Effects of sky radiation on surface reflectance

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www.rayference.eu

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Surface and atmospheric radiative transfer communities seem to live on different "flat" planets.

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The atmospheric community knows that there is something solid below the atmosphere which reflects sun light in a more complicated way than a simple Lambertian surface.

Lambertian “Equivalent” Reflectance (LER) is still widely used, however without a clear mathematical definition.

Assuming the surface BRF is known, how to define a LER?

THE ROLE OF SKY RADIATIONS IN SHAPING SURFACE REFLECTANCE ANISOTROPY

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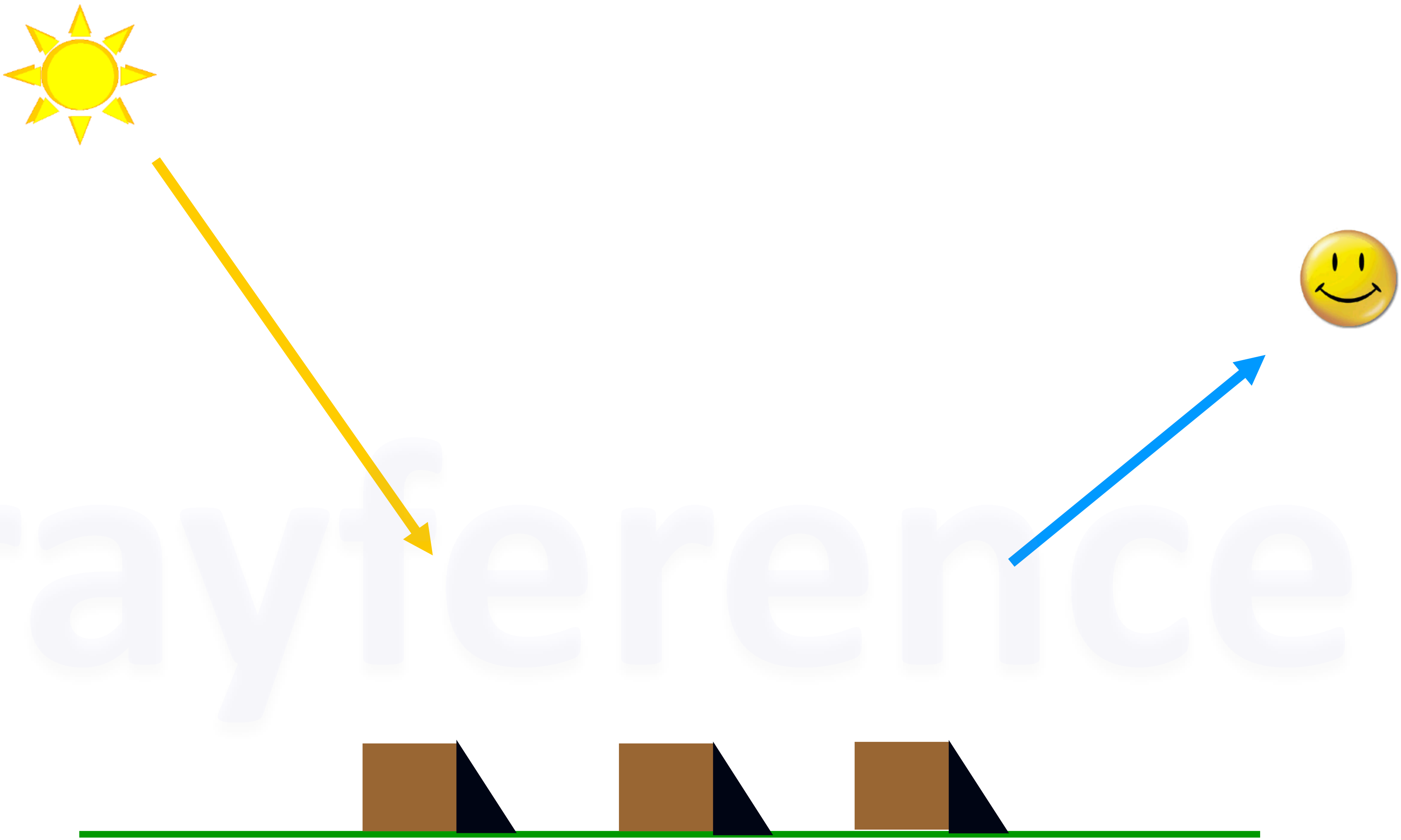

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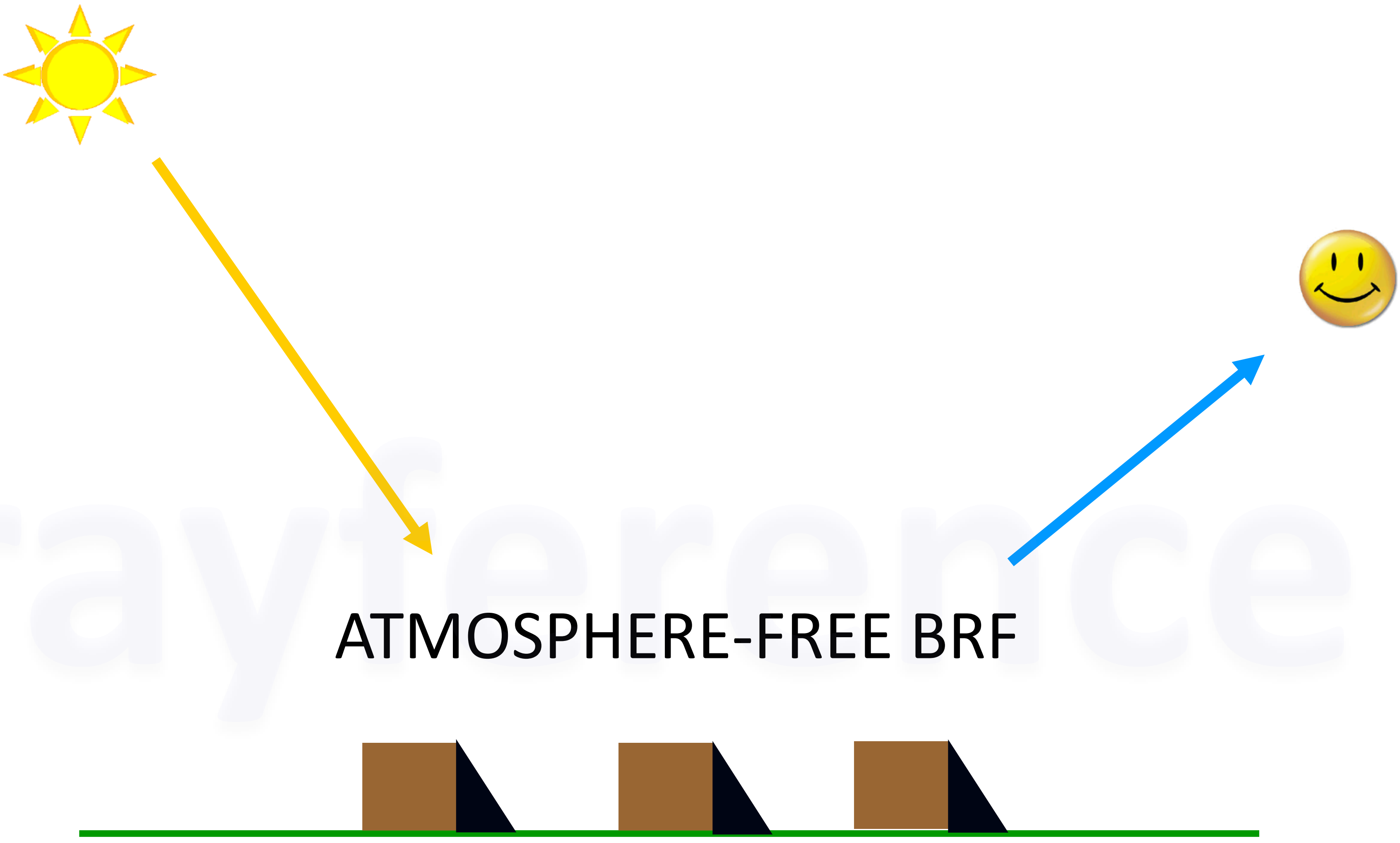
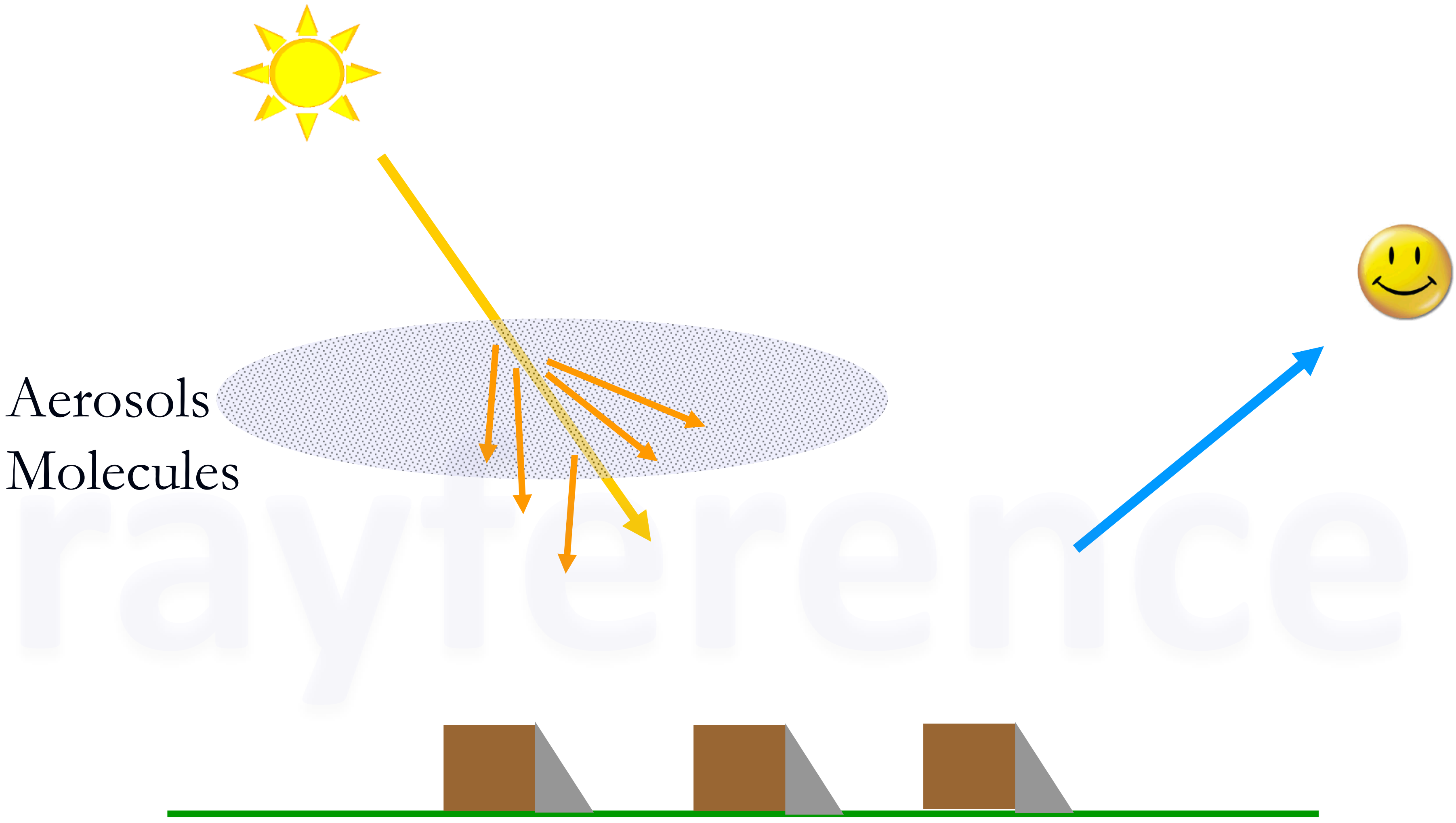

