in primary focus position
- Used a Finite Element Model of the antenna
- The coefficients α_i were determined assuming a uniform grading on the primary reflector
- The resulting $\Delta L(e) \approx 0$ at all elevations!

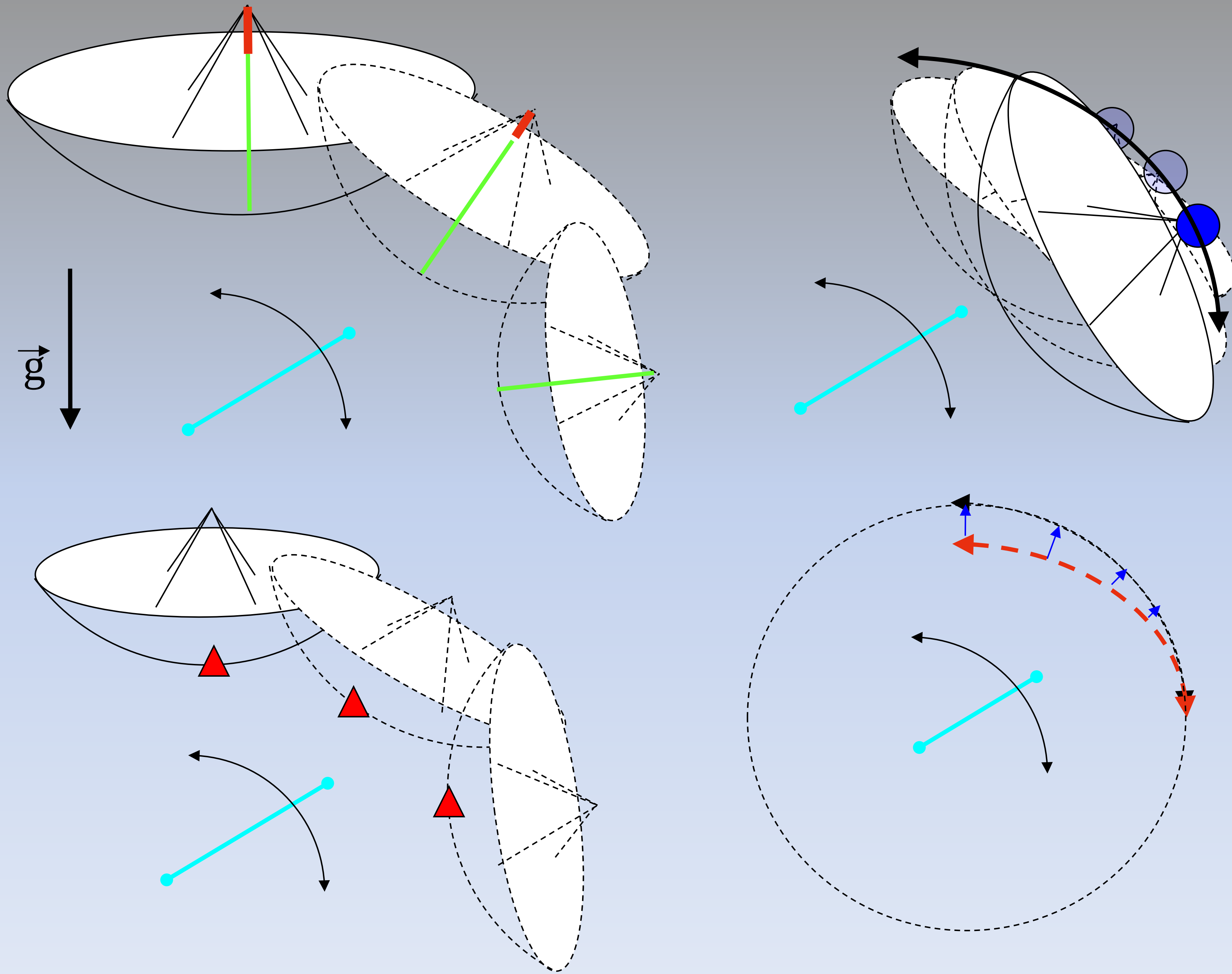
How do gravitational flexures impact VLBI observations?



$$\Delta = D_f + O\cos e$$

How does gravity deform the telescope?

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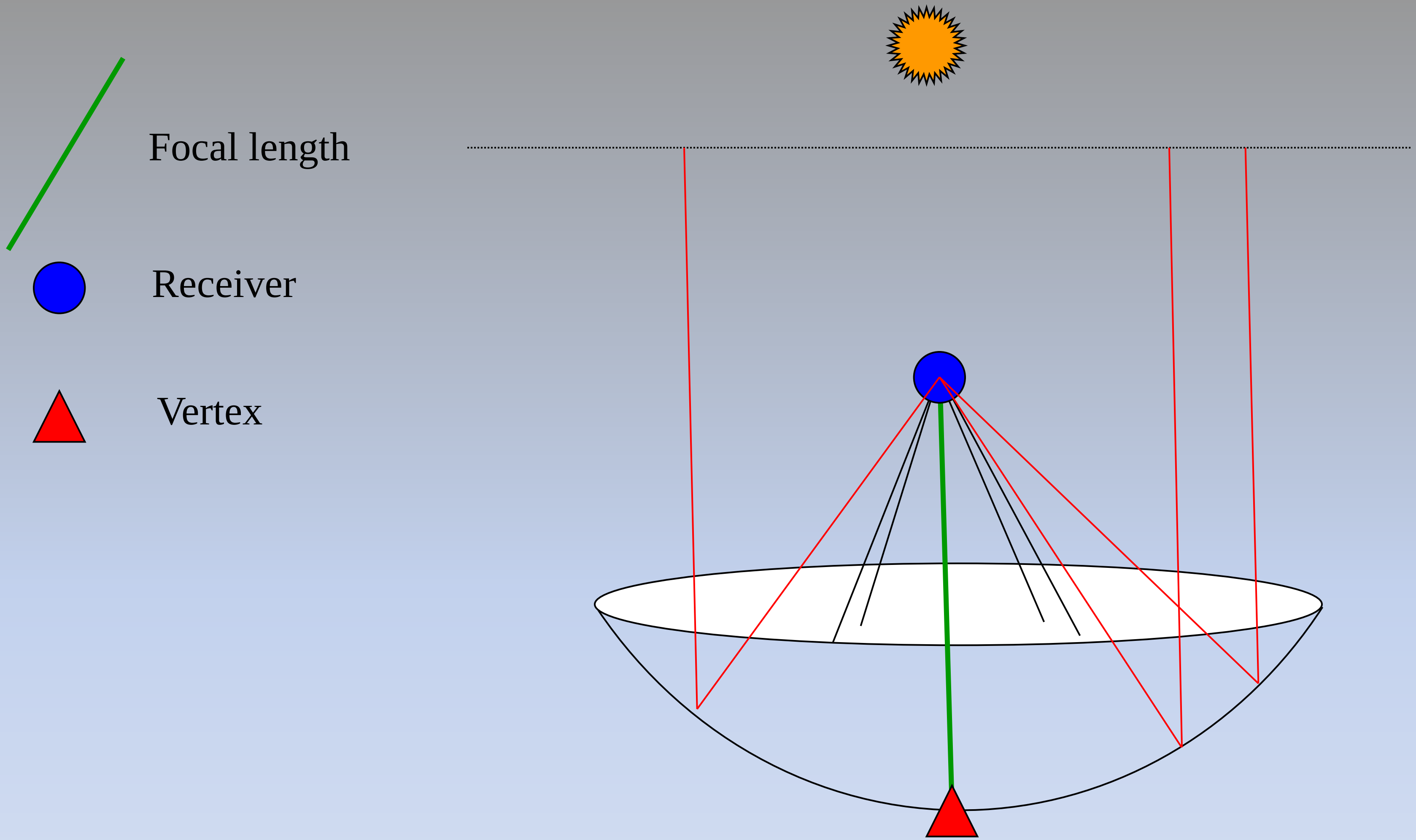
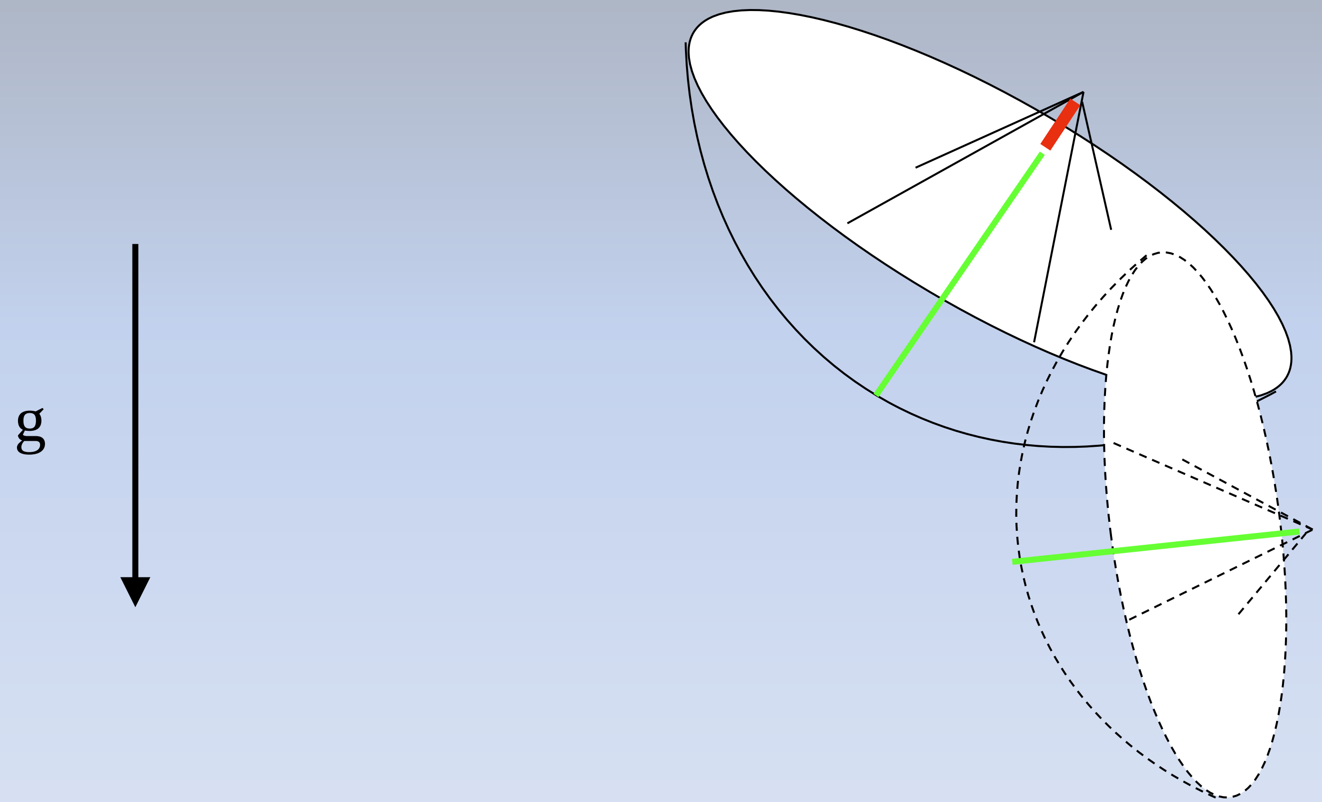