ATMOSPHERE-FREE BRF



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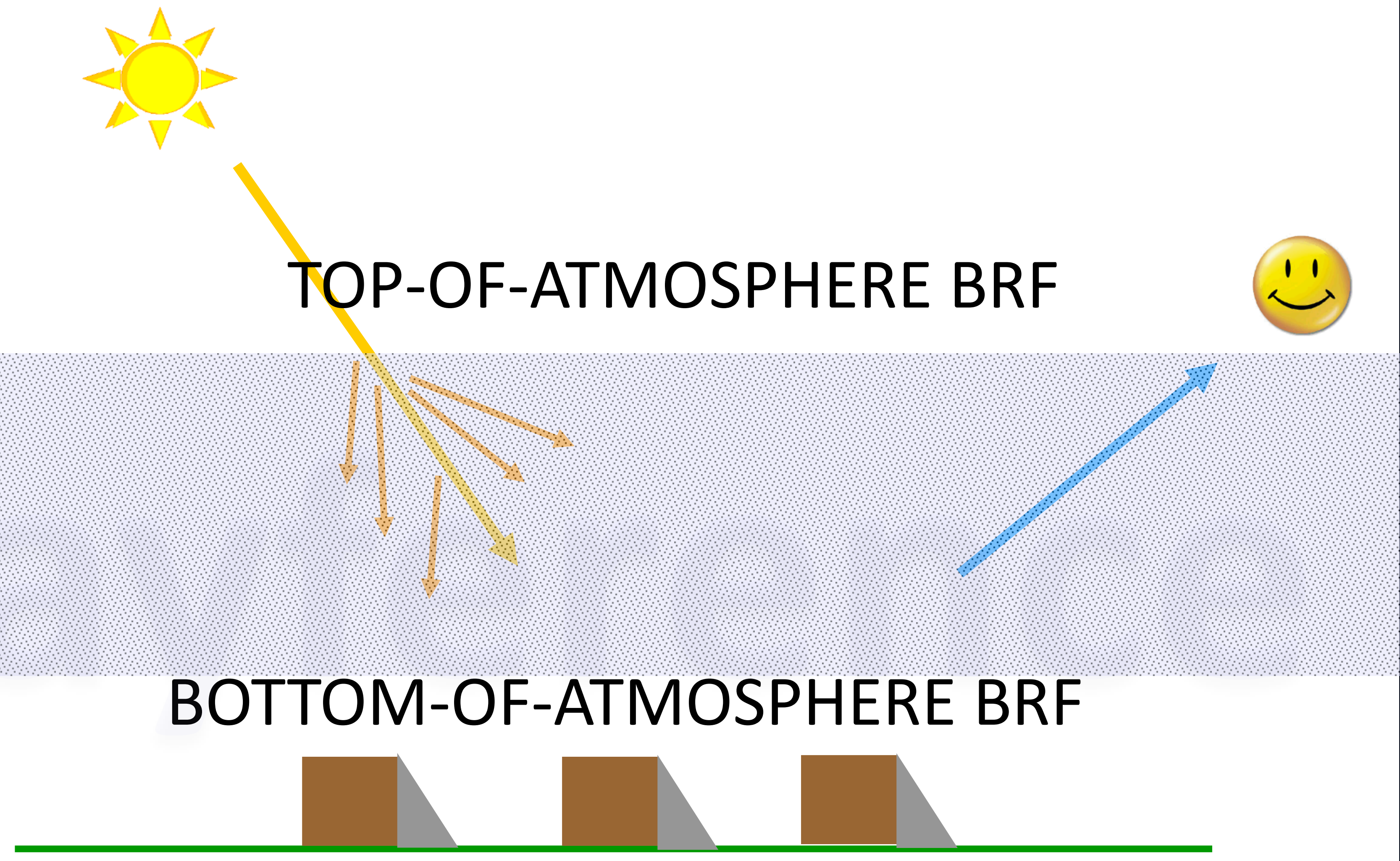
TOP-OF-ATMOSPHERE BRF
BOTTOM-OF-ATMOSPHERE BRF

The **B**ottom-**O**f-**A**tmoisphere (BOA) BRF should not be confused with the atmospheric-free surface BRF.

Atmospheric correction methods usually do not make clear whether the BOA BRF or **A**tmospheric-**F**ree (AF) surface BRF is provided.

These differences can have a significant impact for lower atmospheric composition retrieval over land surfaces.

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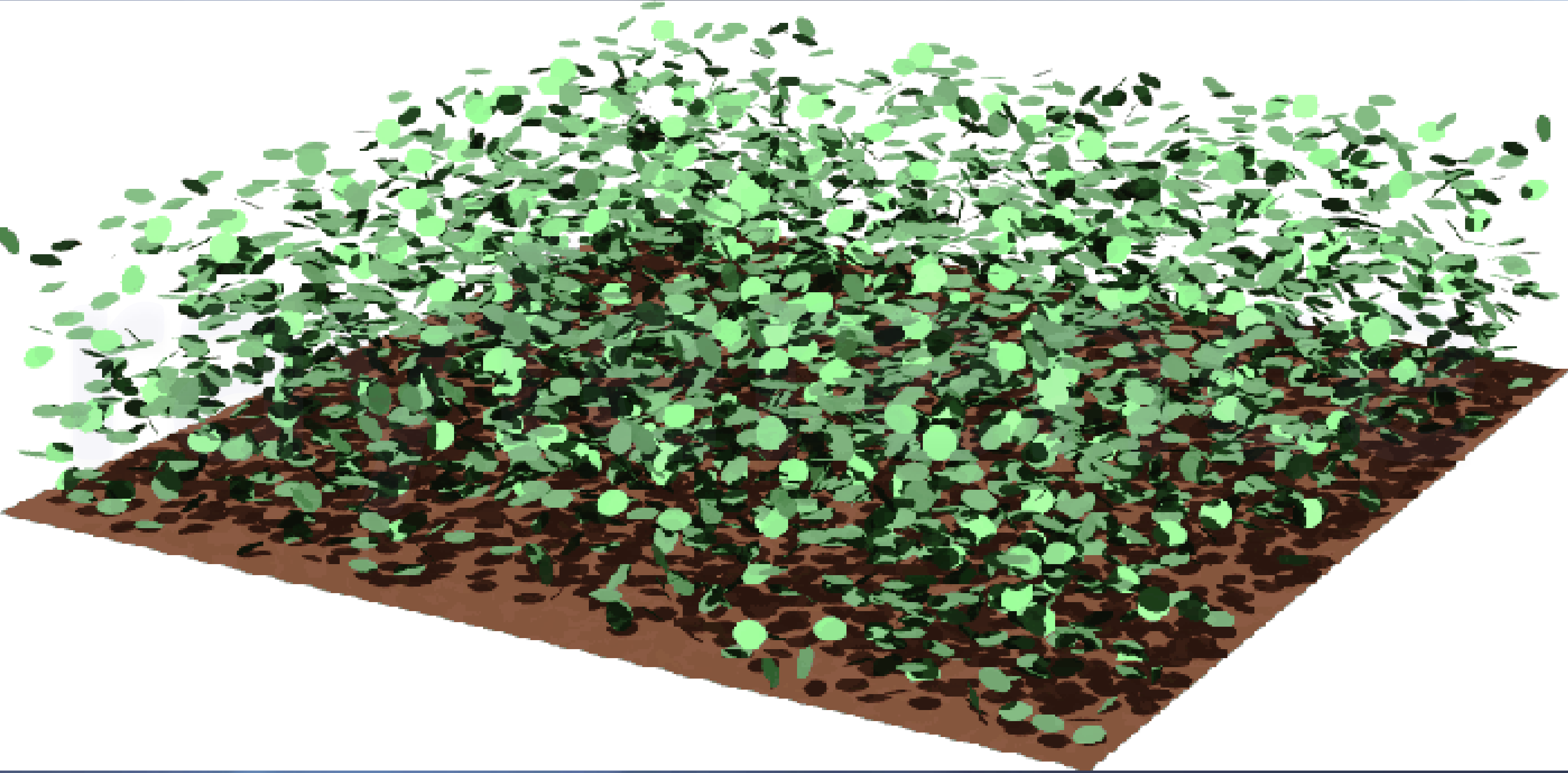
SRF – ATM INTERACTIONS

1D VEGETATED SURFACE RTM



Simulation performed with the model of Gobron, et al. . 1996. “A Semi-Discrete Model for the Scattering of Light by Vegetation.” Journal of Geophysical Research 102: 9431–46.

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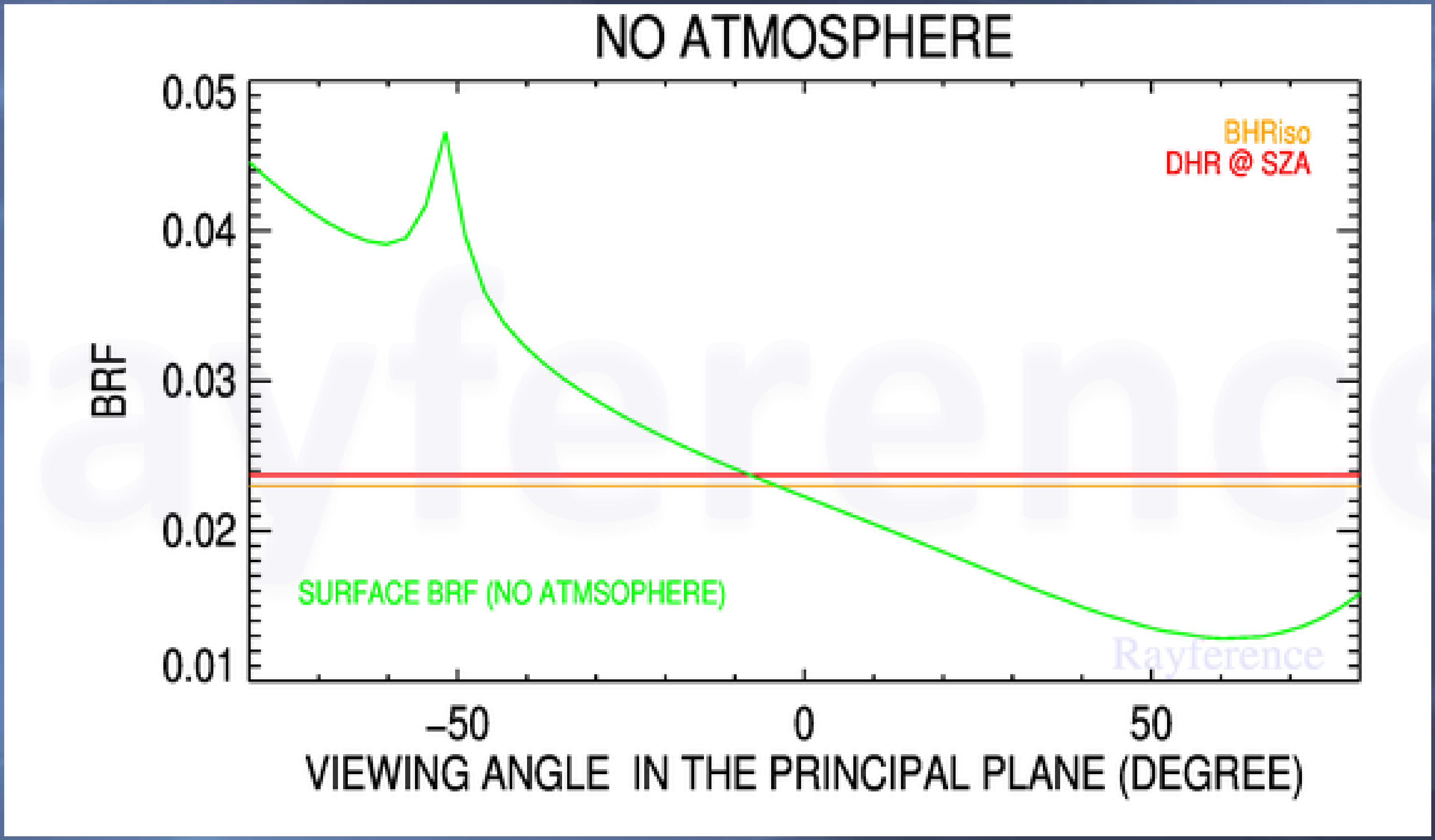
SRF – ATM INTERACTIONS



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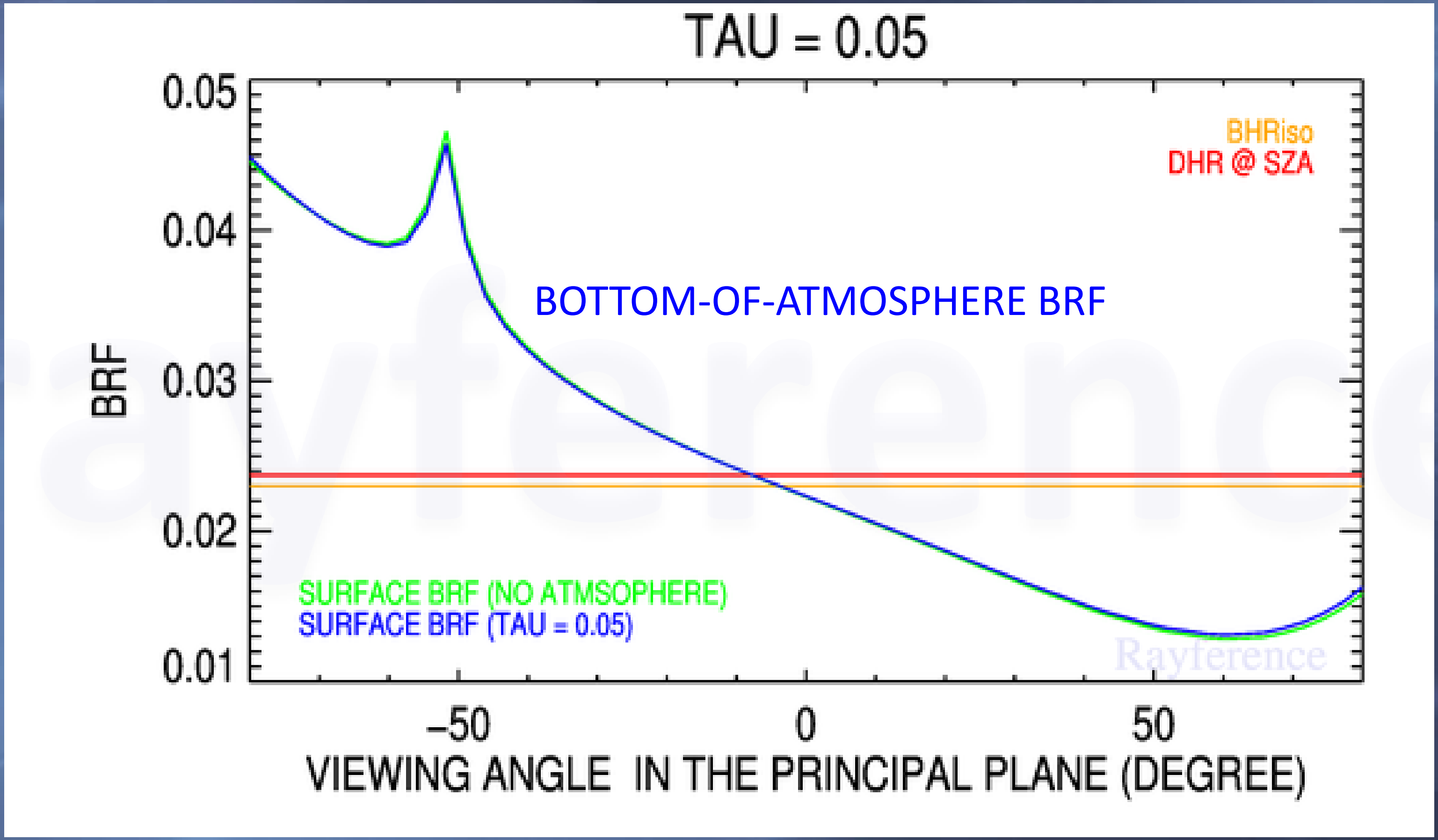
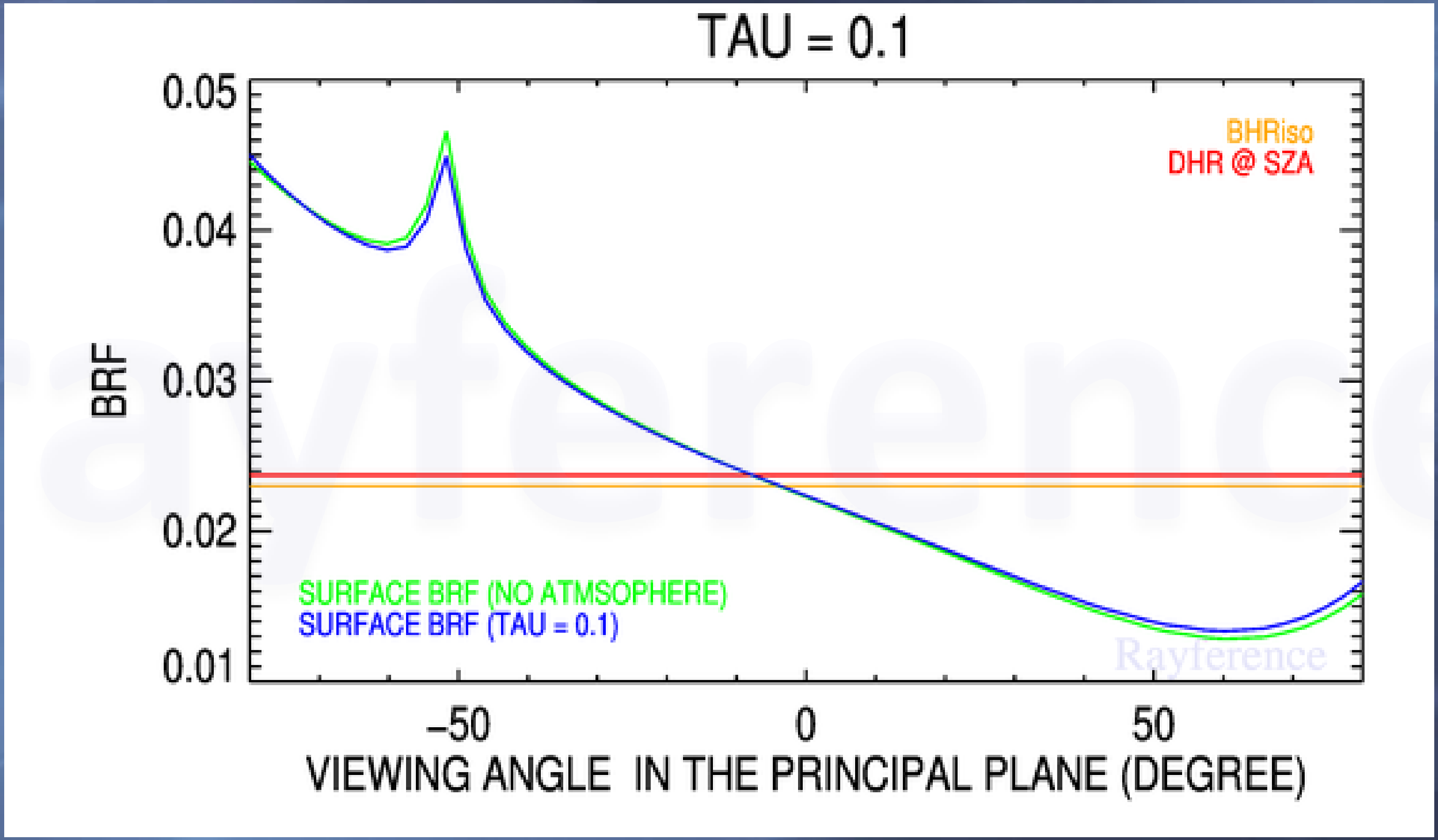
SRF – ATM INTERACTIONS



SRF – ATM INTERACTIONS



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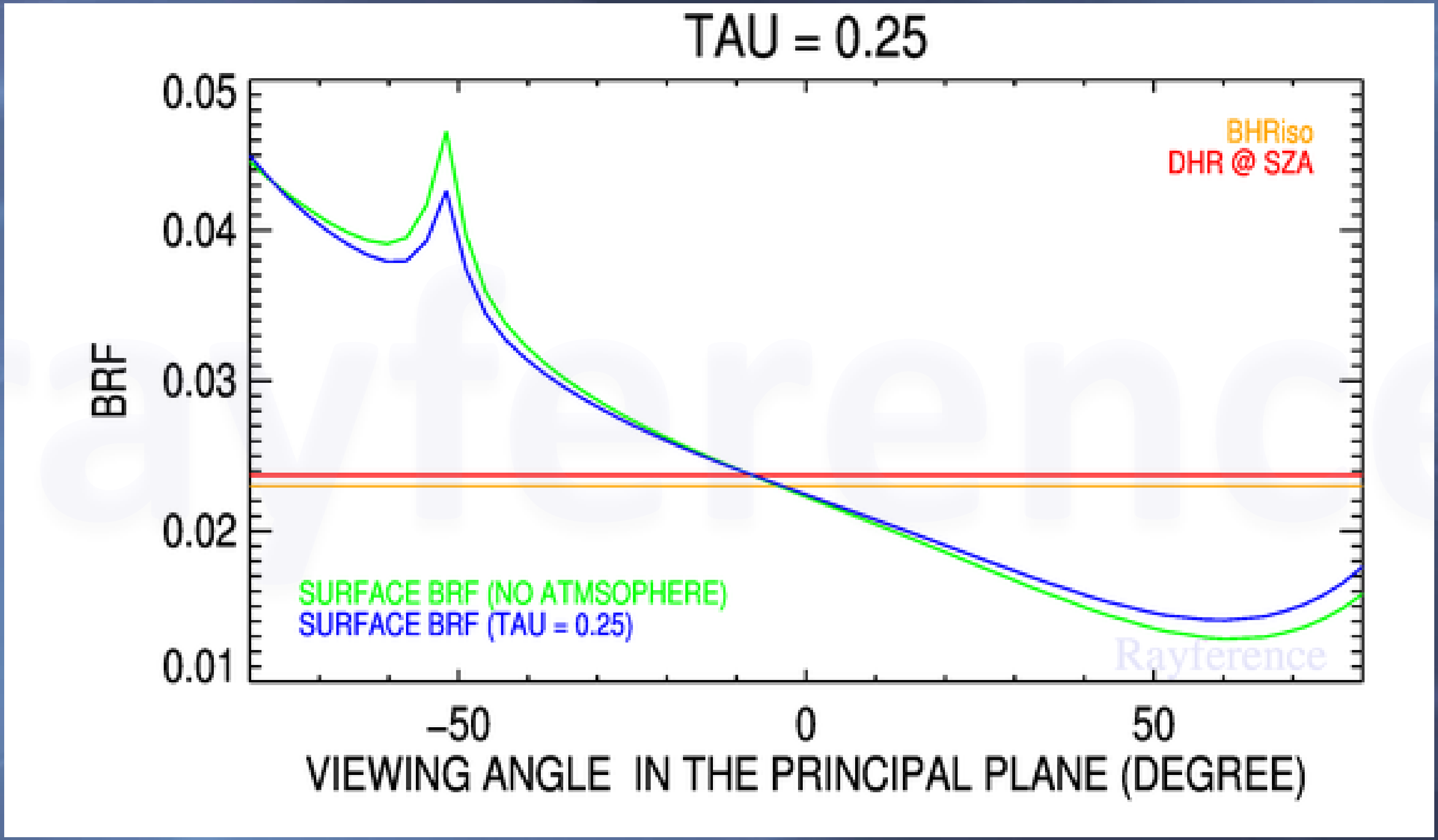
SRF – ATM INTERACTIONS



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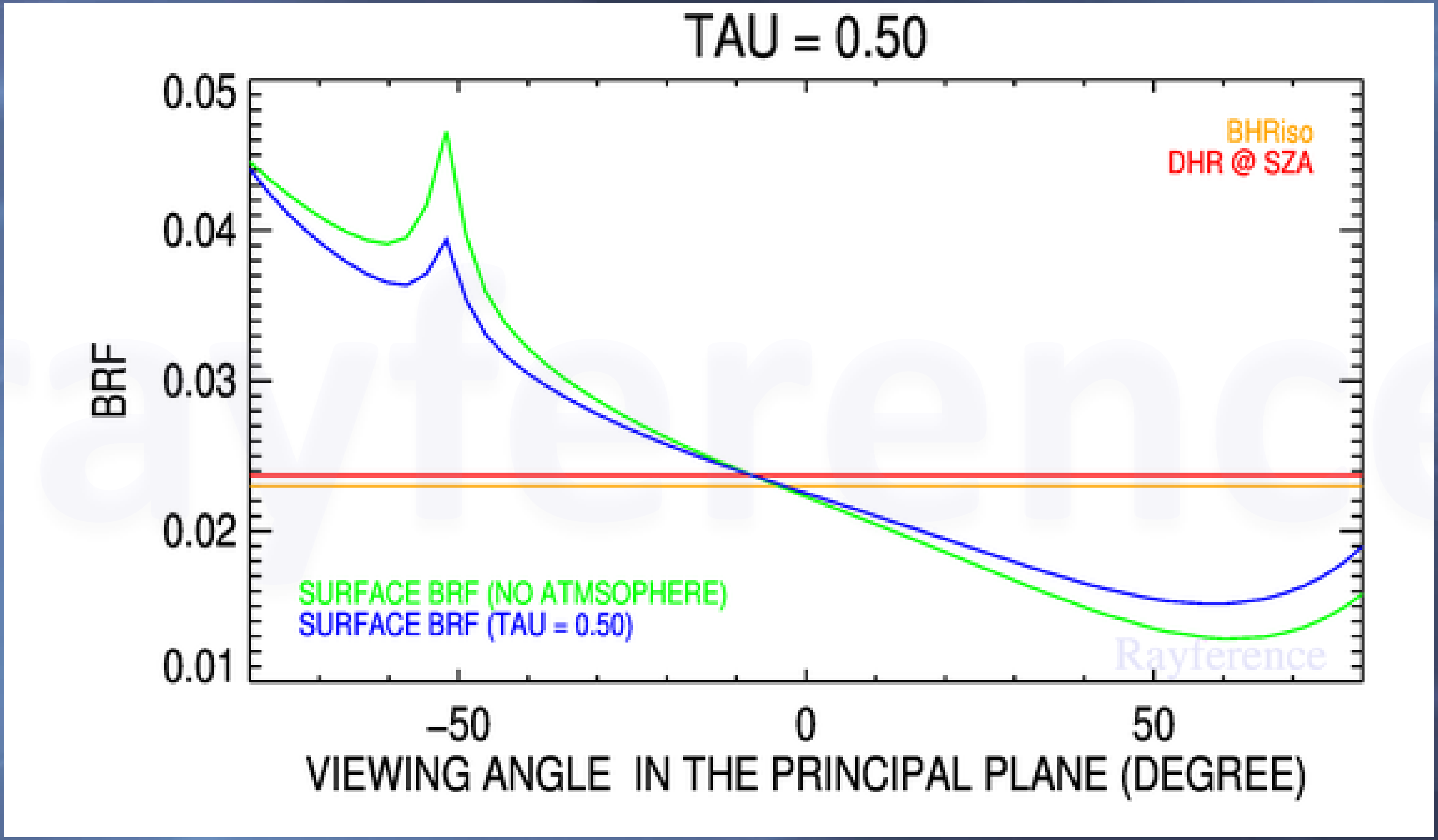
SRF – ATM INTERACTIONS