Focal length
Receiver
Vertex

$$\Delta L(e)=\alpha_F \Delta F(e)+\alpha_R \Delta R(e)+\alpha_V \Delta V(e)$$


g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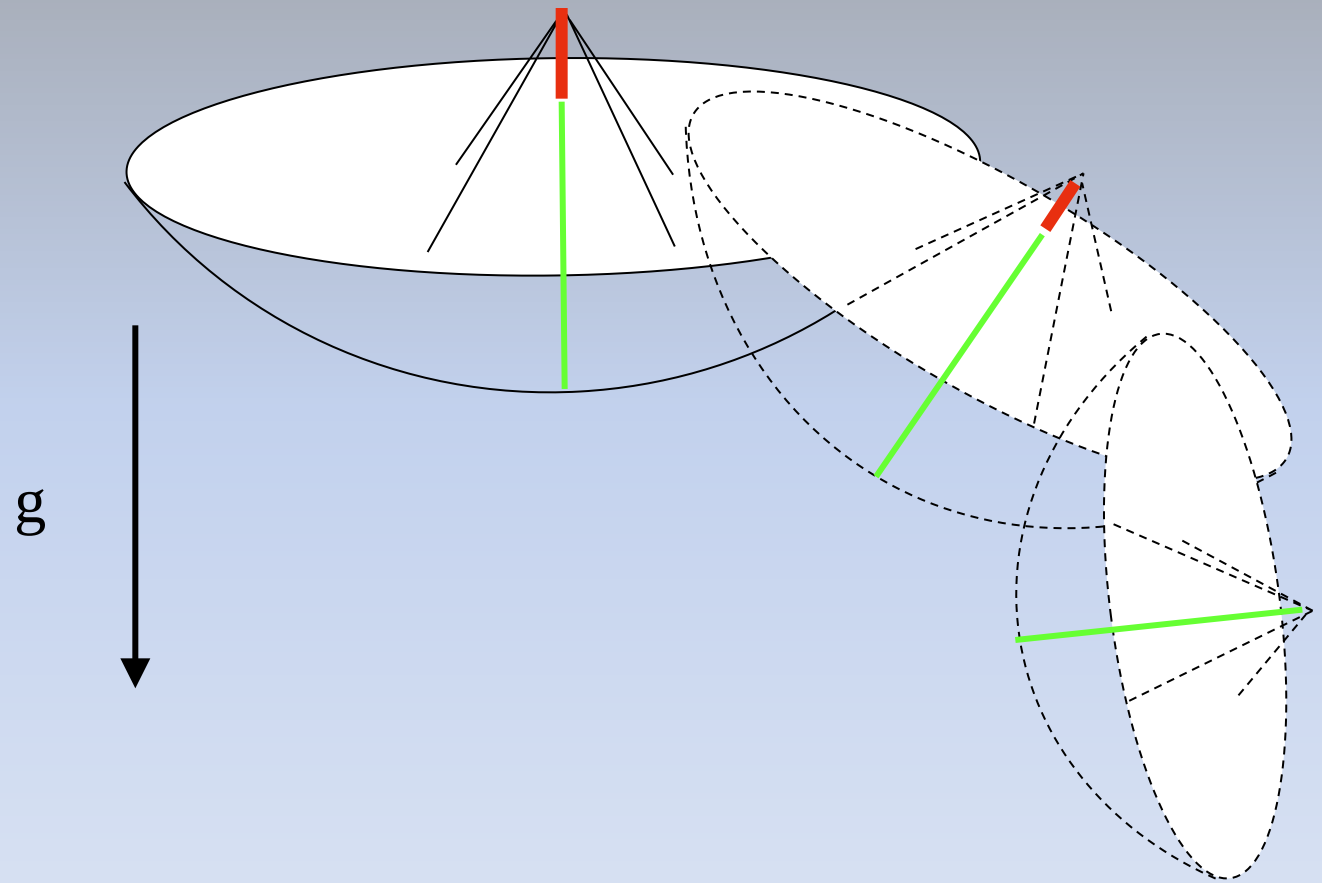
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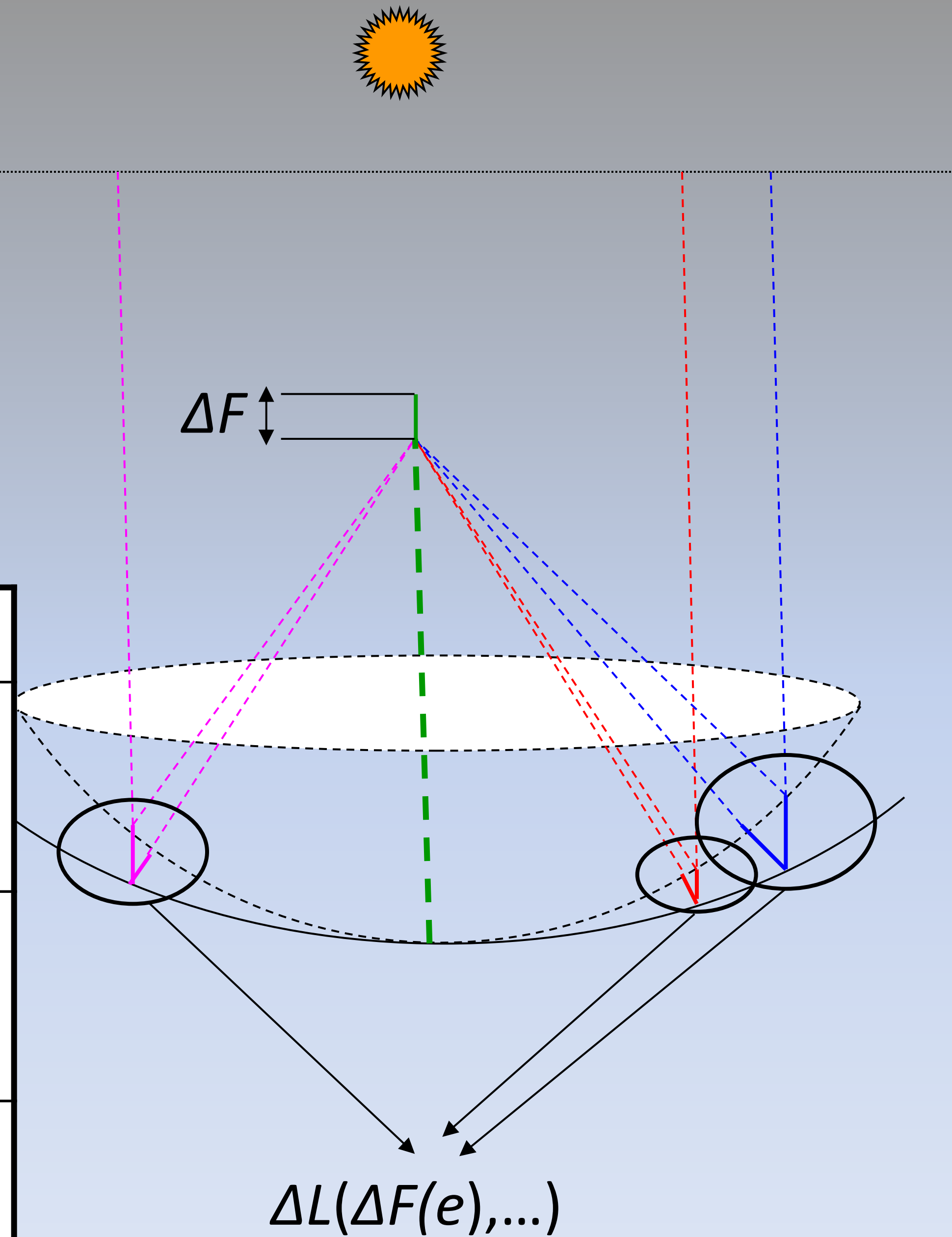
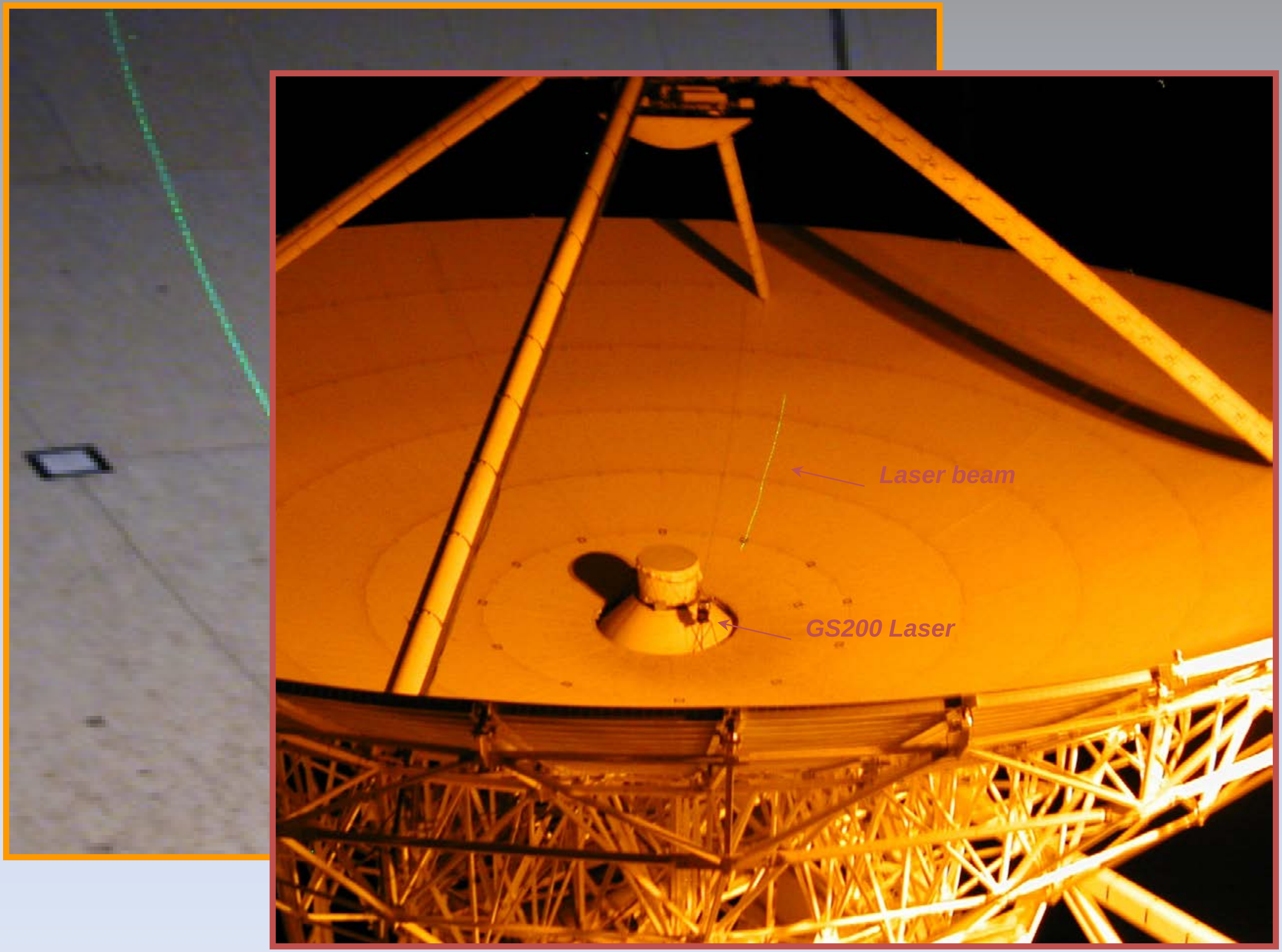
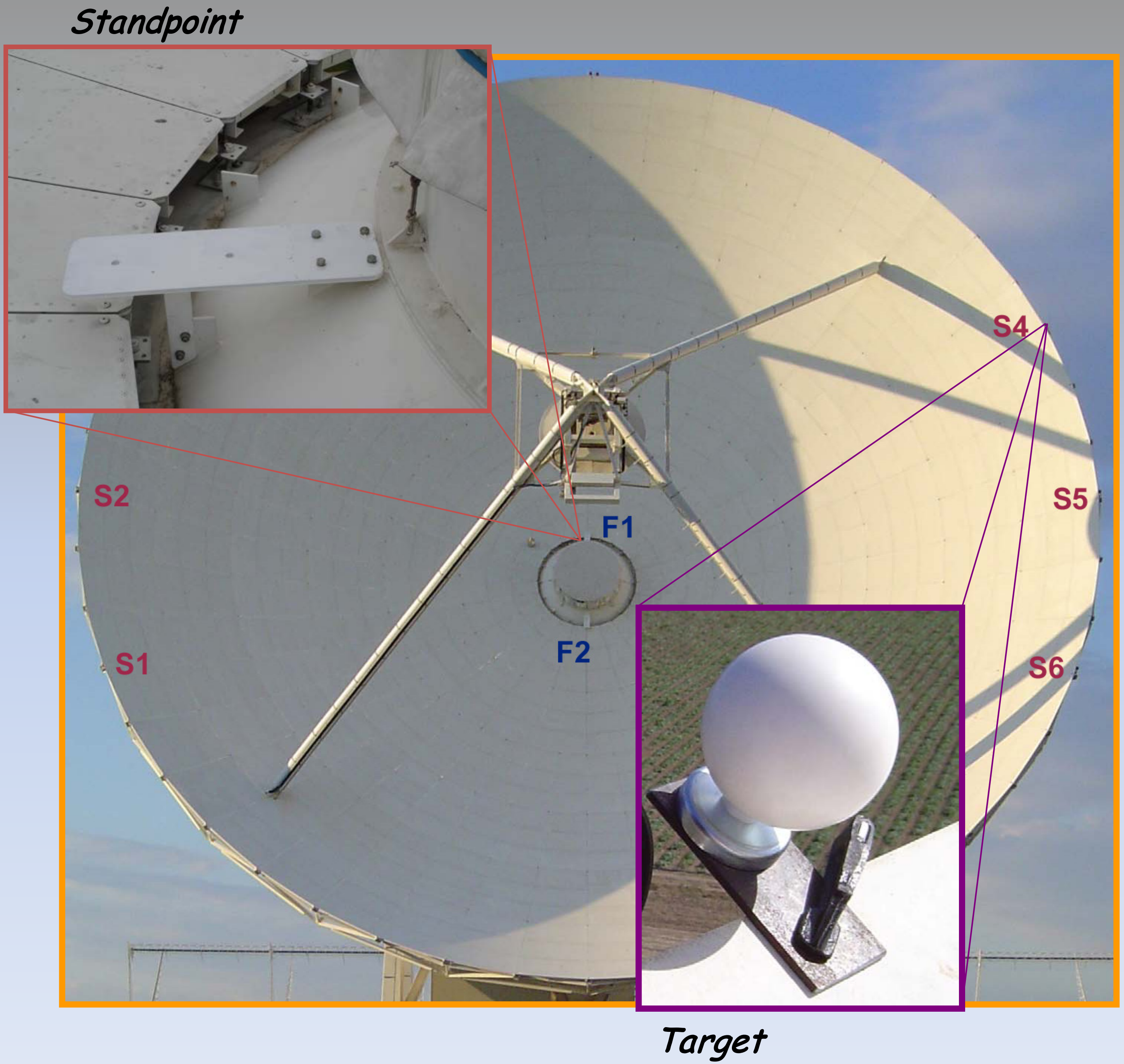
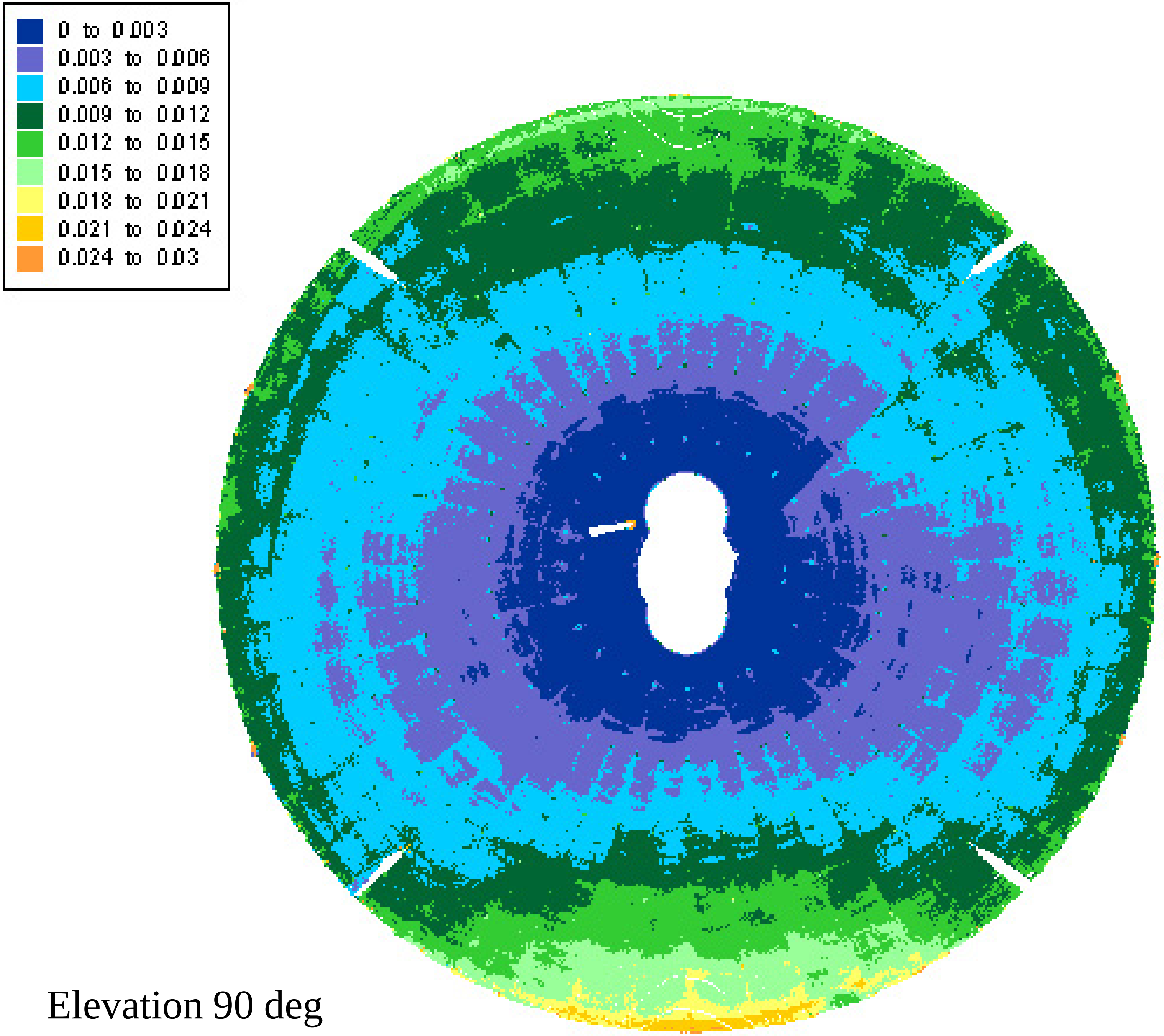