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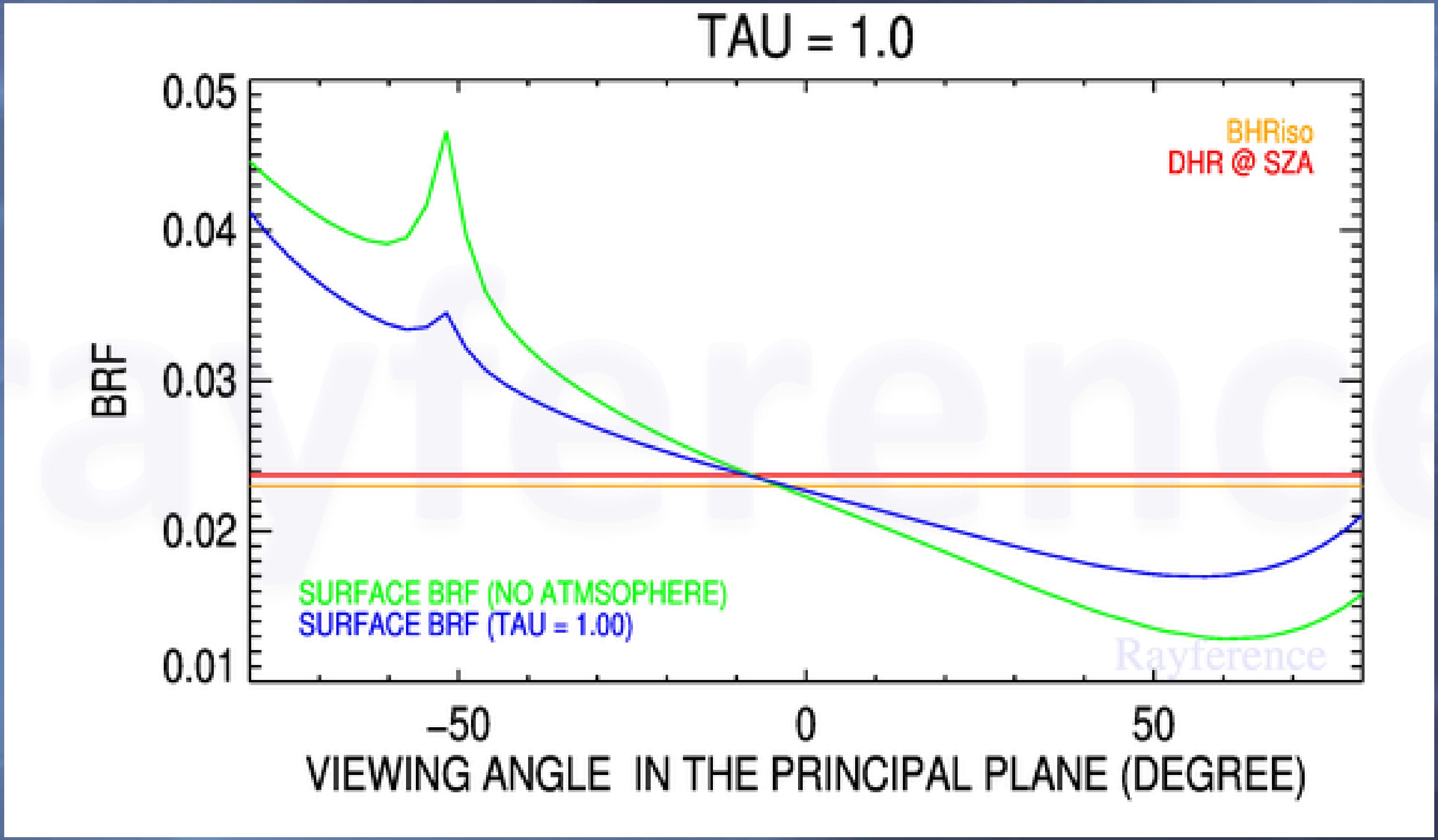
SRF – ATM INTERACTIONS



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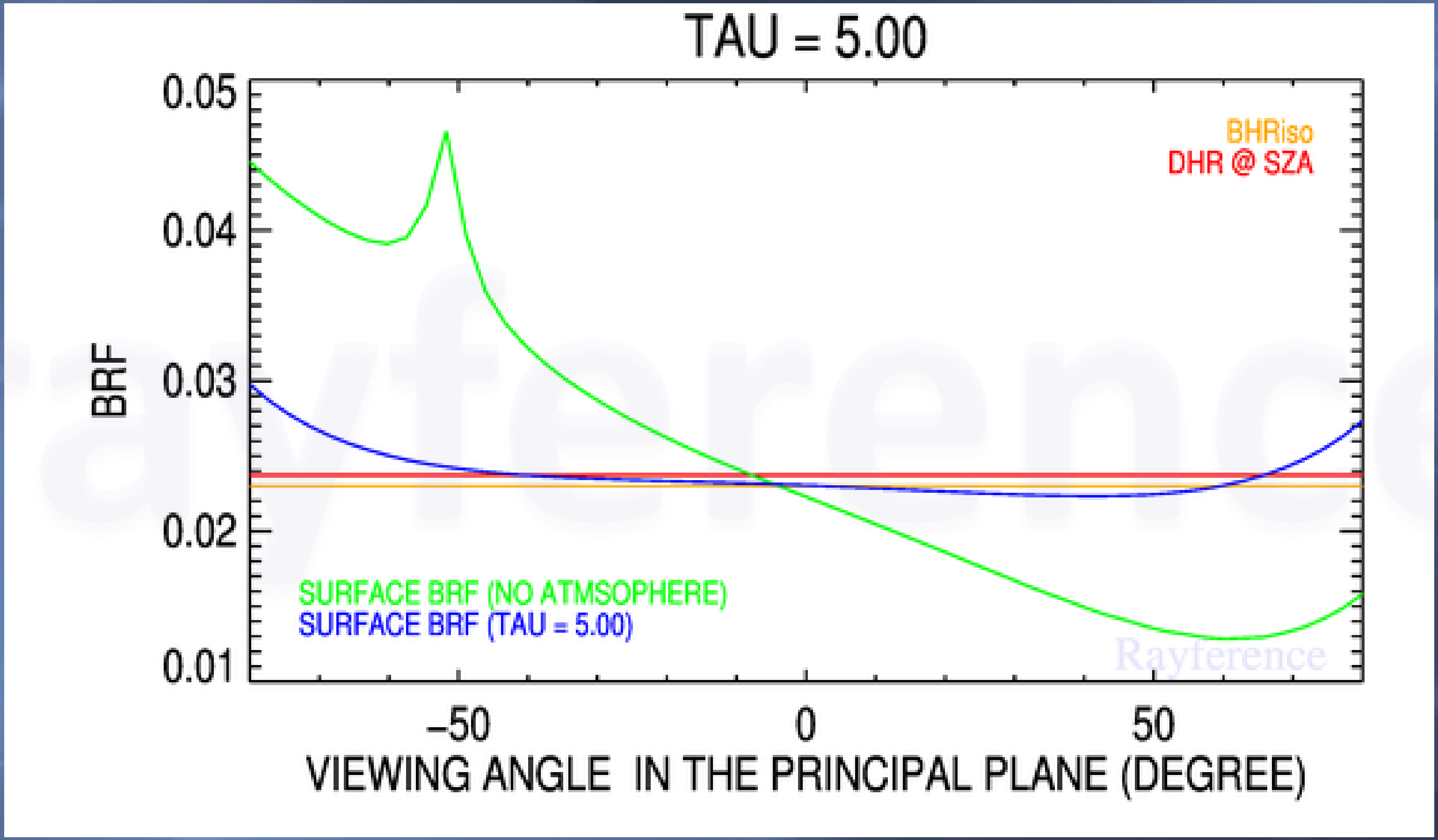
SRF – ATM INTERACTIONS



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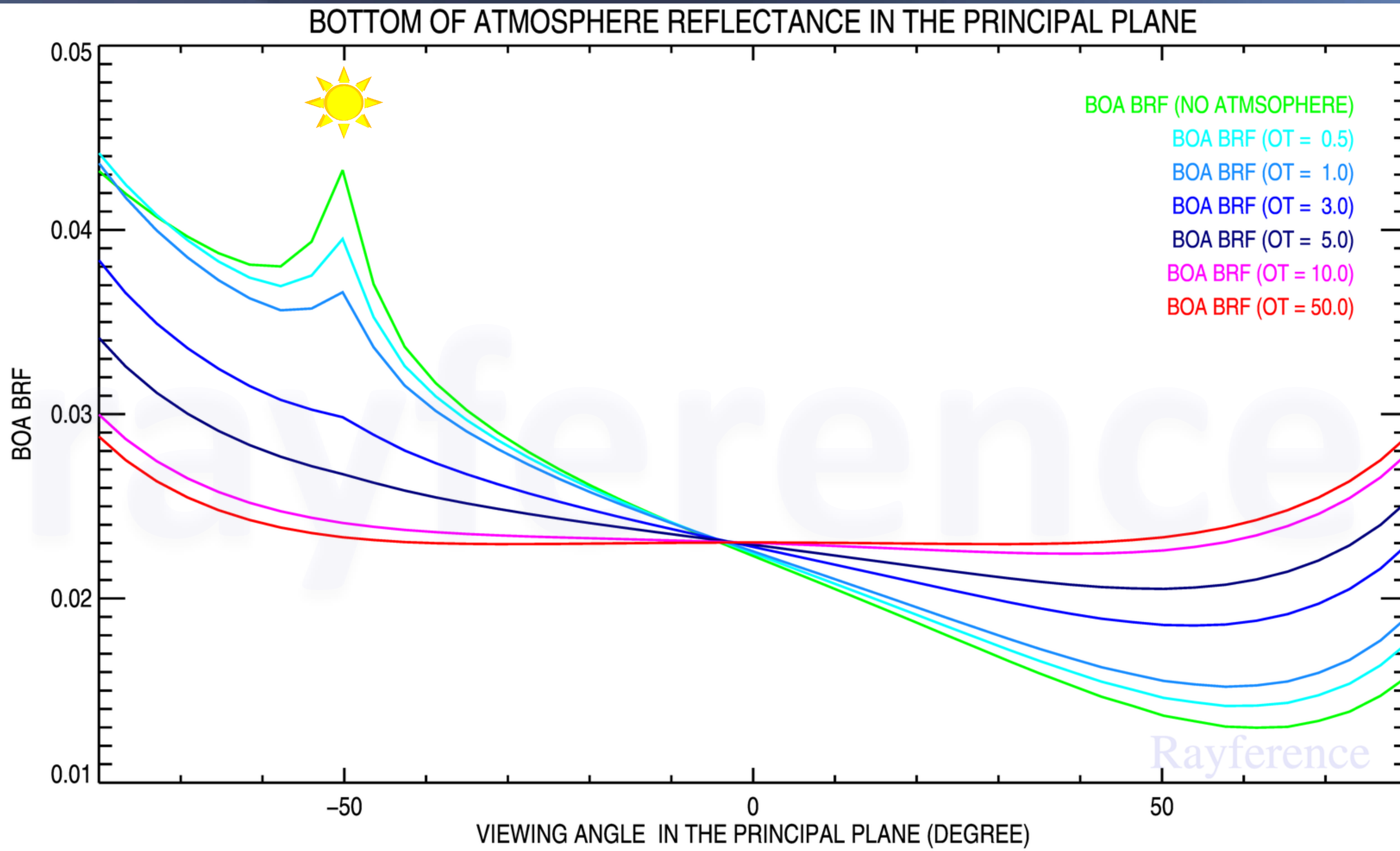

BOTTOM OF ATMOSPHERE REFLECTANCE IN THE PRINCIPAL PLANE
BOA BRF (NO ATMSOPHERE)
BOA BRF (OT = 0.5)
BOA BRF (OT = 1.0)
BOA BRF (OT = 3.0)
BOA BRF (OT = 5.0)
BOA BRF (OT = 10.0)
BOA BRF (OT = 50.0)
BOA BRF
0.05
0.04
0.03
0.02
0.01
−50
0
50
VIEWING ANGLE IN THE PRINCIPAL PLANE (DEGREE)
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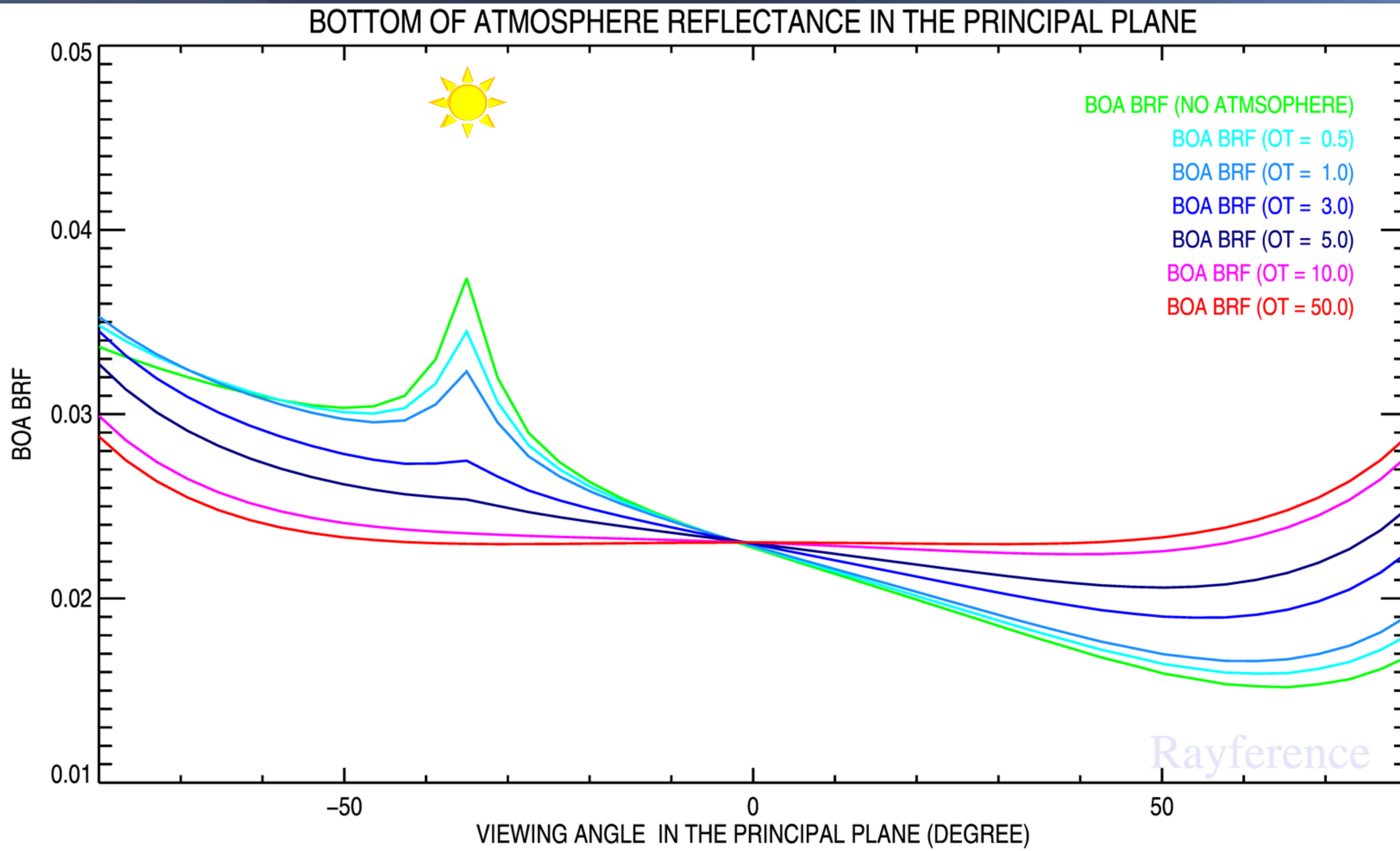

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BOA BRF (OT = 10.0)
BOA BRF (OT = 50.0)
BOA BRF
0.05
0.04
0.03
0.02
0.01
−50
0
50
VIEWING ANGLE IN THE PRINCIPAL PLANE (DEGREE)
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Aerosol optical thickness can change because:

- The particle concentration or extinction coefficient change in time
- Changes in the wavelength of (hyperspectral) observations

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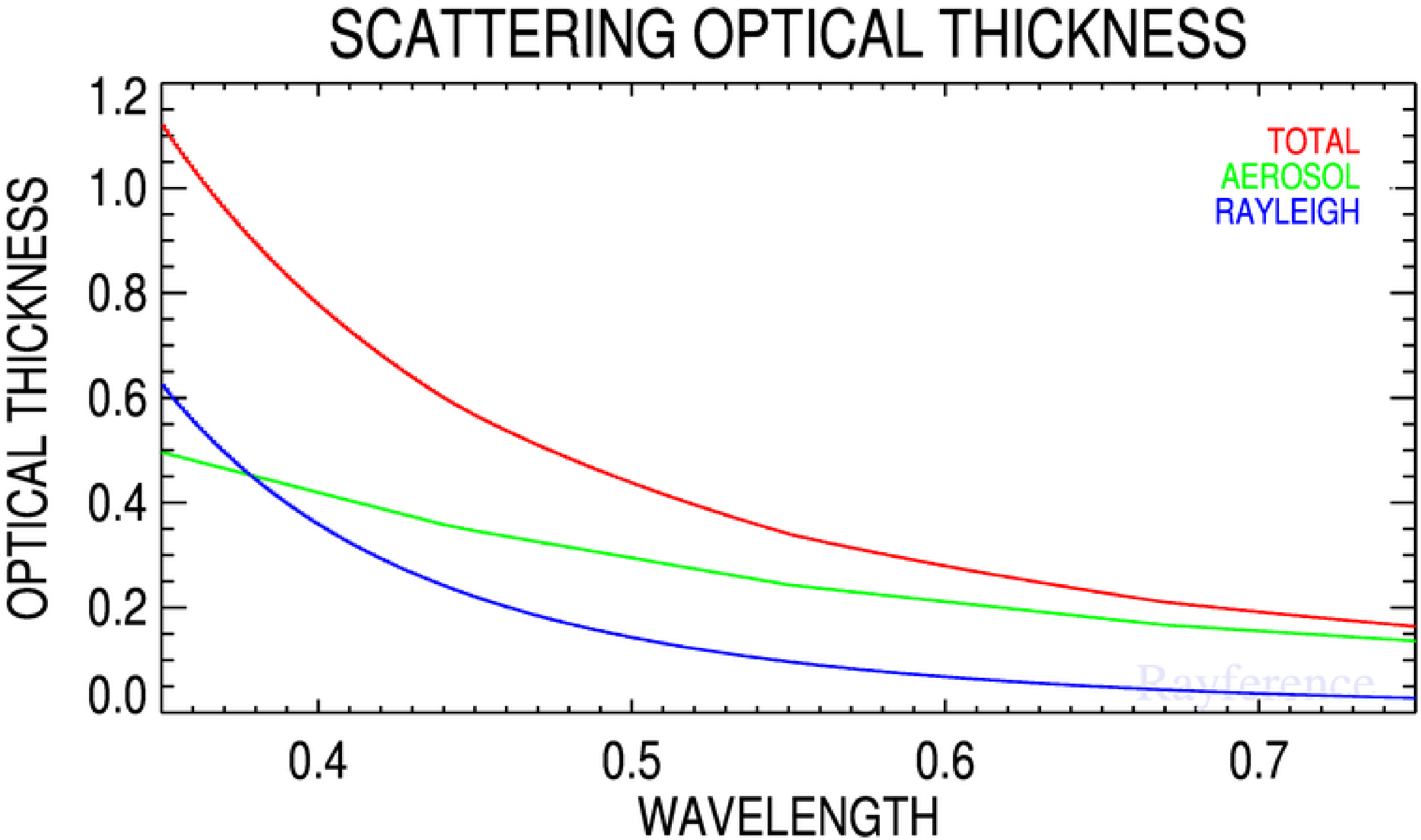
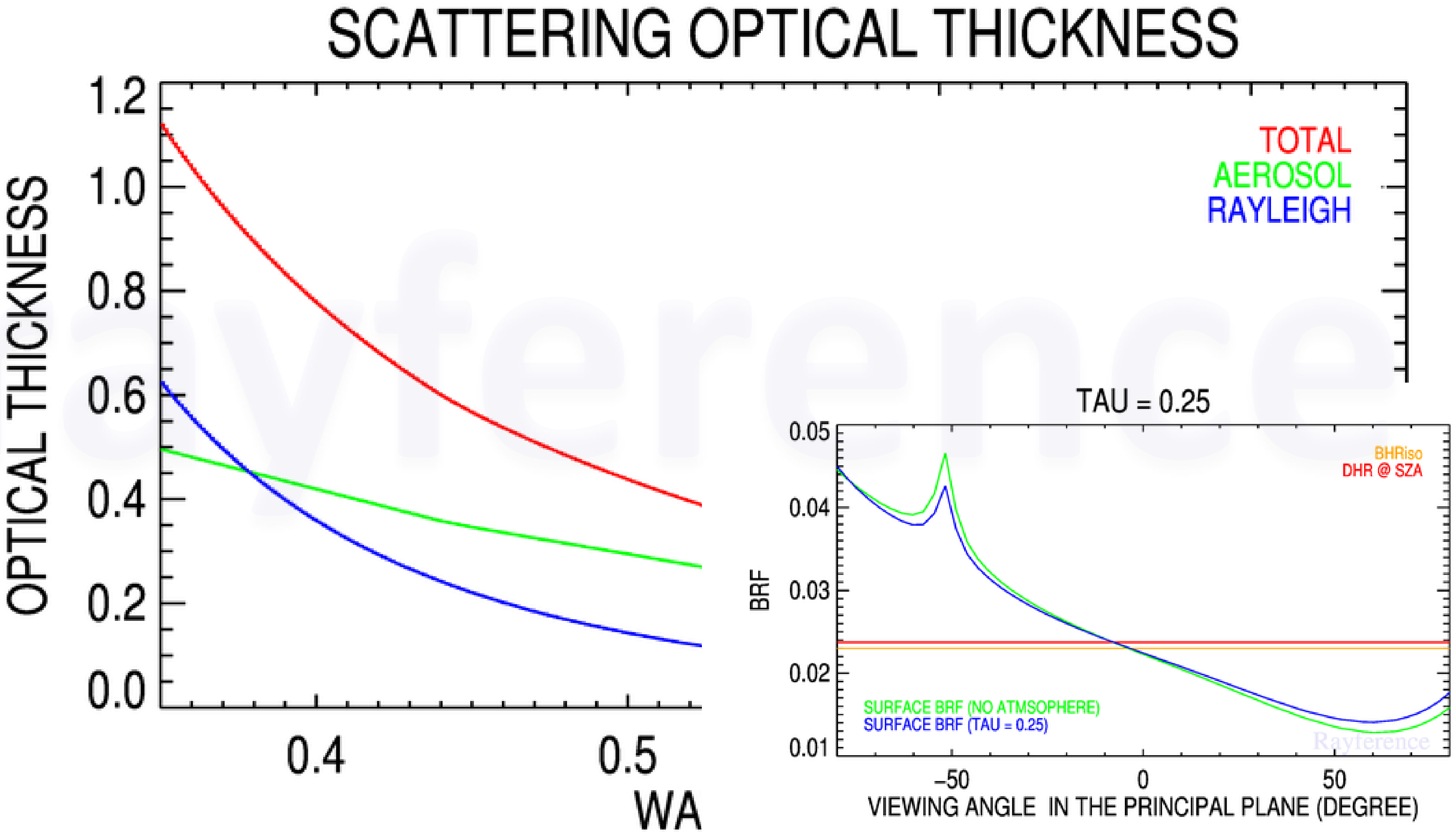
SRF – ATM INTERACTIONS