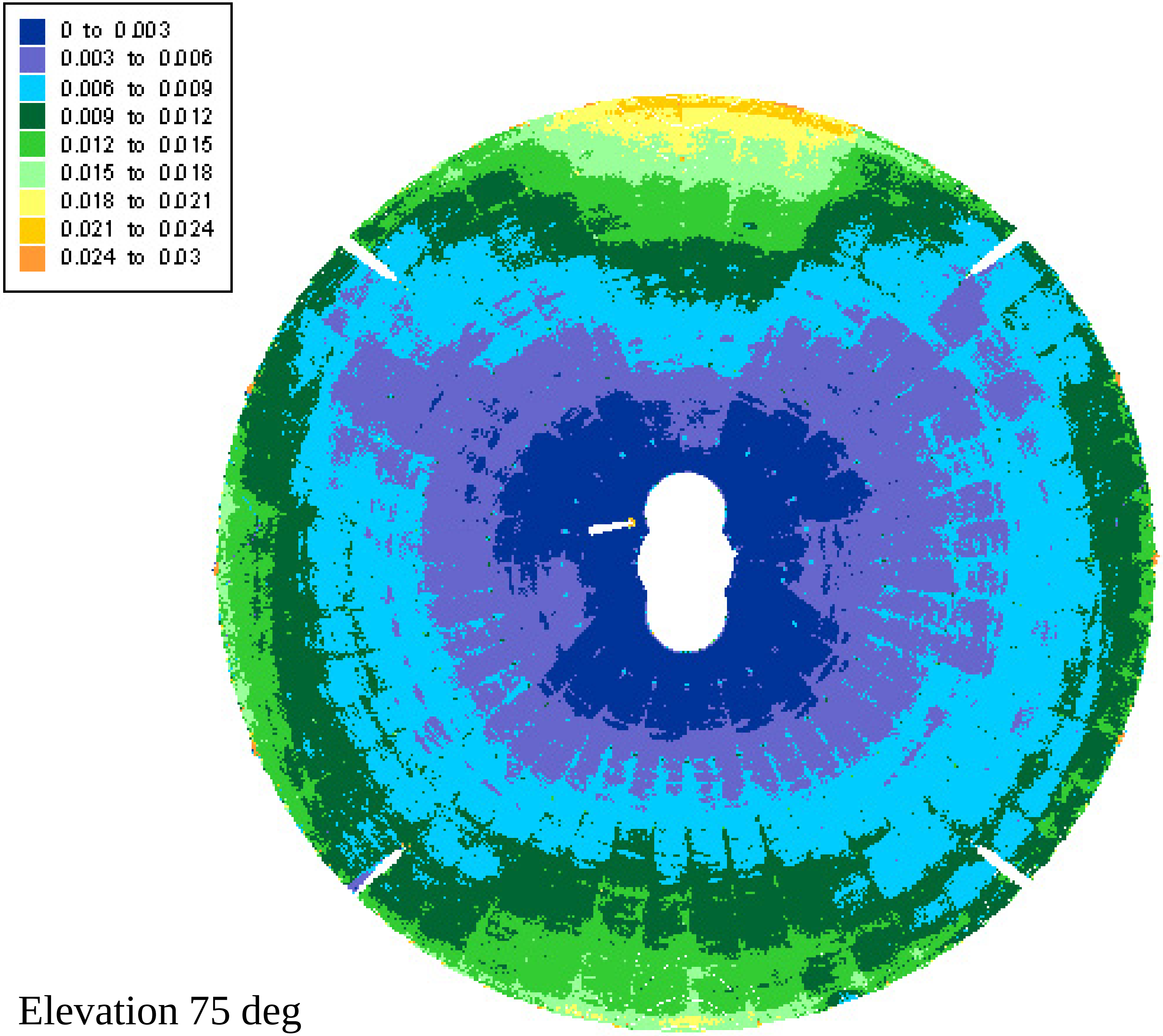
Φ (m)	Δ_{Fmax}(mm)
26	4.5 (Clark & Thomsen 1988)
32	36.3/24.4 (Sarti et al. 2009)
100	12.6 (Holst et al. 2012)