SRF – ATM INTERACTIONS



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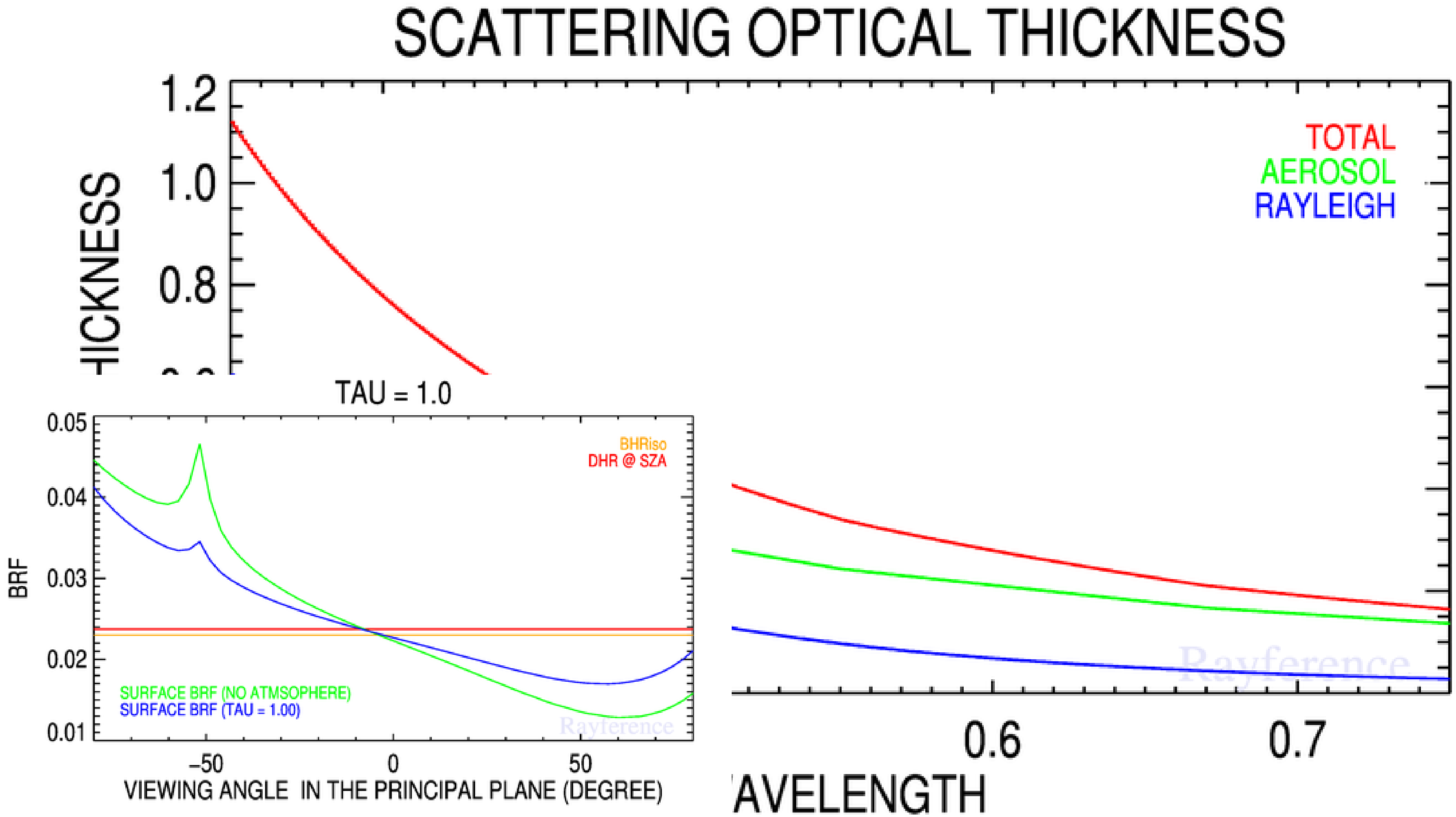
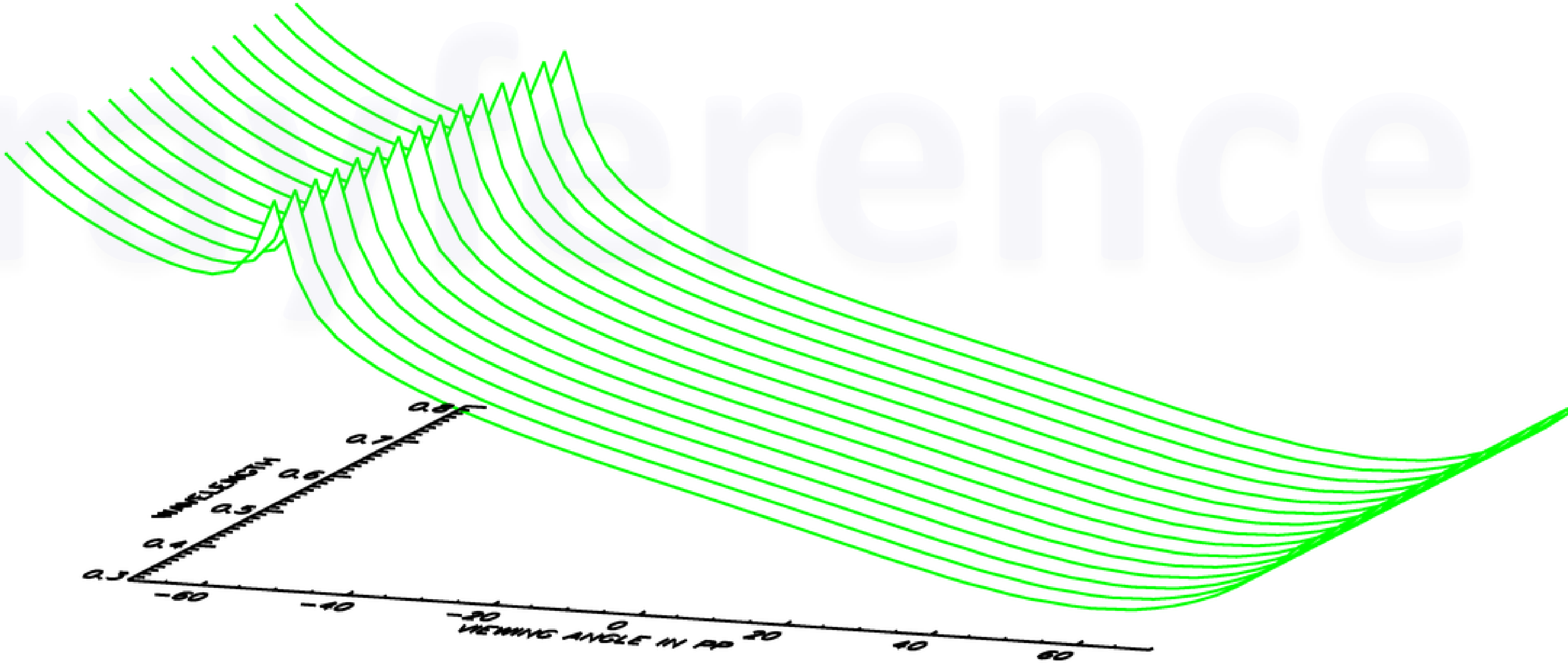


SRF – ATM INTERACTIONS

Constant instrinsic surface properties in the 320 – 750nm range

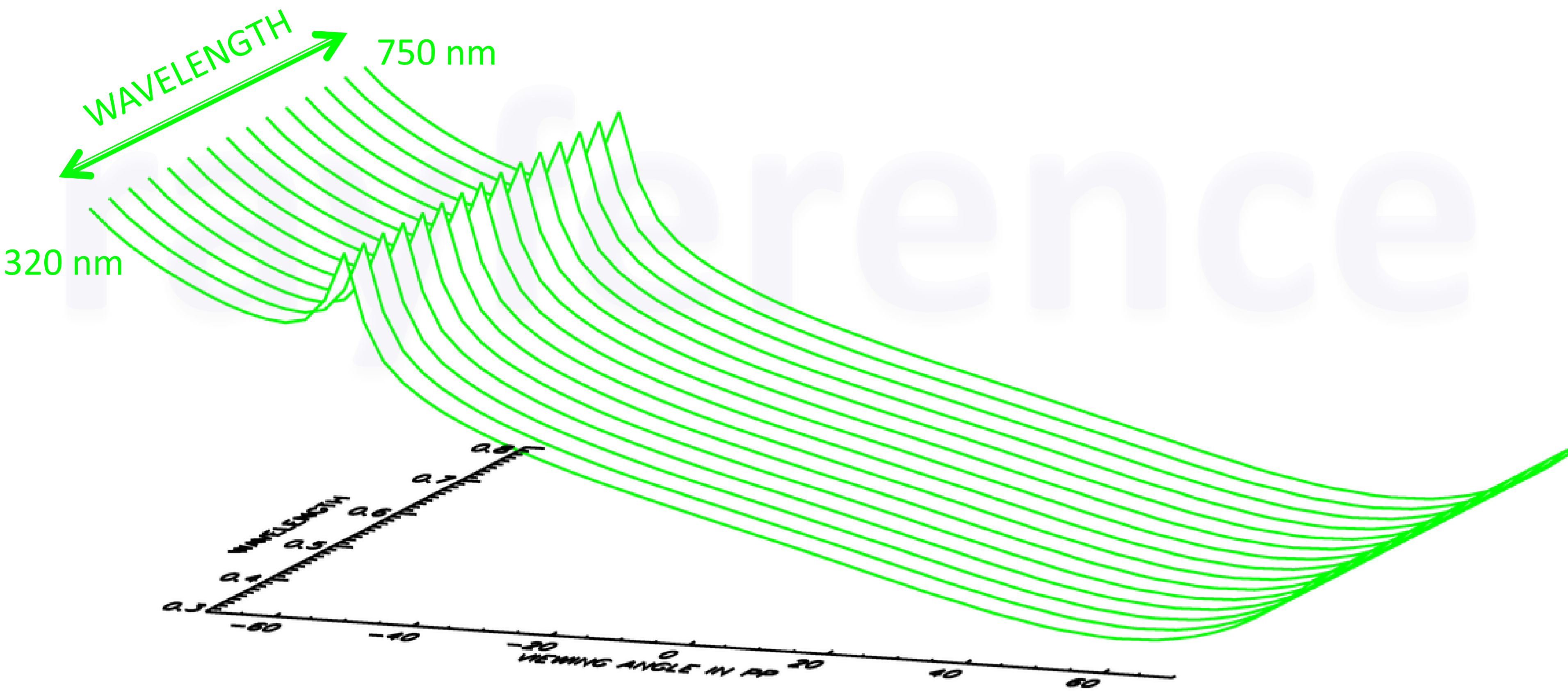
AF SURFACE BRF IN THE PRINCIPAL PLANE IN THE 320 – 750nm SPECTRAL RANGE



SRF – ATM INTERACTIONS

Let’s assume constant intrinsic surface properties in the 320 – 750nm range

AF SURFACE BRF IN THE PRINCIPAL PLANE IN THE 320 – 750nm SPECTRAL RANGE



SRF – ATM INTERACTIONS

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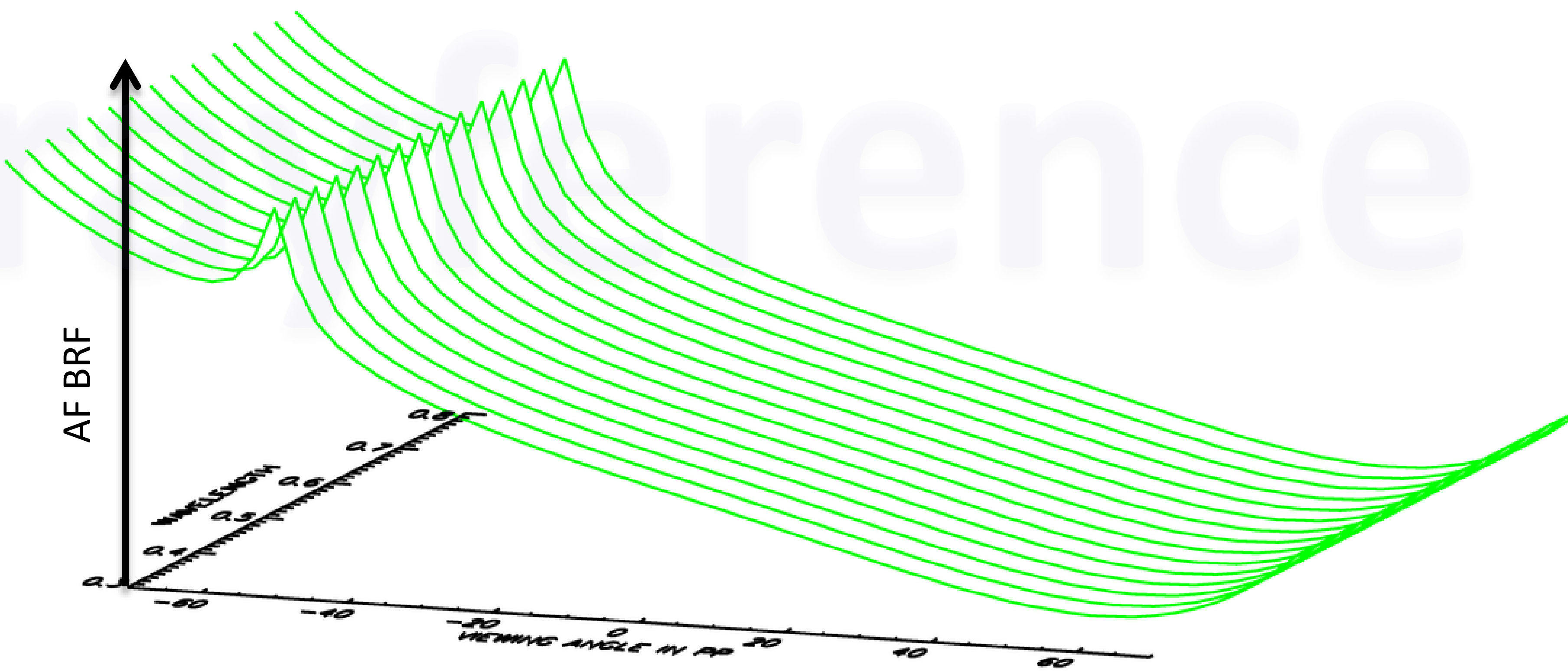

SRF – ATM INTERACTIONS

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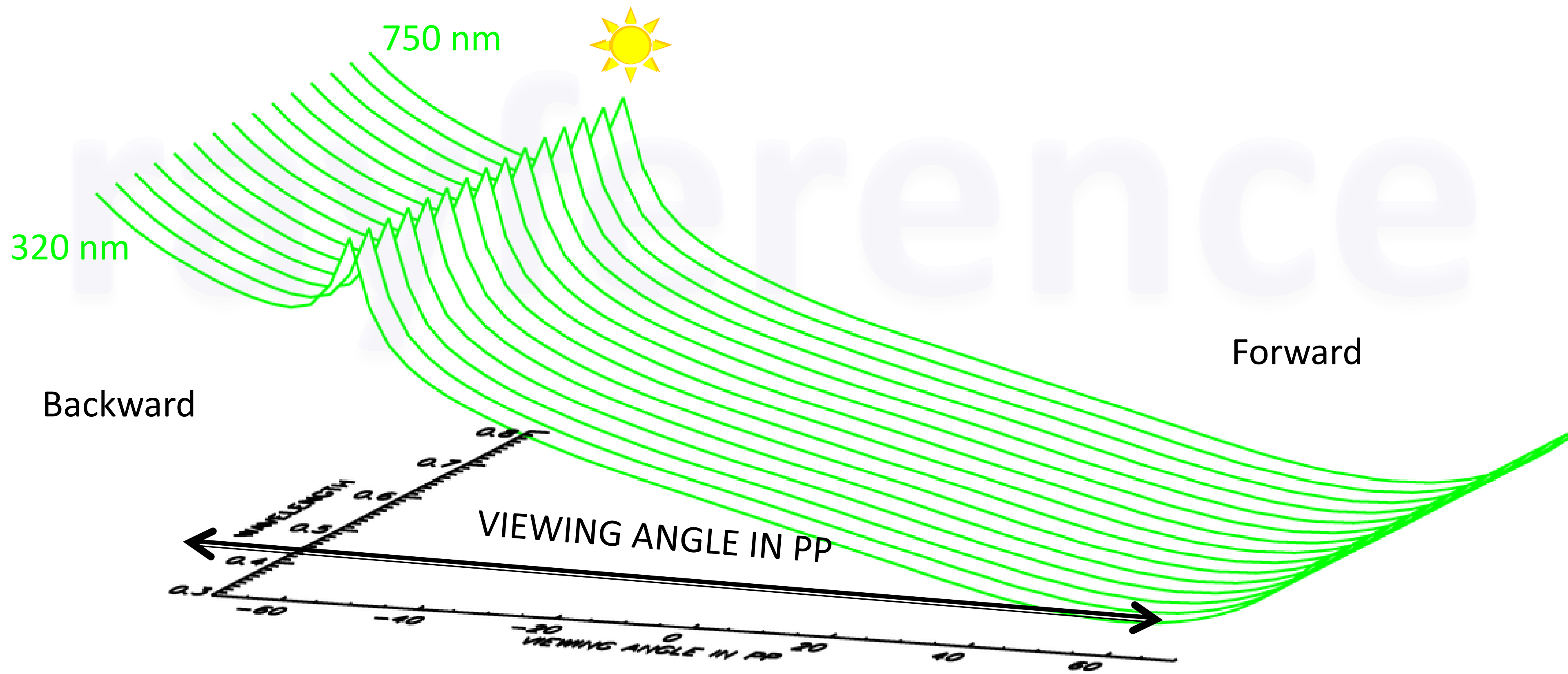
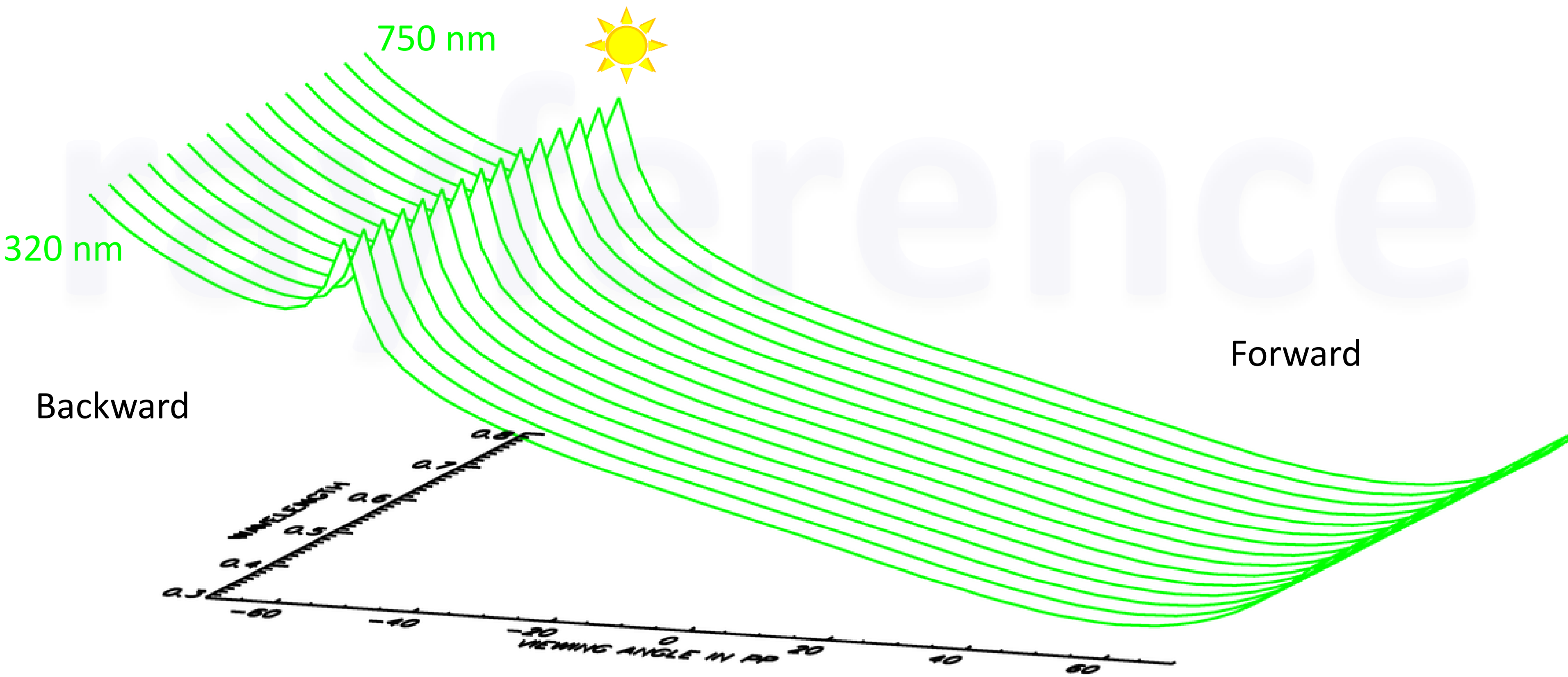


SRF – ATM INTERACTIONS

Let’s put an atmosphere on top of the surface

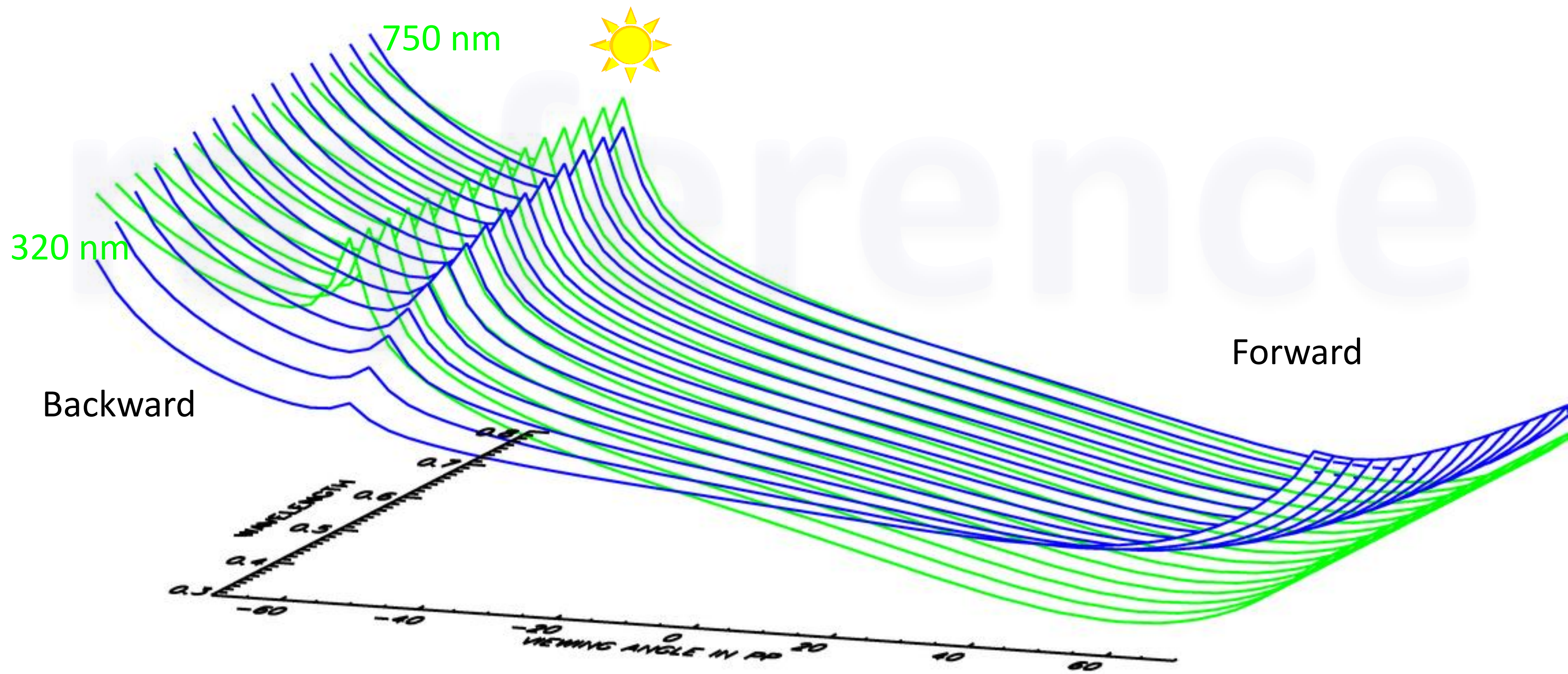
AF SURFACE BRF IN THE PRINCIPAL PLANE IN THE 320 – 750nm SPECTRAL RANGE



SRF – ATM INTERACTIONS

Let's put an atmosphere on top of the surface

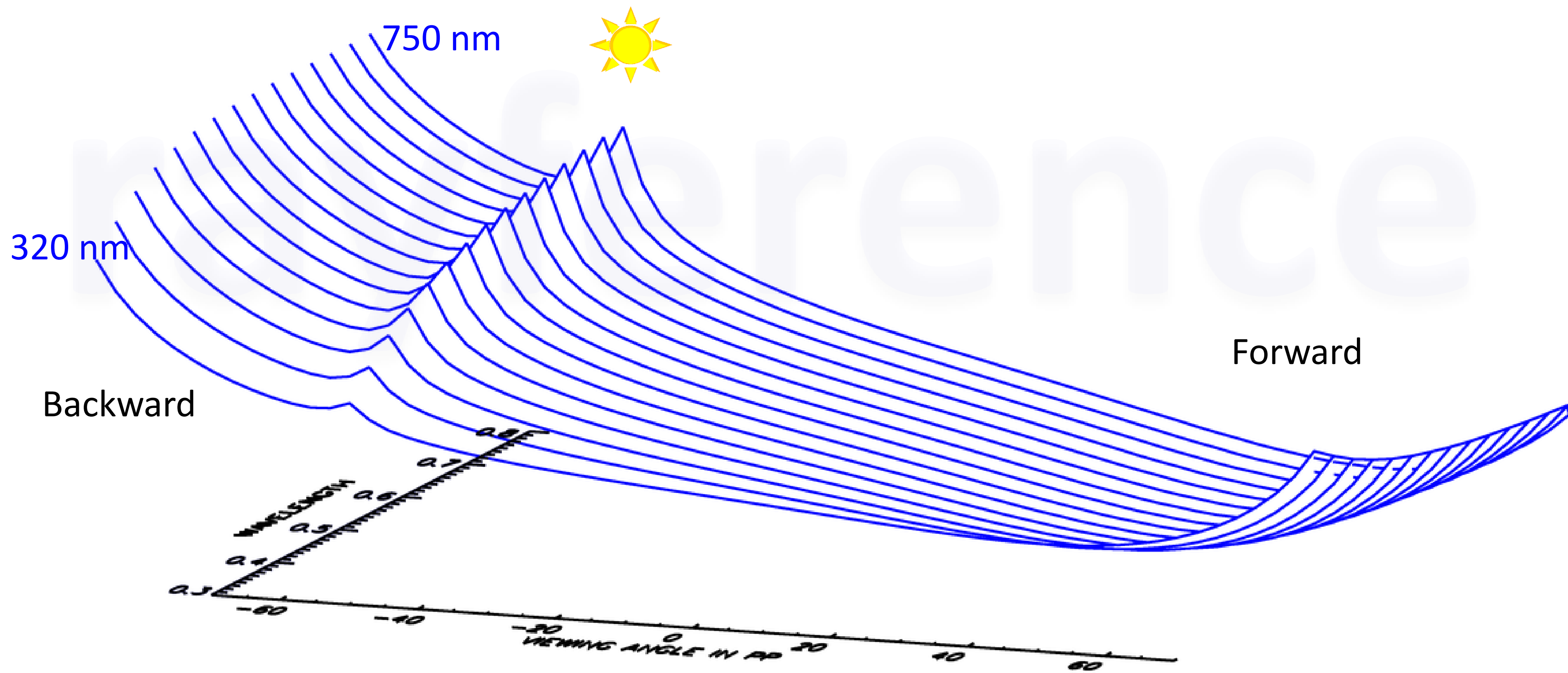
BOA BRF IN THE PRINCIPAL PLANE IN THE 320 – 750nm SPECTRAL RANGE