Laser beam
GS200 Laser

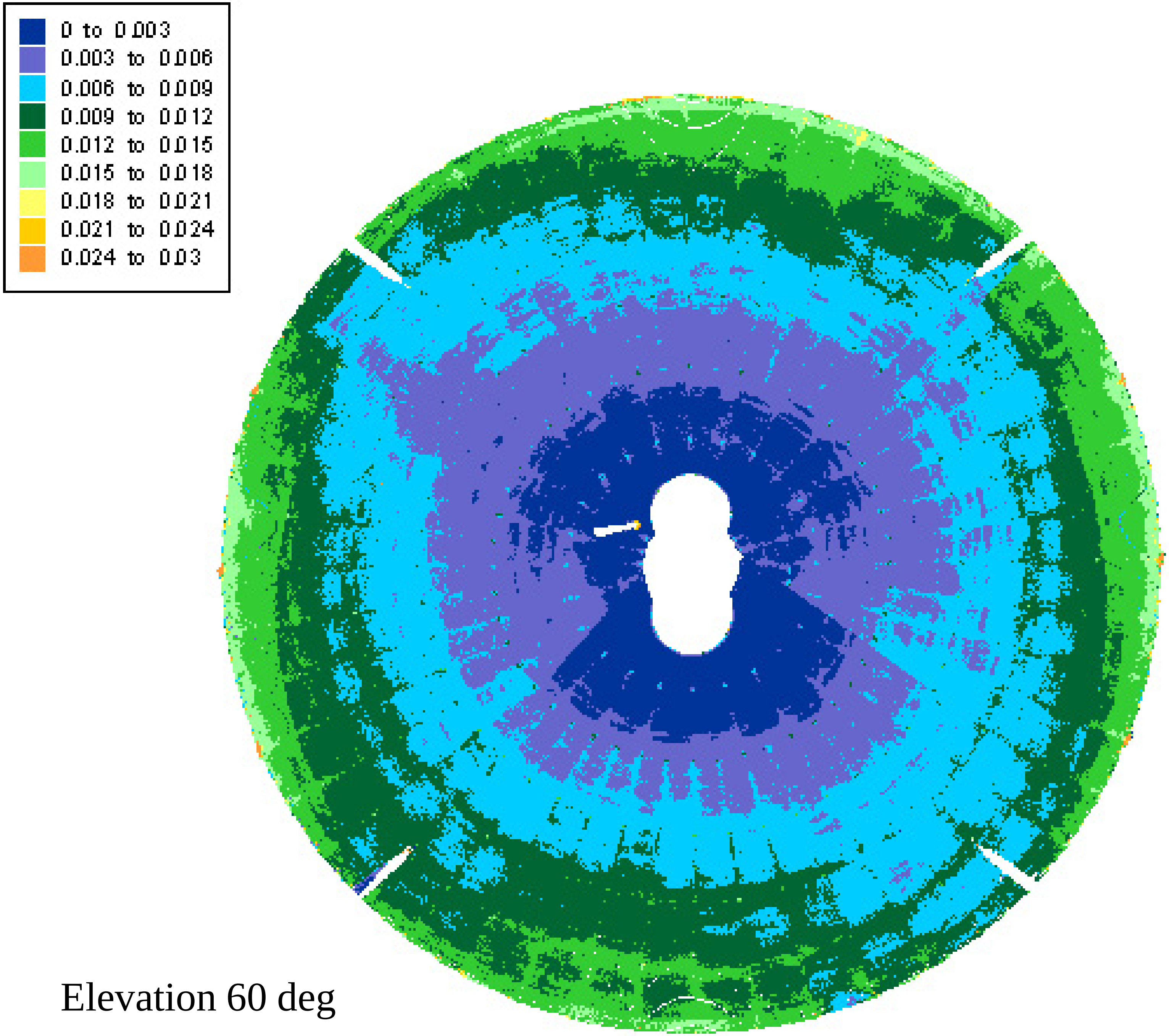

Standpoint
S2
S1
F1
F2
S4
S5
S6
Target



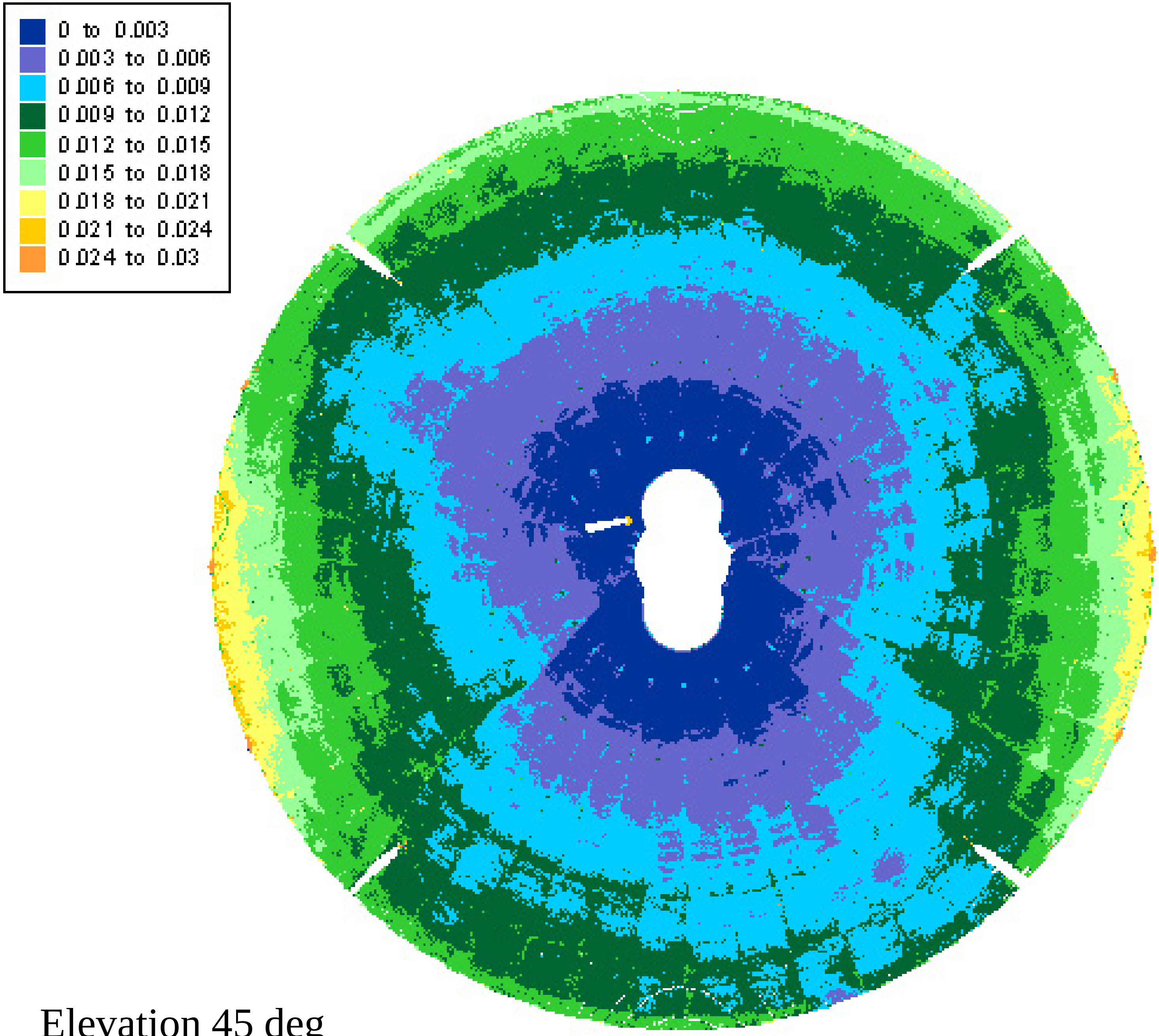
Elevation 90 deg



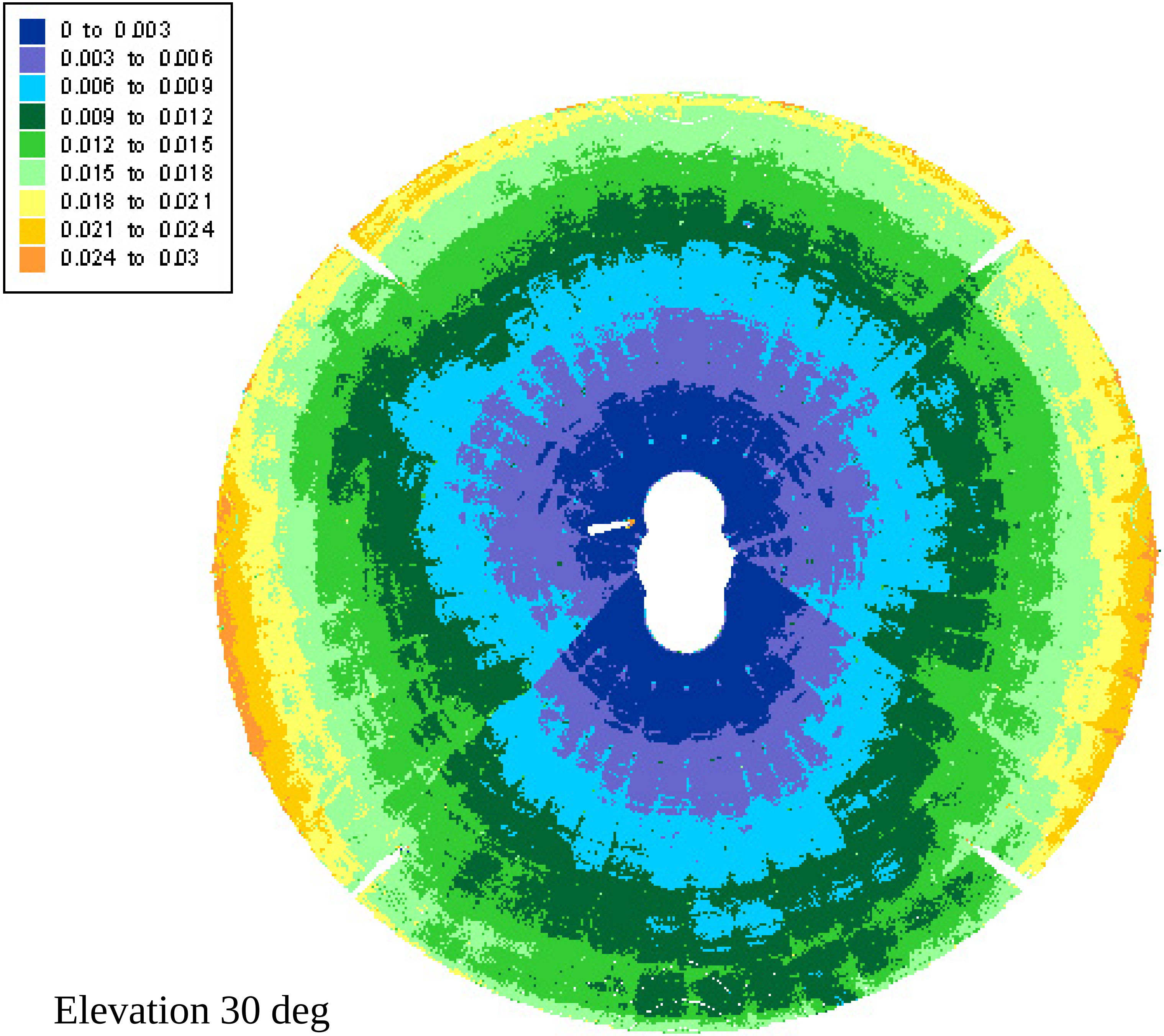
Elevation 75 deg



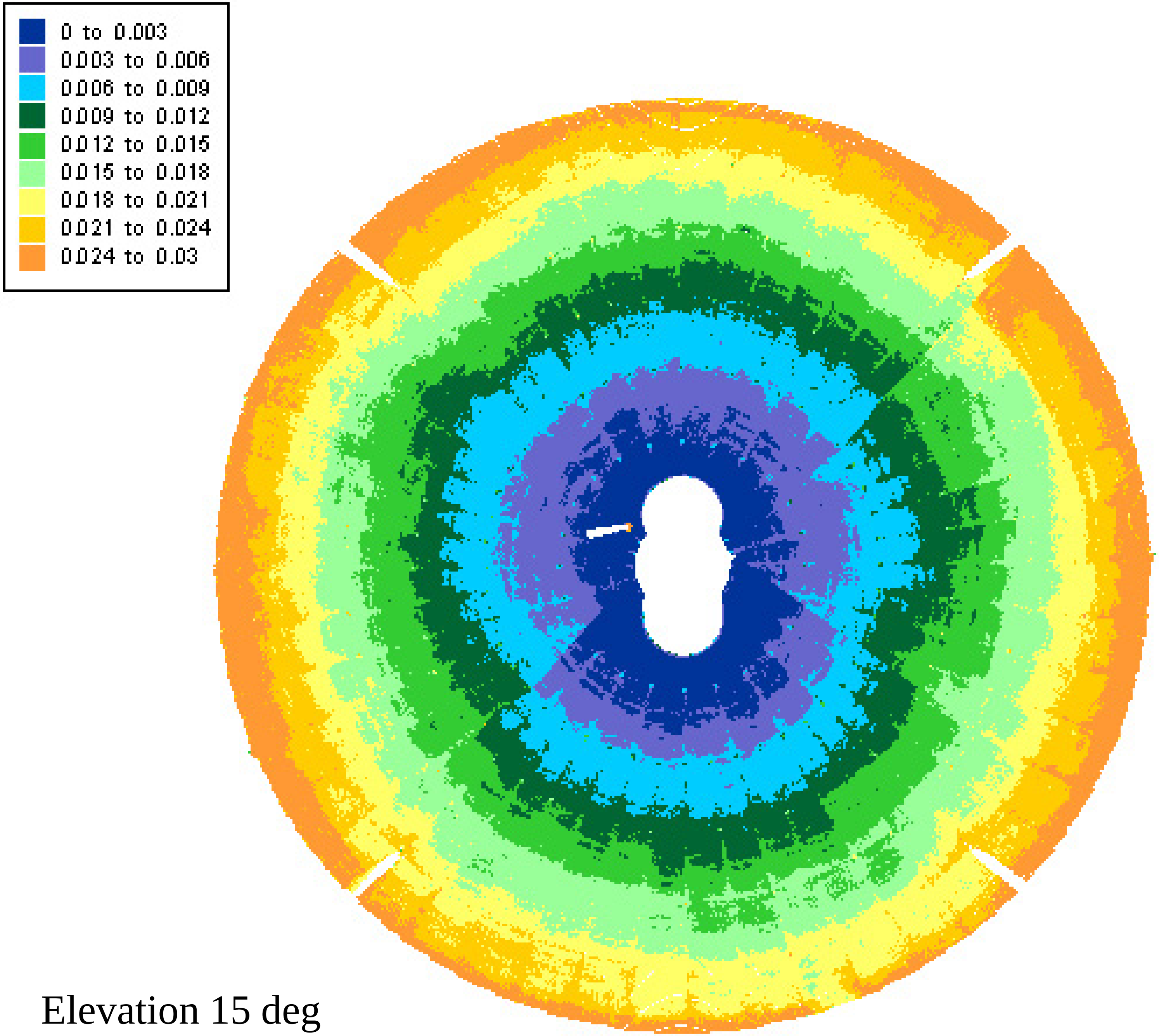
Elevation 60 deg



Elevation 45 deg



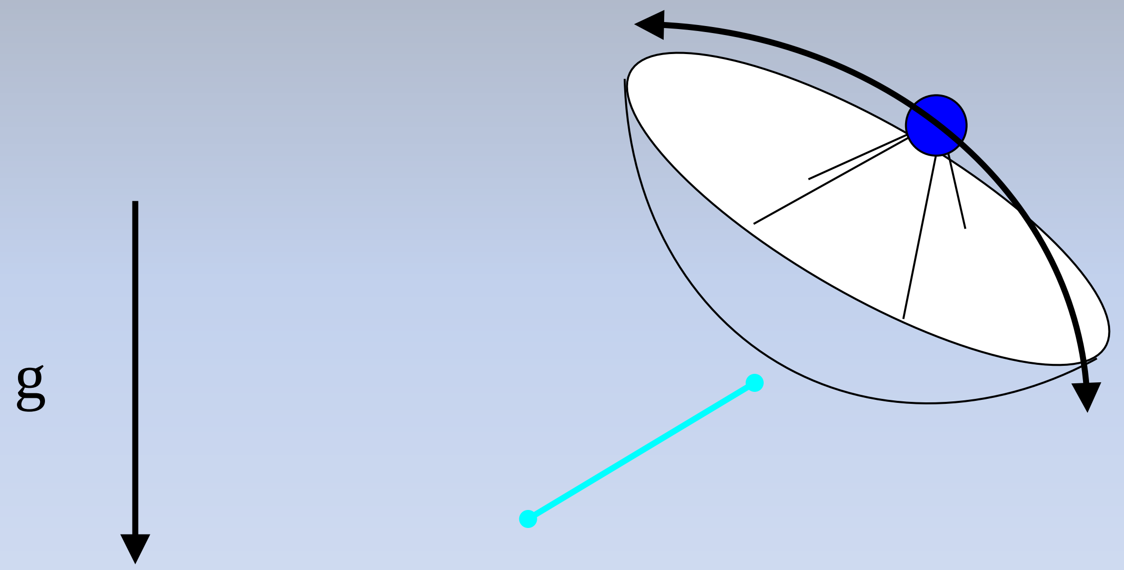
Elevation 30 deg



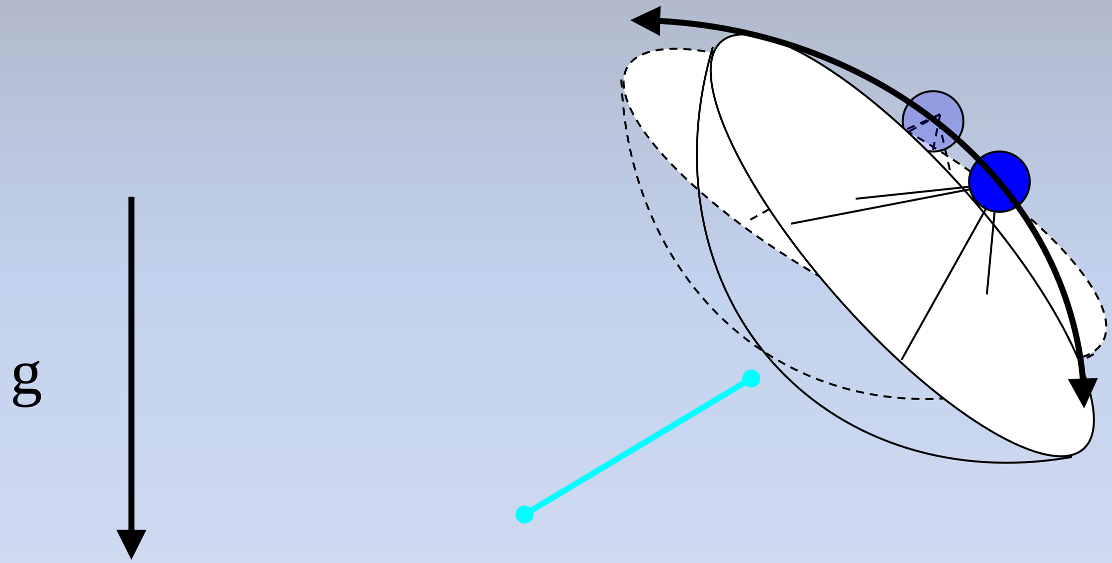
Elevation 15 deg

$$\Delta L(e)=\alpha_F \Delta F(e)+\alpha_R \Delta R(e)+\alpha_V \Delta V(e)$$

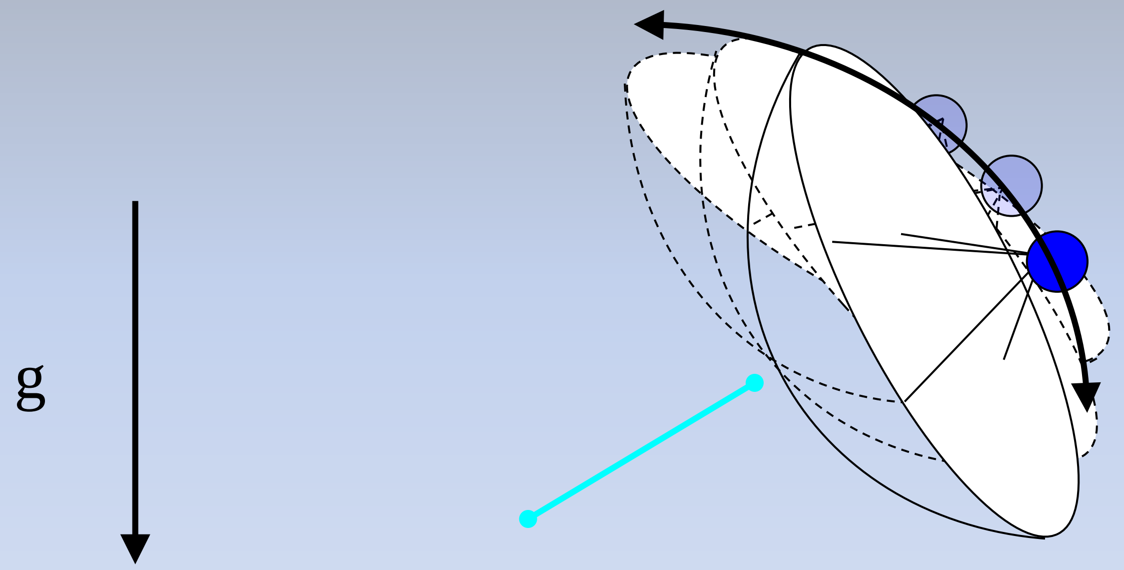
Displacement of the receiver



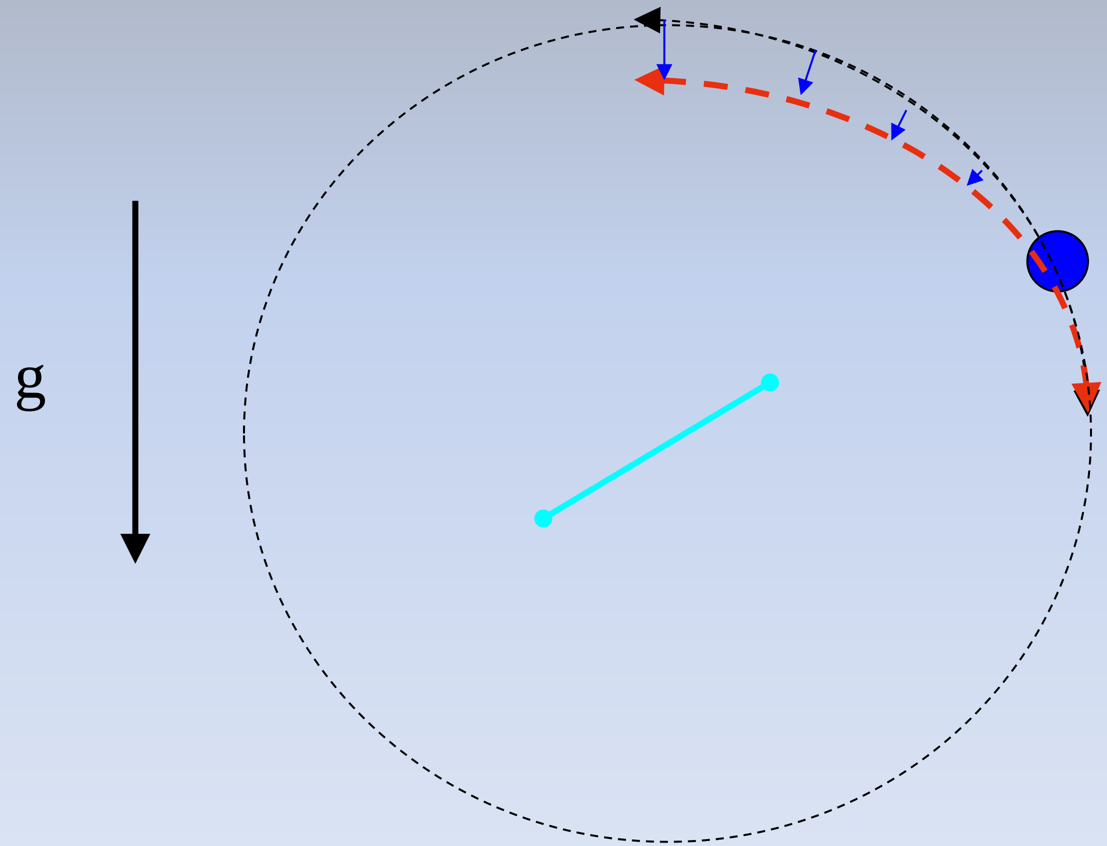
Displacement of the receiver

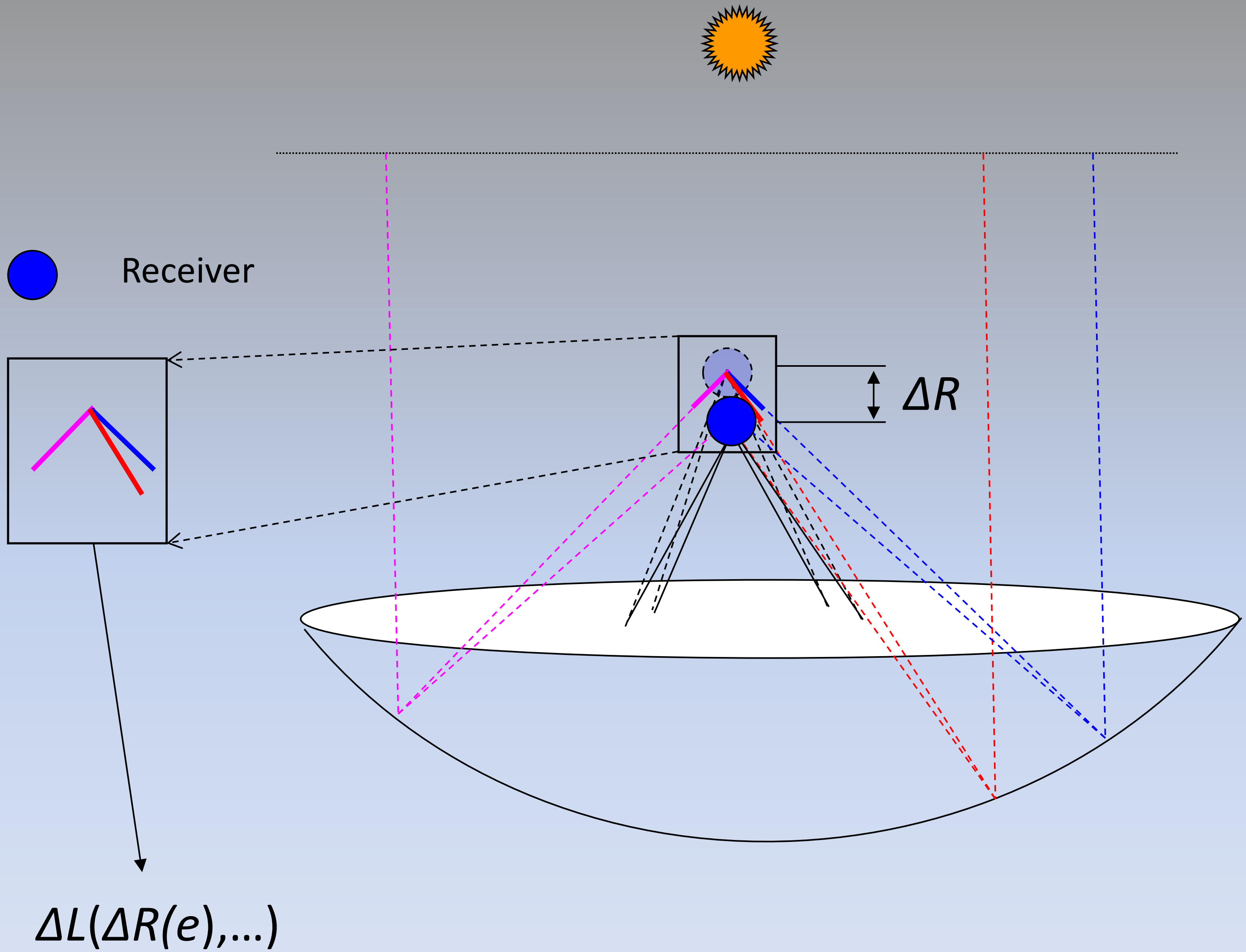


Displacement of the receiver



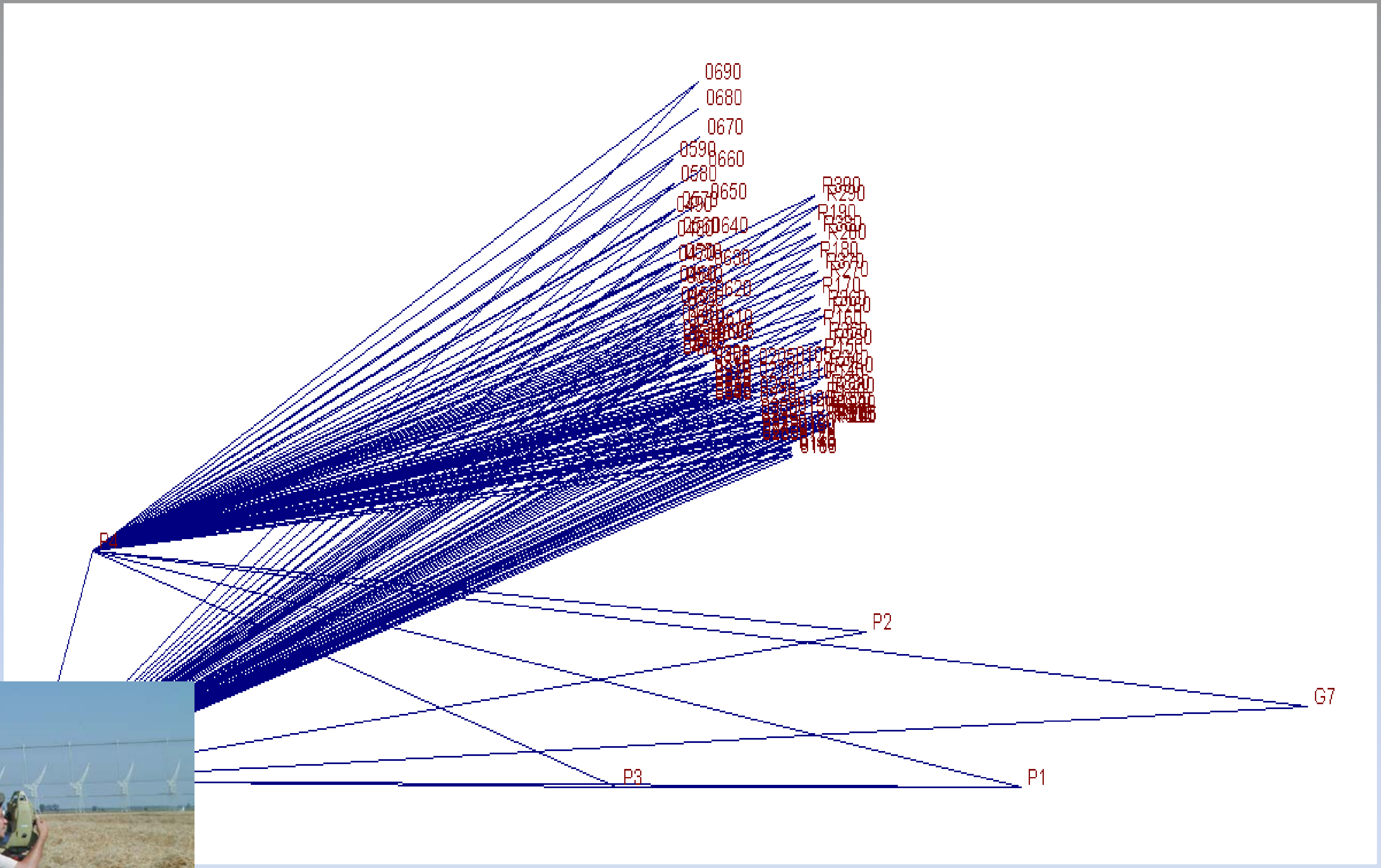
Displacement of the receiver

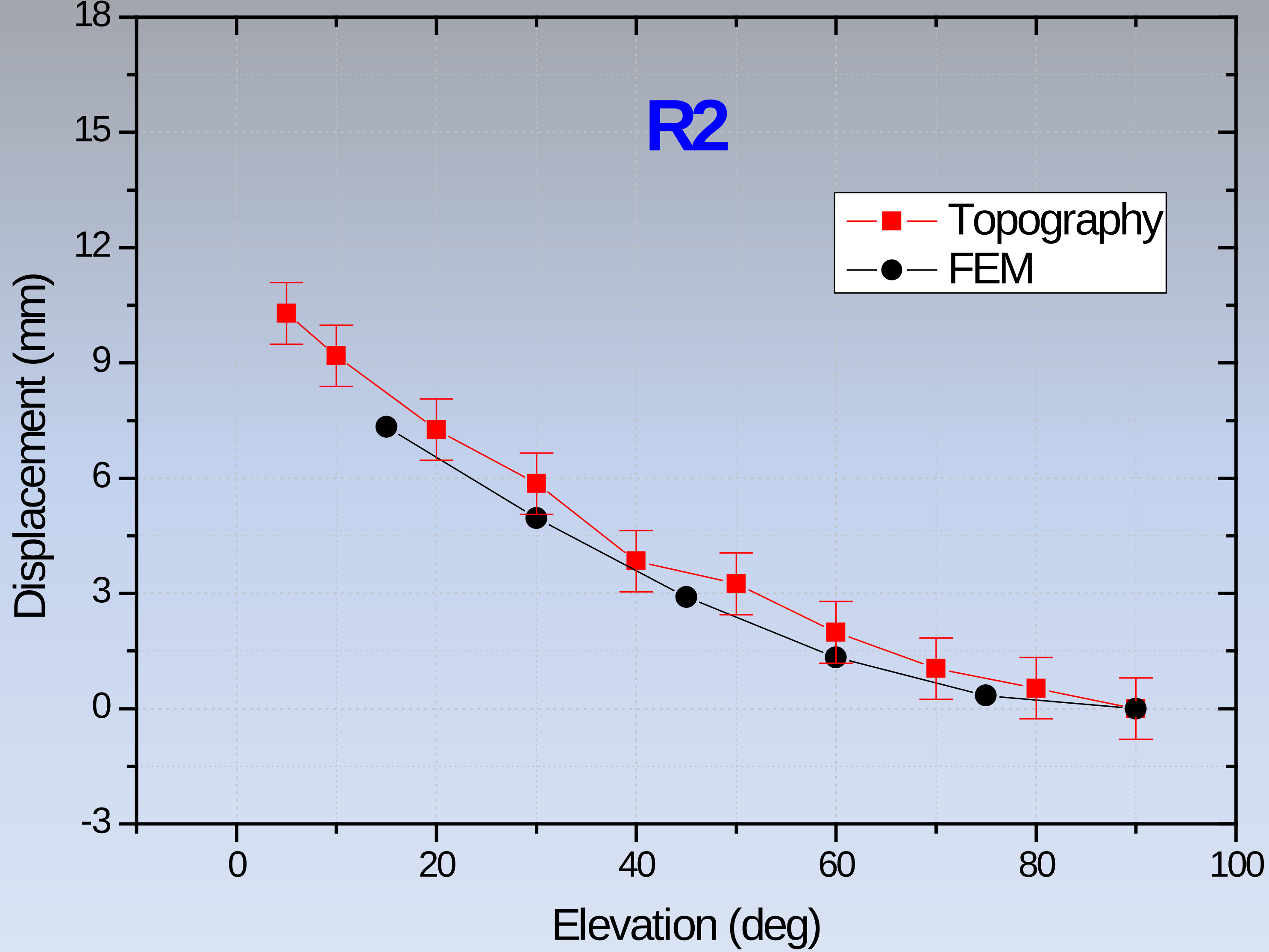


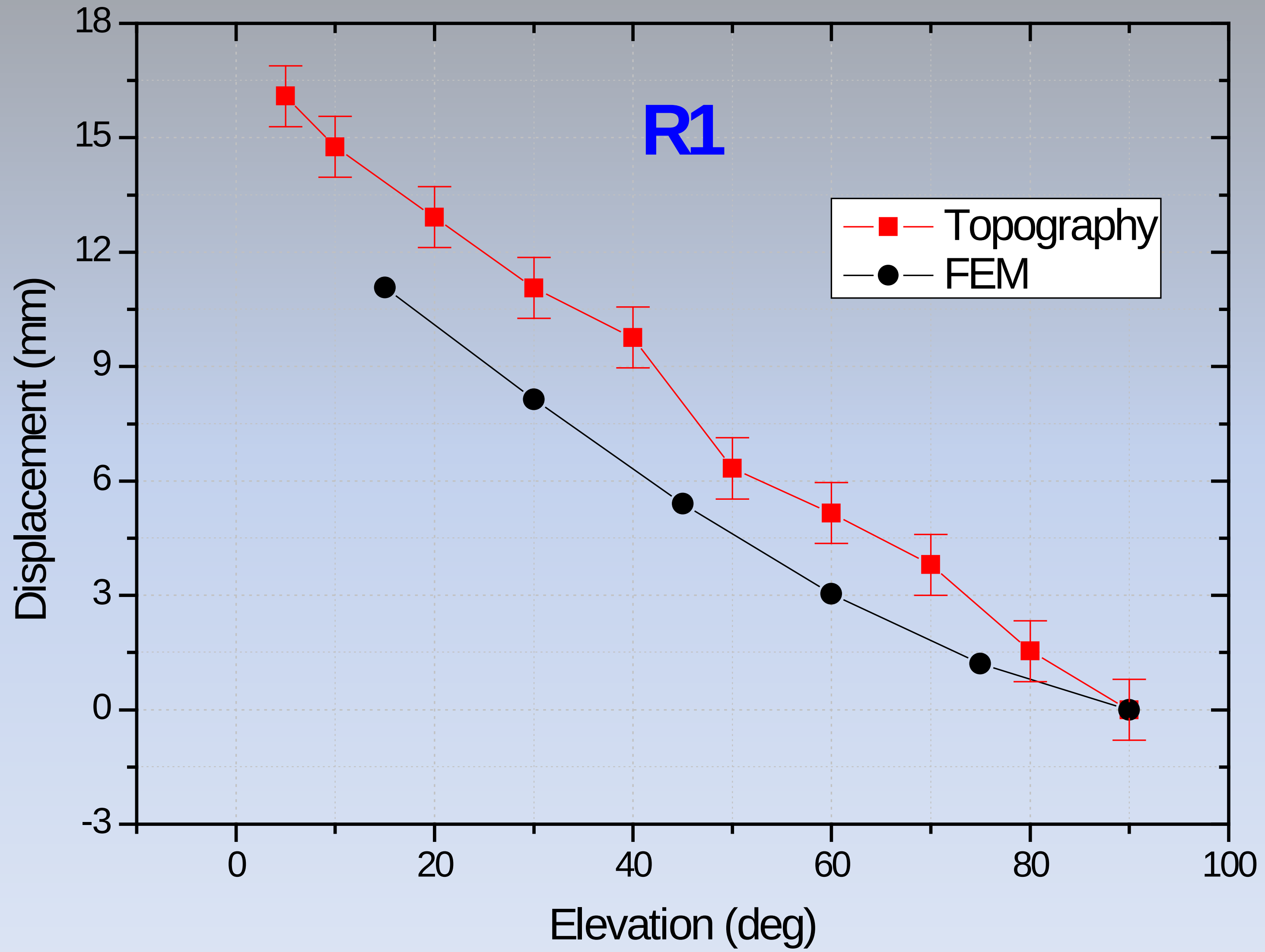


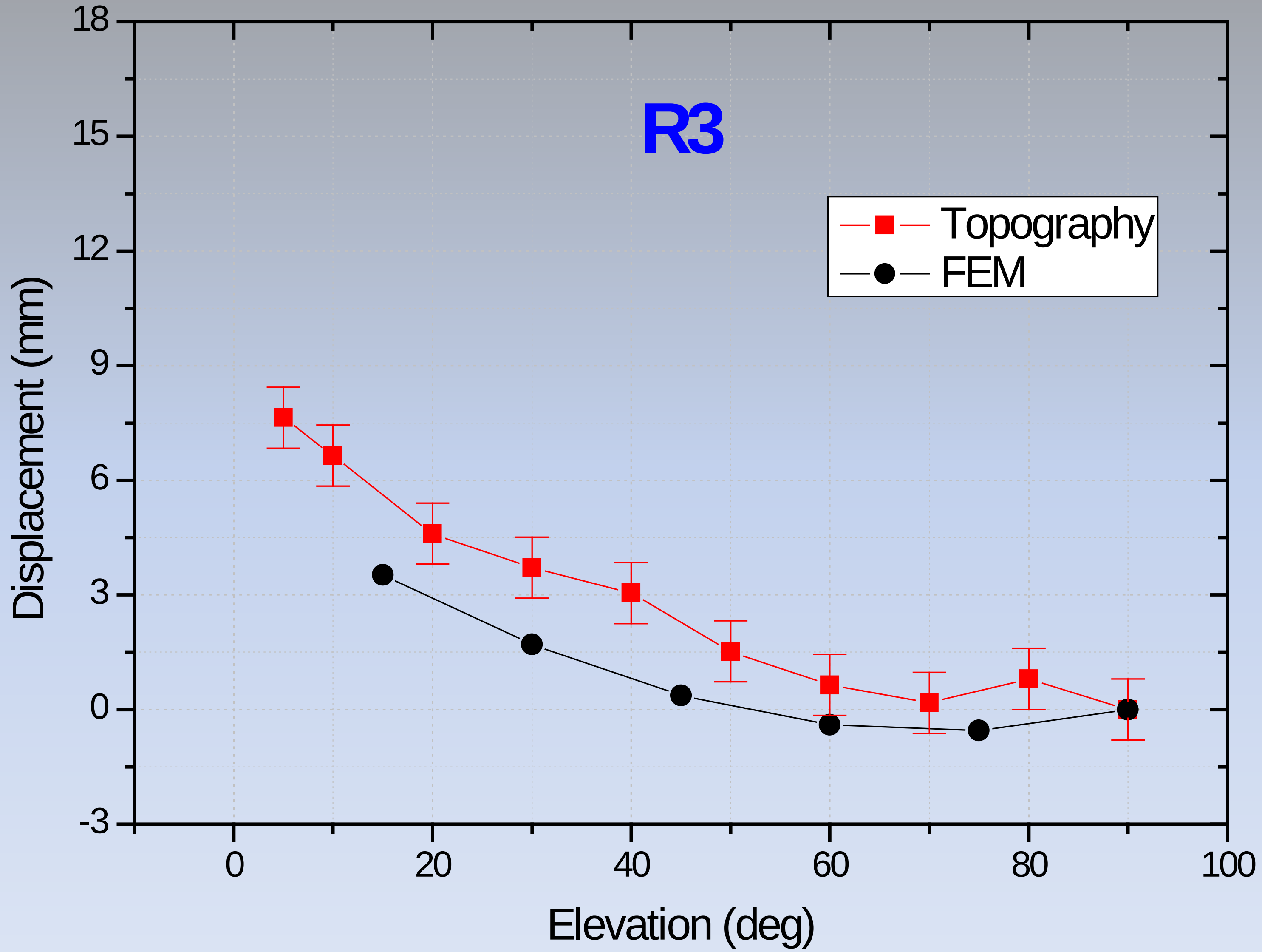
Receiver
ΔR
ΔL(ΔR(e),…)


R3
R2
R1

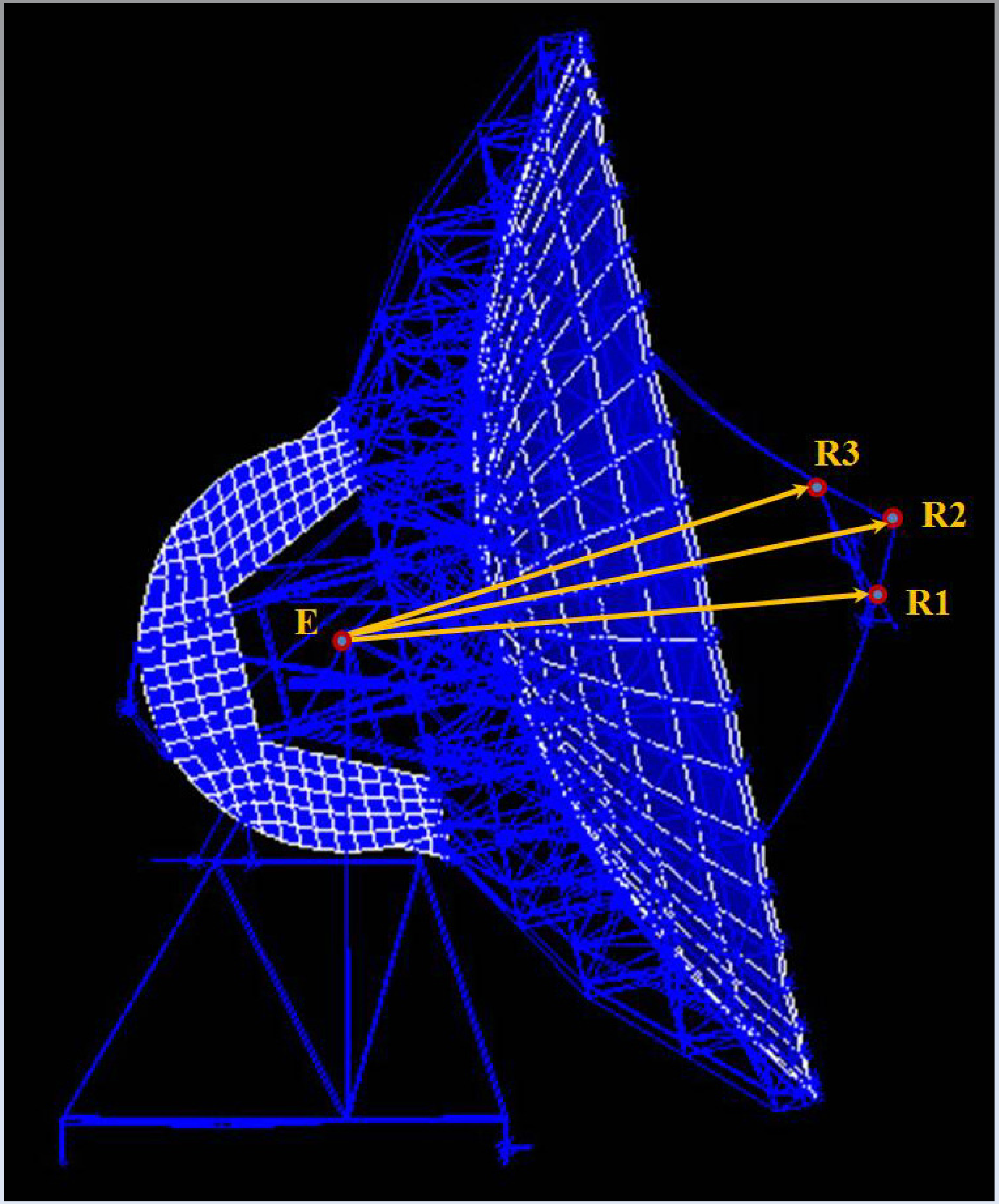

0690
0680
0670
0590
0660
0580
0650
0640
P4
P2
G7
P3
P1

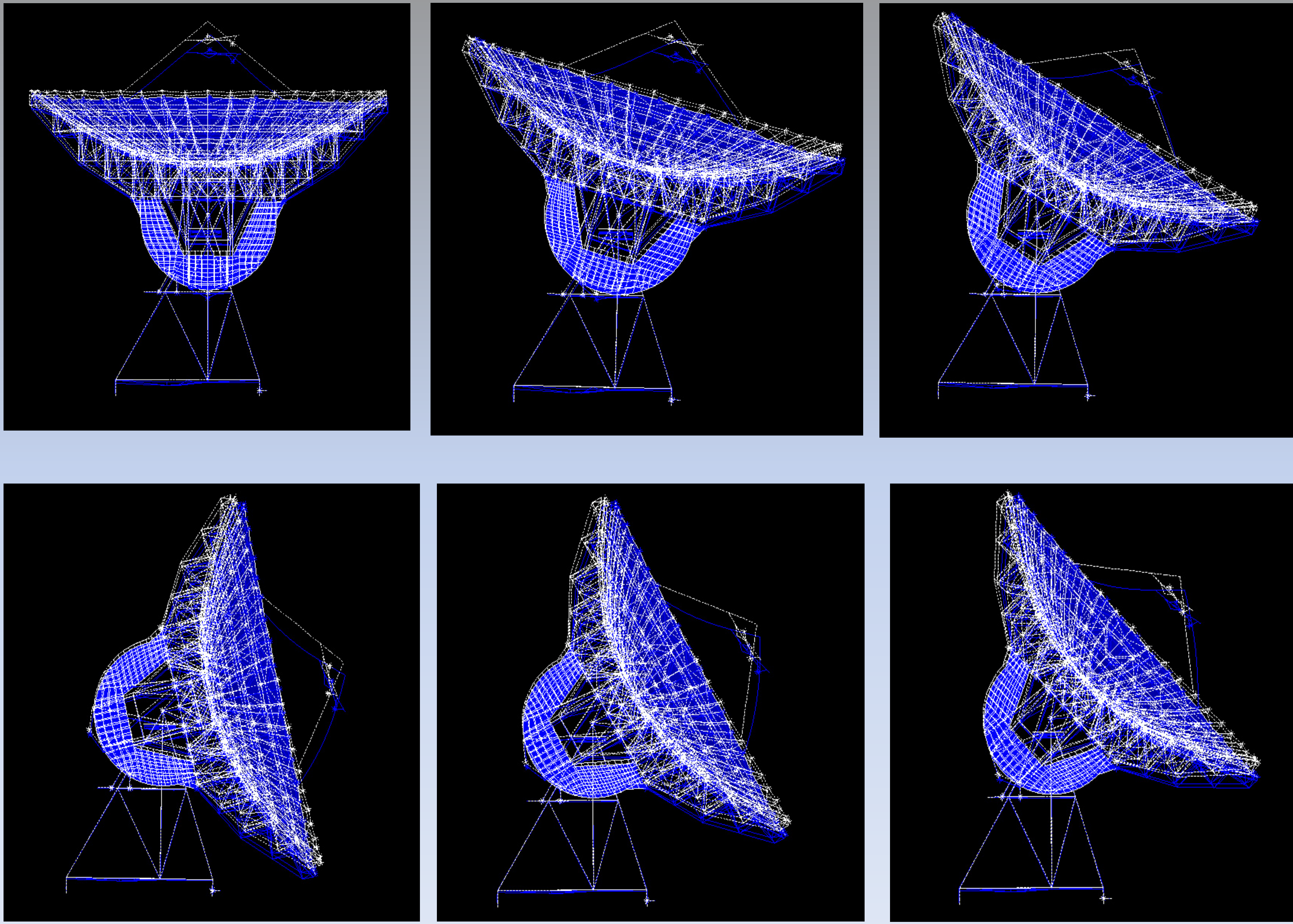

R2
Topography
FEM
Displacement (mm)
Elevation (deg)
18
15
12
9
6
3
0
-3
0
20
40
60
80
100


R1
Topography
FEM
18
15
12
9
6
3
0
-3
0
20
40
60
80
100
Displacement (mm)
Elevation (deg)



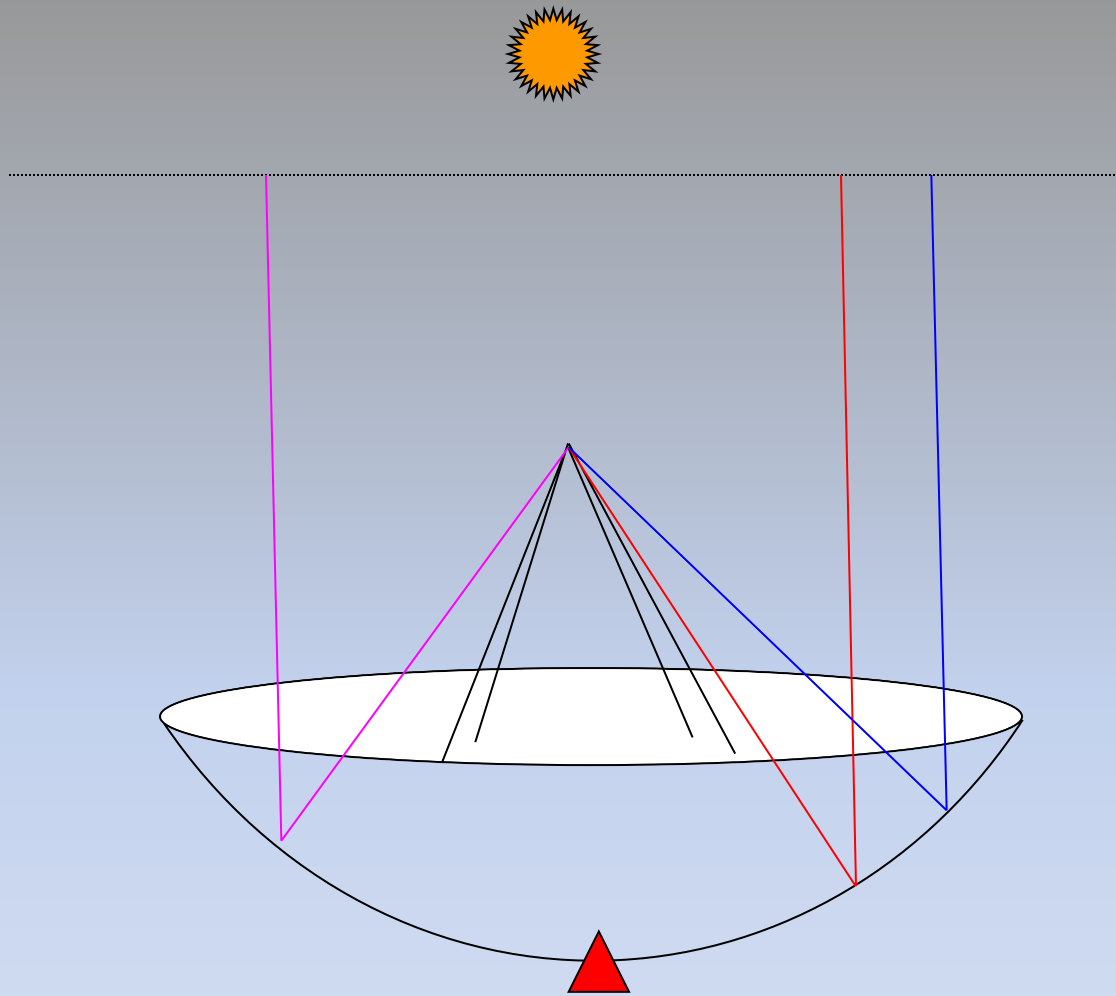
R3
Topography
FEM
Displacement (mm)
Elevation (deg)
18
15
12
9
6
3
0
-3
0
20
40
60
80
100

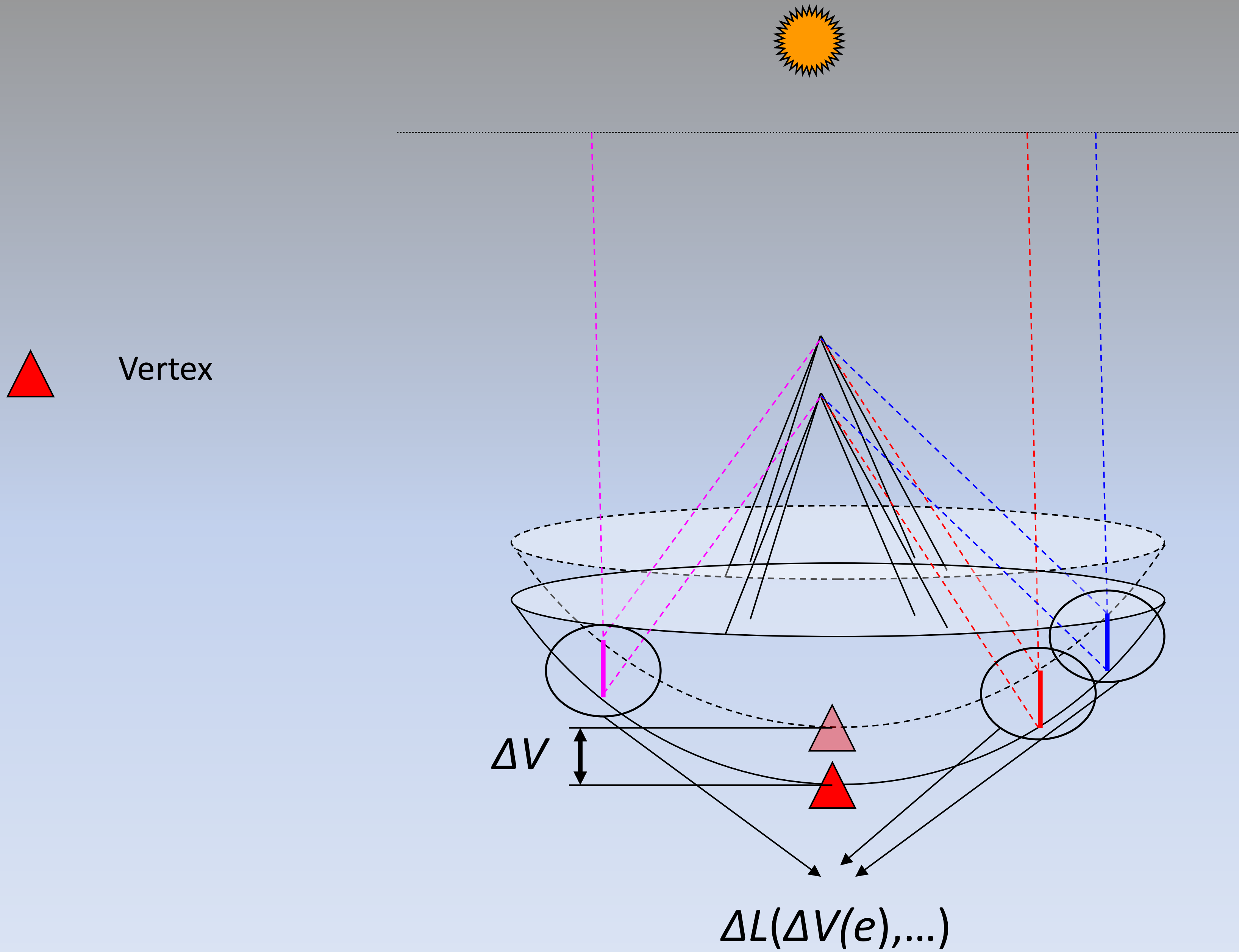

R3
R2
R1
E

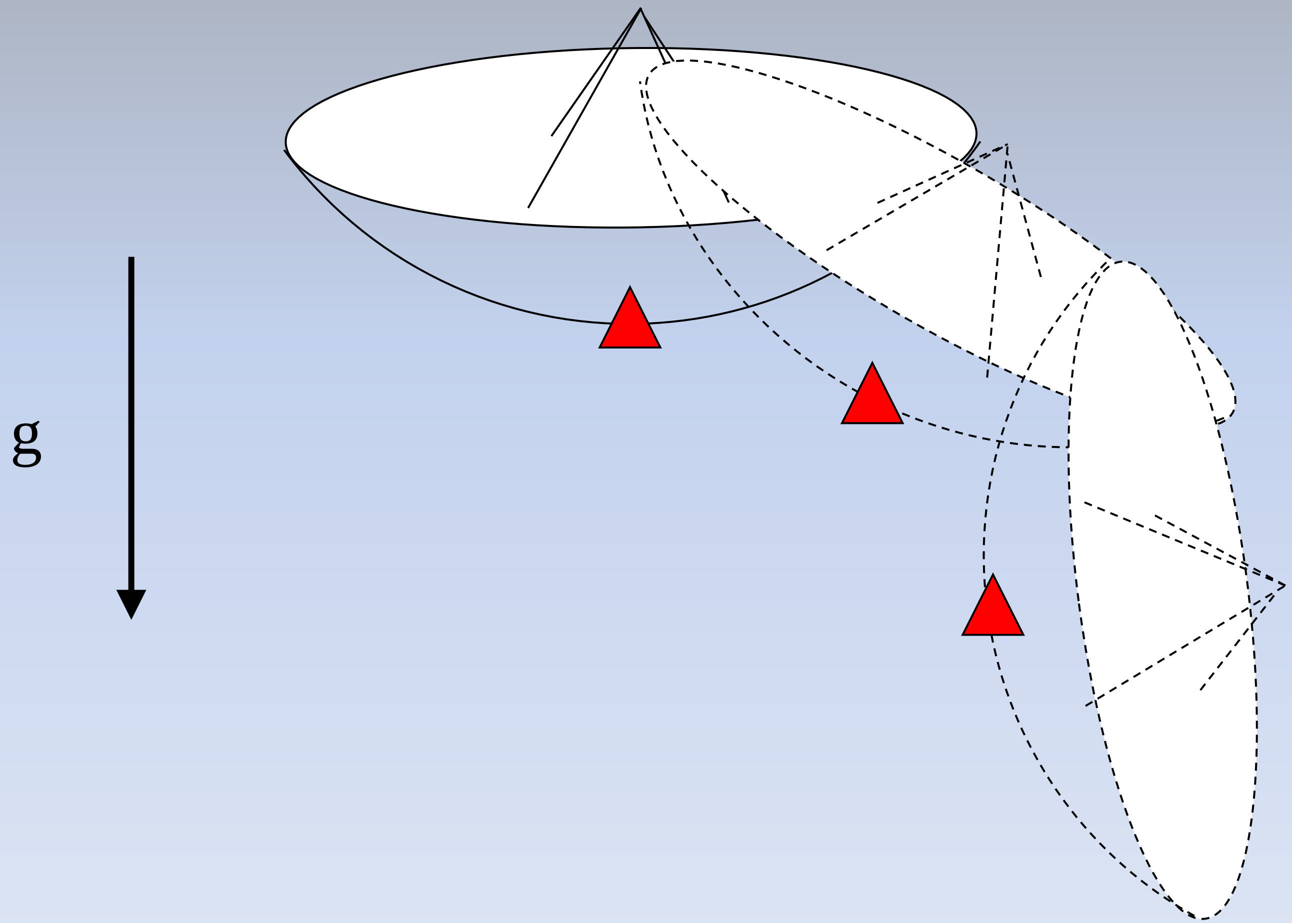


$$\Delta L(e)=\alpha_F \Delta F(e)+\alpha_R \Delta R(e)+\alpha_V \Delta V(e)$$

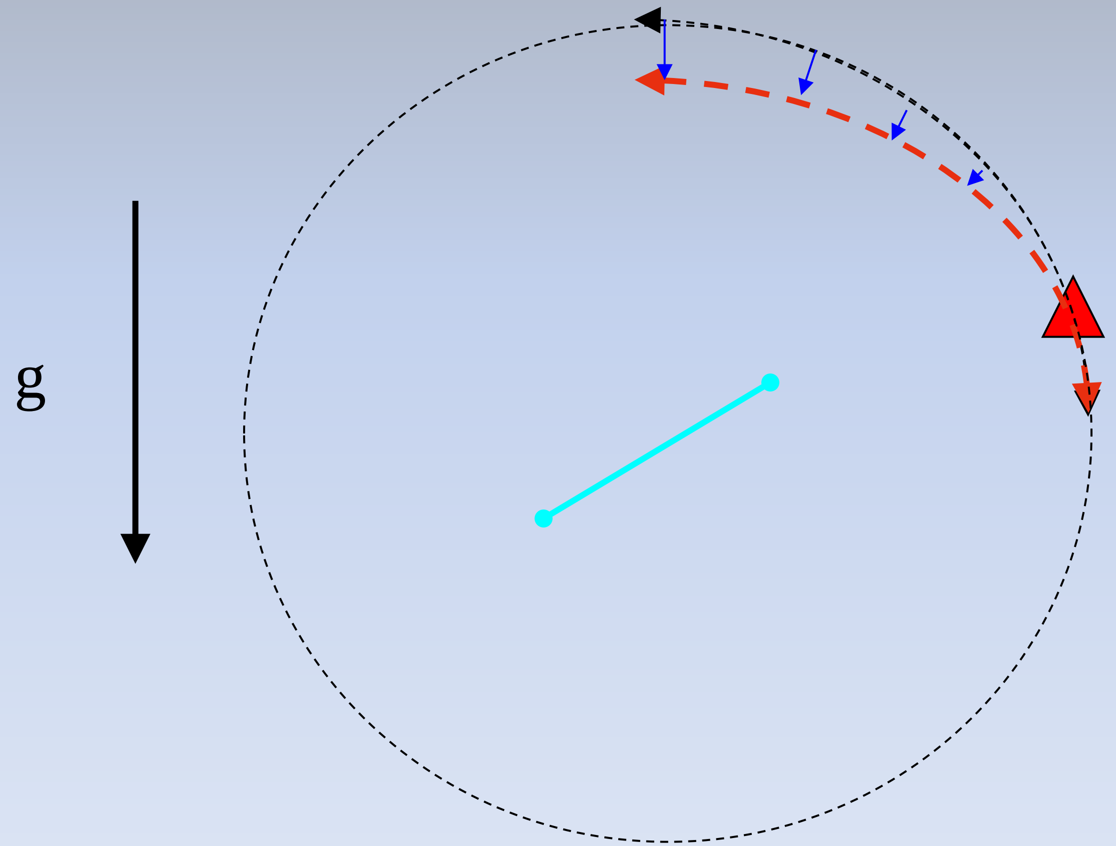
Vertex

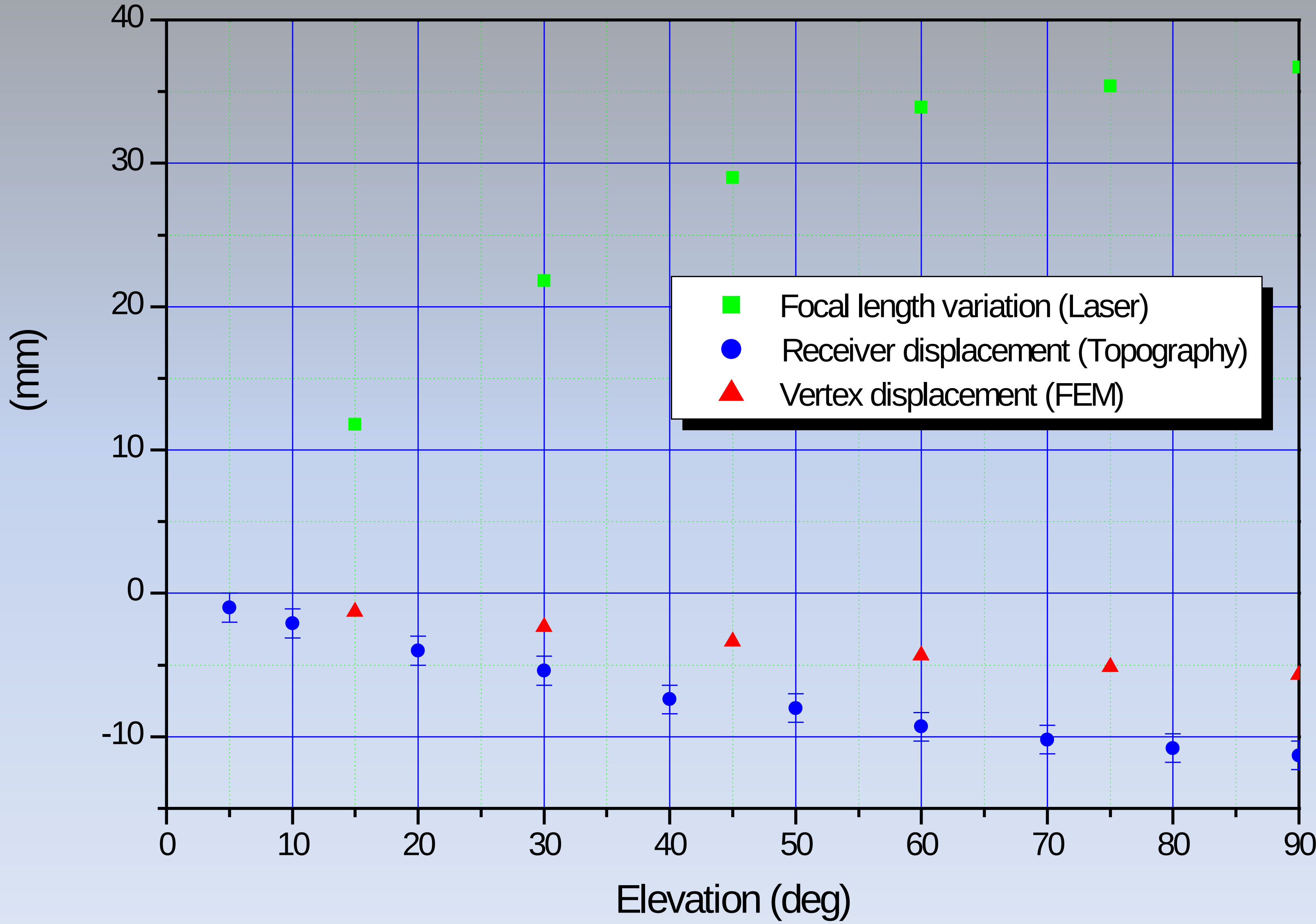



Vertex
ΔV
ΔL(ΔV(e),...)

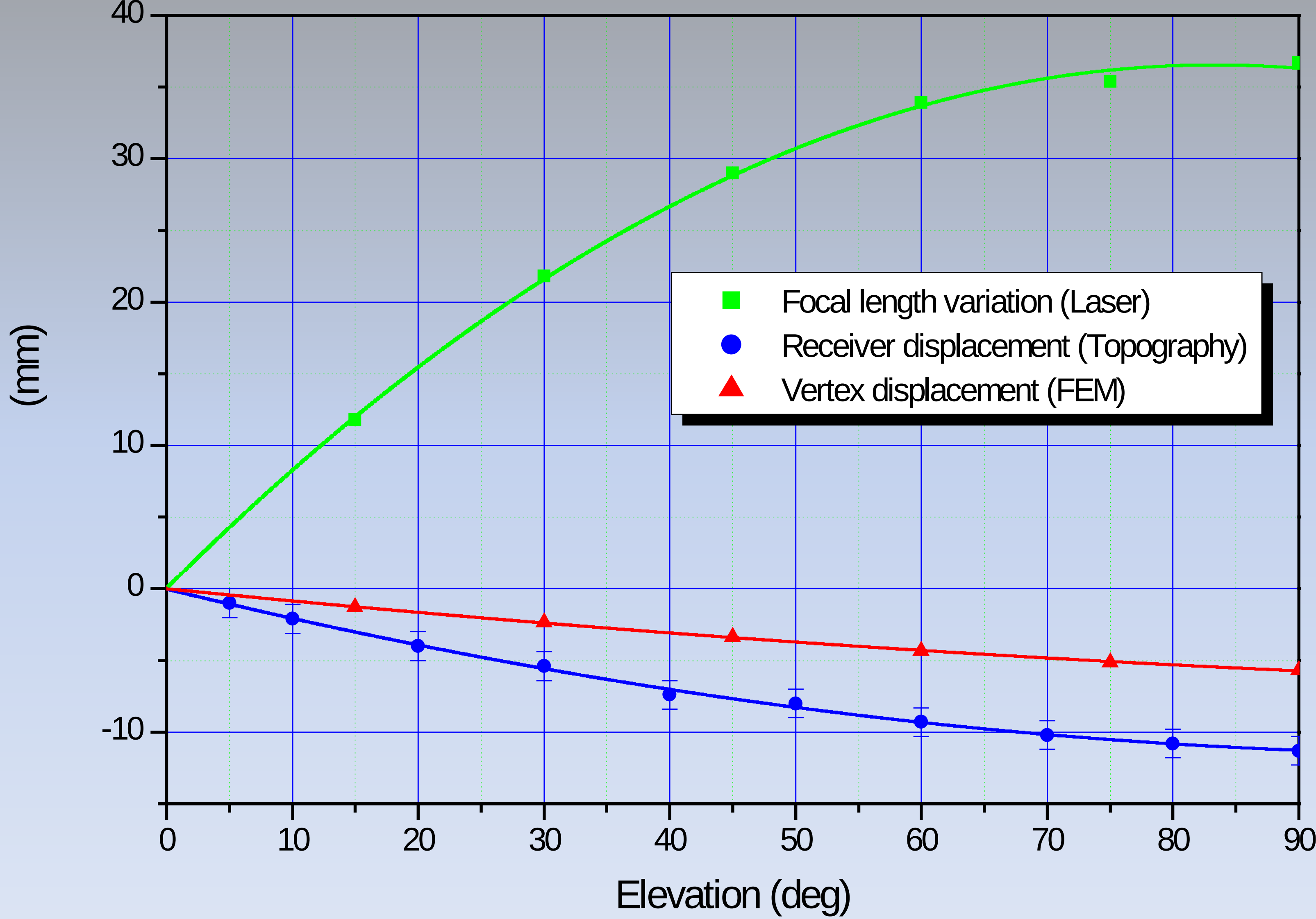

g

Displacement of the vertex





40
30
20
10
0
-10
(mm)
0
10
20
30
40
50
60
70
80
90
Elevation (deg)
Focal length variation (Laser)
Receiver displacement (Topography)
Vertex displacement (FEM)



40
30
20
10
0
-10
(mm)
0
10
20
30
40
50
60
70
80
90
Elevation (deg)
Focal length variation (Laser)
Receiver displacement (Topography)
Vertex displacement (FEM)

How were the Δs determined so far?

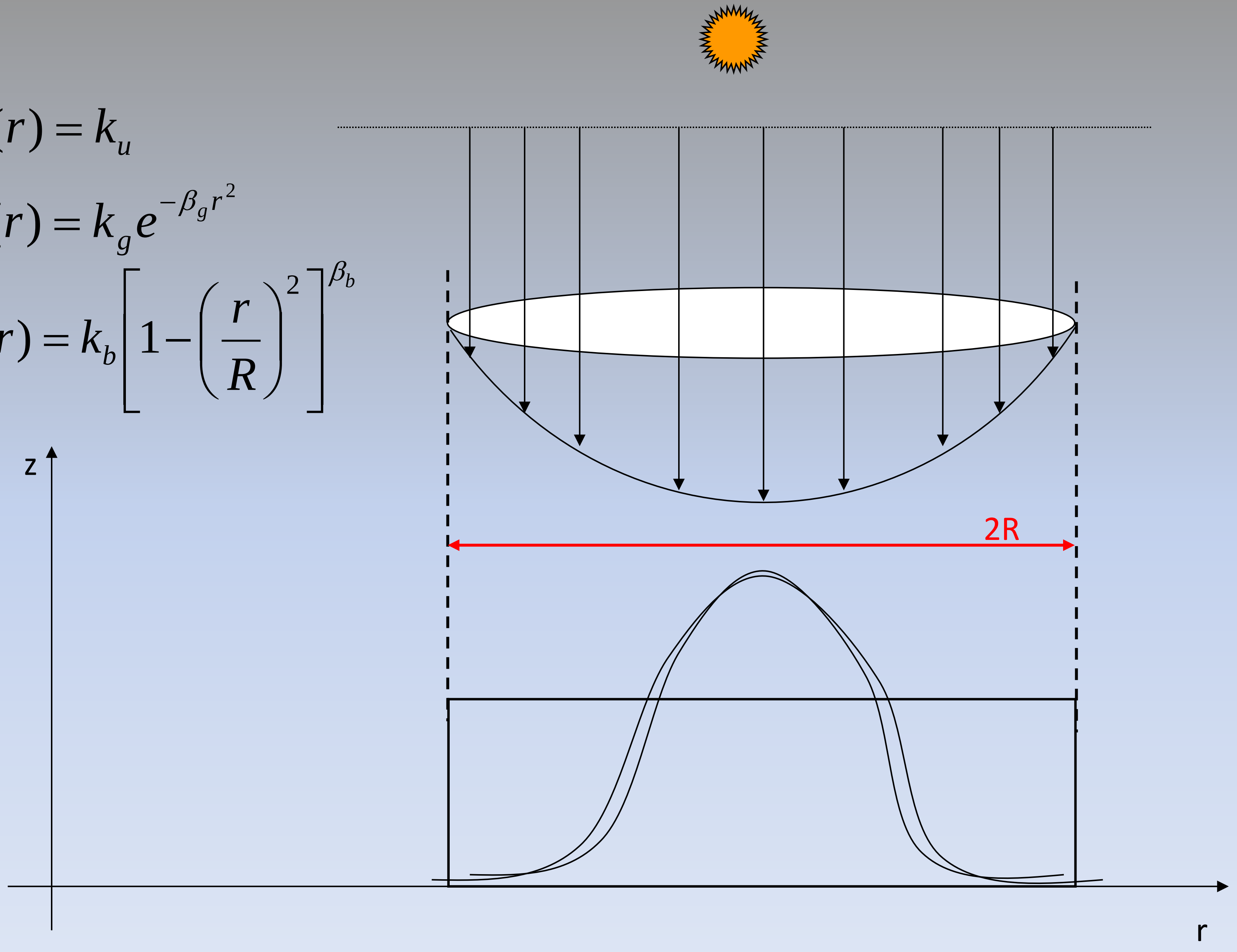
- Laser scanning for ΔF: *Sarti et al. 2009; Holst et al. 2012; (J Surv Eng*)
- Finite Element Model: all Δs in Clark and Thomsen 1988 (NASA Tech Rep); ΔF in *Sarti el al. 2009 (J Geodesy*)
- Triangulation and trilateration: ΔR in *Sarti el al. 2009 (J Geodesy*)

$$\Delta L(e)=\alpha_F \Delta F(e)+\alpha_R \Delta R(e)+\alpha_V \Delta V(e)$$

$$I_u(r) = k_u$$

$$I_g(r) = k_g e^{-\beta_g r^2}$$

$$I_b(r) = k_b \left[1 - \left(\frac{r}{R}\right)^2\right]^{\beta_b}$$



$$\alpha_R^i = \int_S h(r) I(r) dS$$

Primary focus configuration:

$$\alpha'_F = 1 - \alpha'_R$$

$$\alpha'_V = -1 - \alpha'_R$$

Cassegrainian configuration:

$$\alpha''_F = 2 - 2\alpha''_R$$

$$\alpha''_V = -1 - 2\alpha''_R$$

Abbondanza & Sarti (2010), J Geodesy

Table 1 Values of the linear coefficients α computed for the Medicina and Noto telescopes for primary and Cassegrainian configurations adopting (a) IFun1: uniform, (b) IFun2: Gaussian and (c) IFun3: binomial illumination functions

	IFun 1	IFun 2	IFun 3	4[a]
Primary focus				
α'_R	0.56	0.75	0.68	0.62
α'_V	−1.56	−1.75	−1.68	−1.62
α'_F	0.44	0.25	0.32	0.38
	IFun 1	IFun 2	IFun 3	4[b]
Secondary focus				
α''_R	0.77	0.84	0.83	0.81
α''_V	−2.54	−2.68	−2.66	−2.62
α''_F	0.46	0.32	0.34	0.38

Last column contains values based on a rule of thumb as derived by and adapted from Cha (1987)

[a] Adapted from Cha (1987)

[b] Derived by Cha (1987)

Abbondanza & Sarti, 2010 J Geodesy

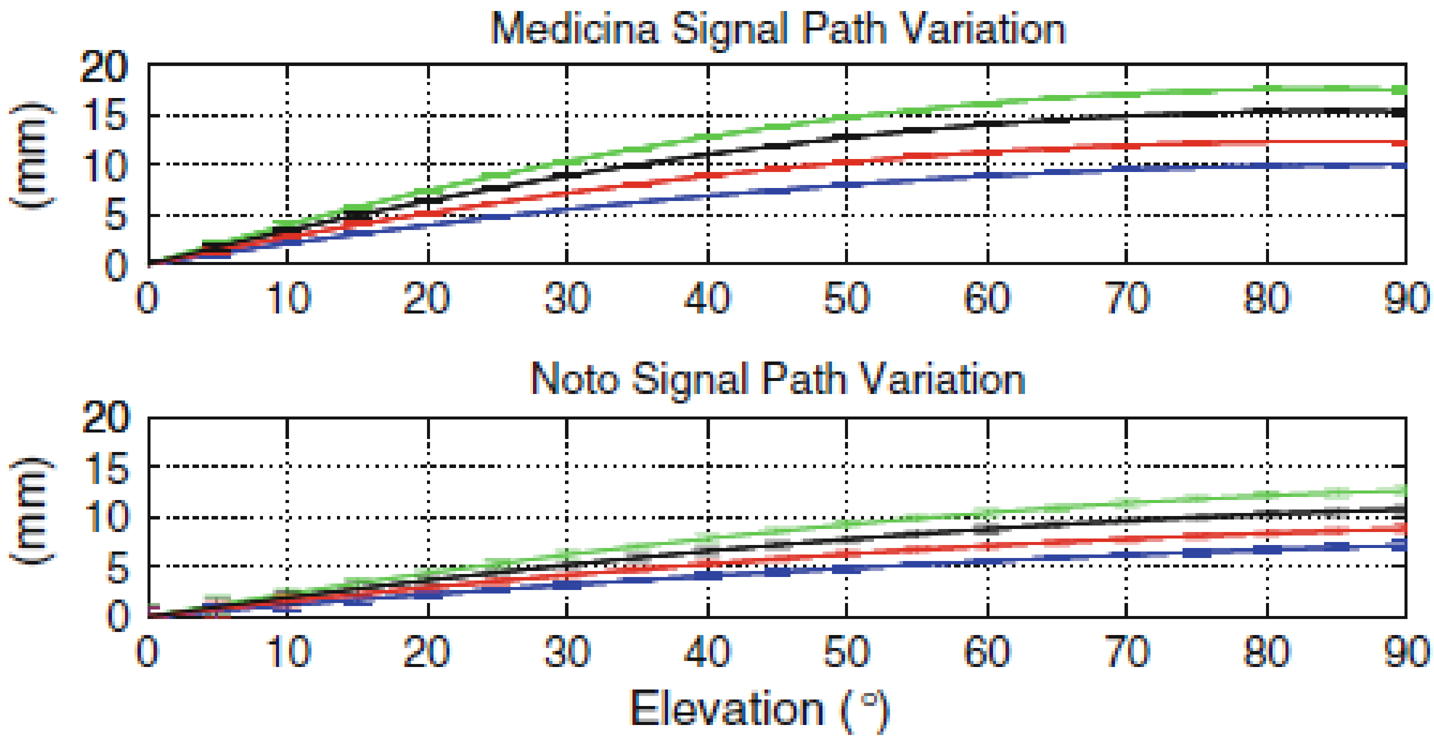


Fig. 3 Signal path variations of Medicina and Noto telescopes computed with α coefficients contained in Table 1: the *green curve* corresponds to the uniform illumination function; the *black curve* to the simplified computation reported in *column* 4; the *red* and *blue curves* correspond to the binomial and Gaussian illumination function, respectively

ΔL in VLBI data analysis

(*Sarti et al. 2011, J Geodesy*)

- VTD/Solve allows computation of theoretical VLBI path delay (Petrov 2008, Ref Manual)
- 7.08 millions of VLBI observations processed with VTD/Solve
- 345 experiments for Medicina; 150 for Noto
- Ran two solutions:
  - R1: reference solution without SPV model
  - A1: as R1 but SPV models for Medicina and Noto applied

Station	ΔU (mm)	ΔE (mm)	ΔN (mm)	# Sess
DSS65	0.0	0.0	0.0	86
MATERA	0.0	0.0	0.0	632
MEDICINA	**8.9**	0.0	0.0	345
NOTO	**6.7**	0.0	0.0	150
NYALES20	0.0	0.0	0.0	912
ONSALA60	0.0	0.0	0.0	632
WETTZELL	0.0	0.0	0.0	2612

Sarti et al. 2011, J Geodesy

Conclusions

- Gravitational deformations
  - may deform the structure of the telescope to a non negligible extent
  - modify the Up component of the telescopes Reference Point
  - do not modify the estimate of other S-geodetic parameters
  - may impact the scale of the VLBI network
- ΔL models
  - are strictly telescope-dependent and as such should be determined specifically for each VLBI telescope
  - must be computed properly:
    - with α_i coefficients computed with realistic IF
    - with ΔR, ΔV and ΔF models deriving from *ad hoc* high precision terrestrial surveys and/or FEM
  - Cannot be inferred from the telescope dimensions (NO scaling!)
- The height bias cannot be determined relying on VLBI data alone!