SRF – ATM INTERACTIONS

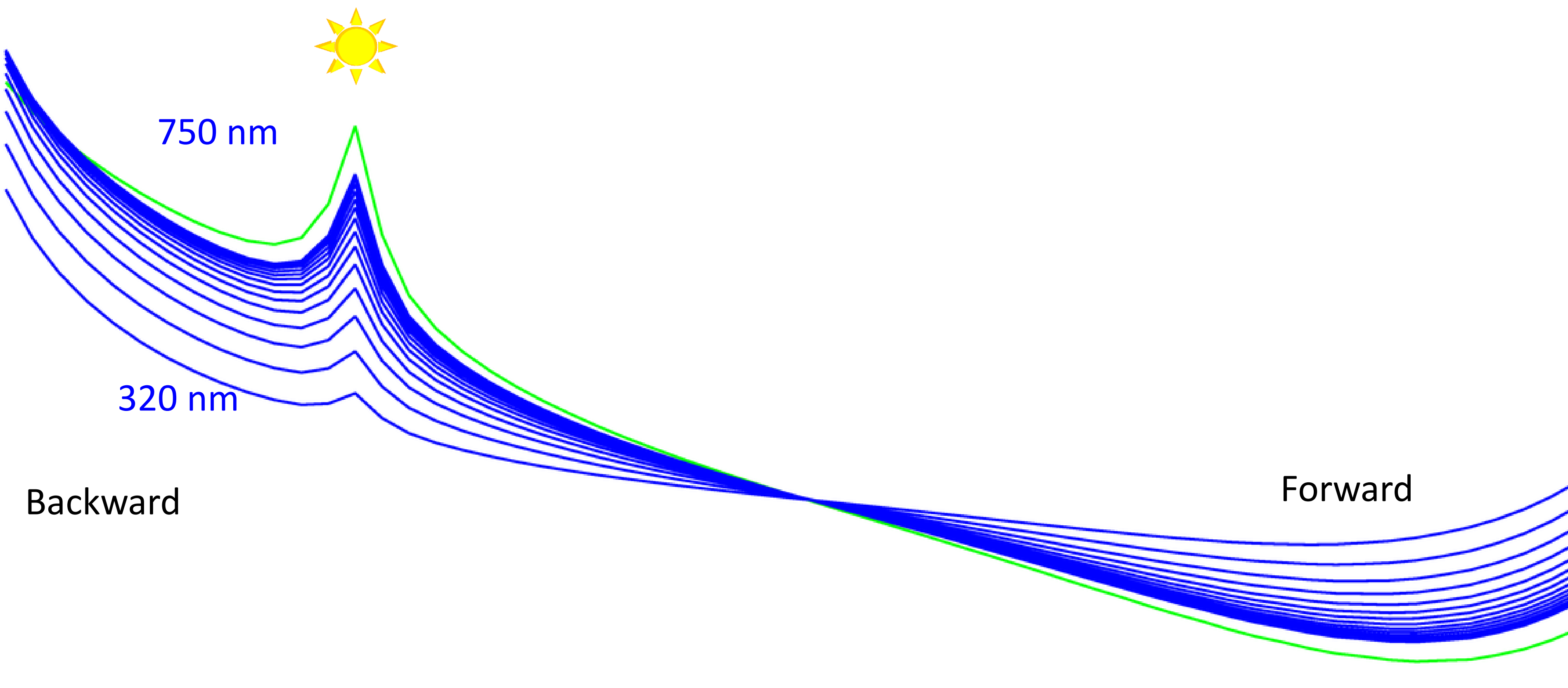
Let's put an atmosphere on top of the surface

BOA BRF IN THE PRINCIPAL PLANE IN THE 320 – 750nm SPECTRAL RANGE



SRF – ATM INTERACTIONS

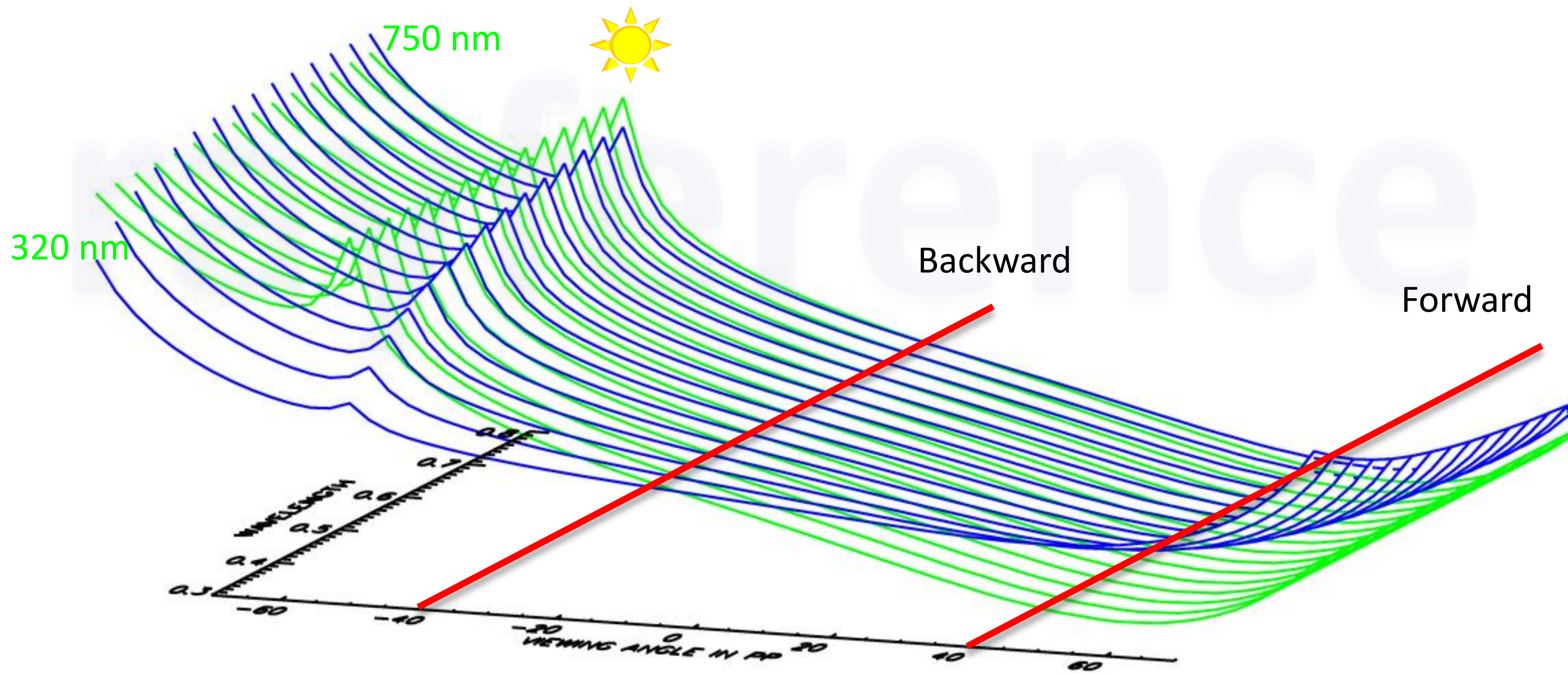
Let's put an atmosphere on top of the surface



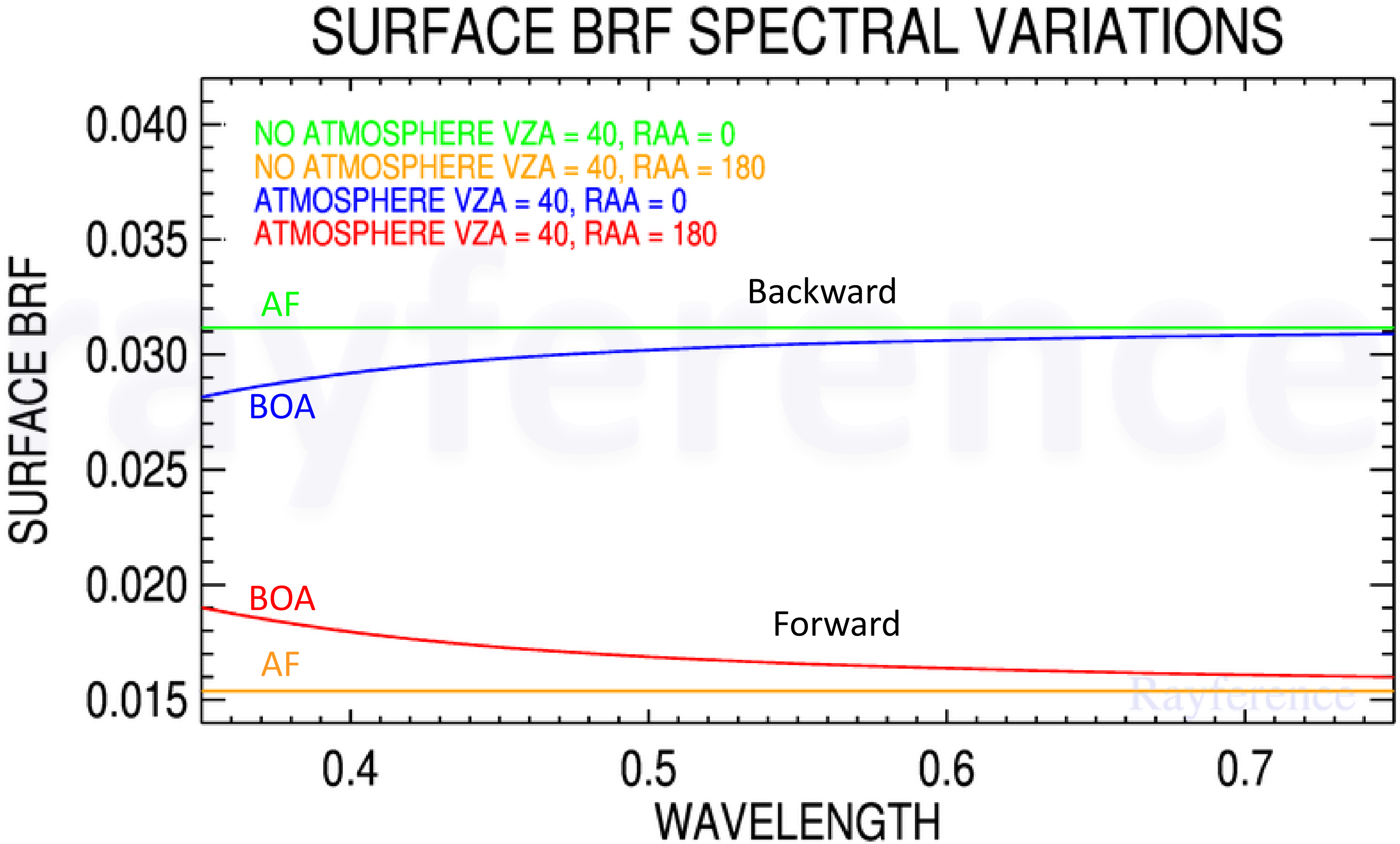
SRF – ATM INTERACTIONS

Analysis of the AF – BOA BRF

BOA BRF IN THE PRINCIPAL PLANE IN THE 320 – 750nm SPECTRAL RANGE

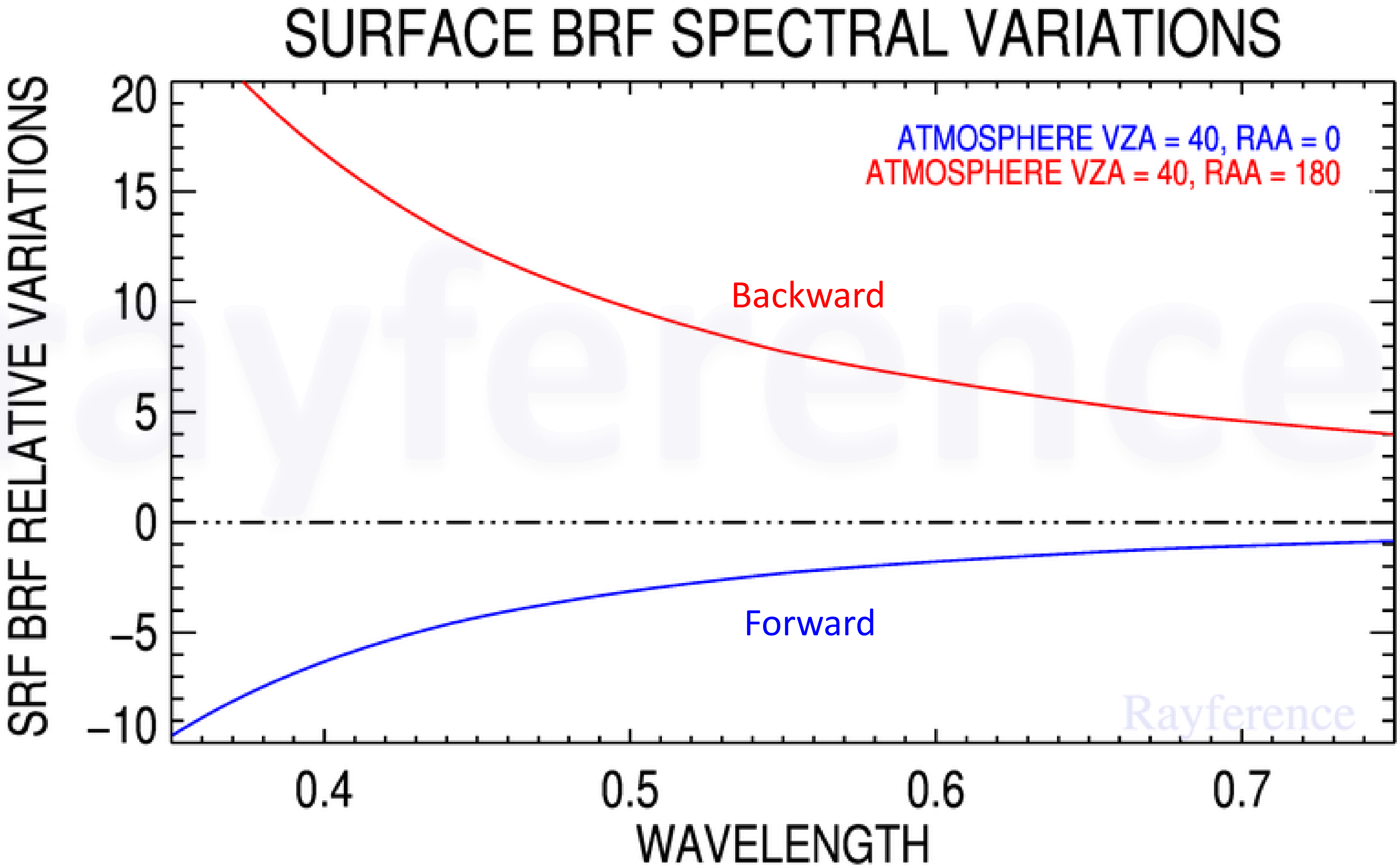


SRF – ATM INTERACTIONS

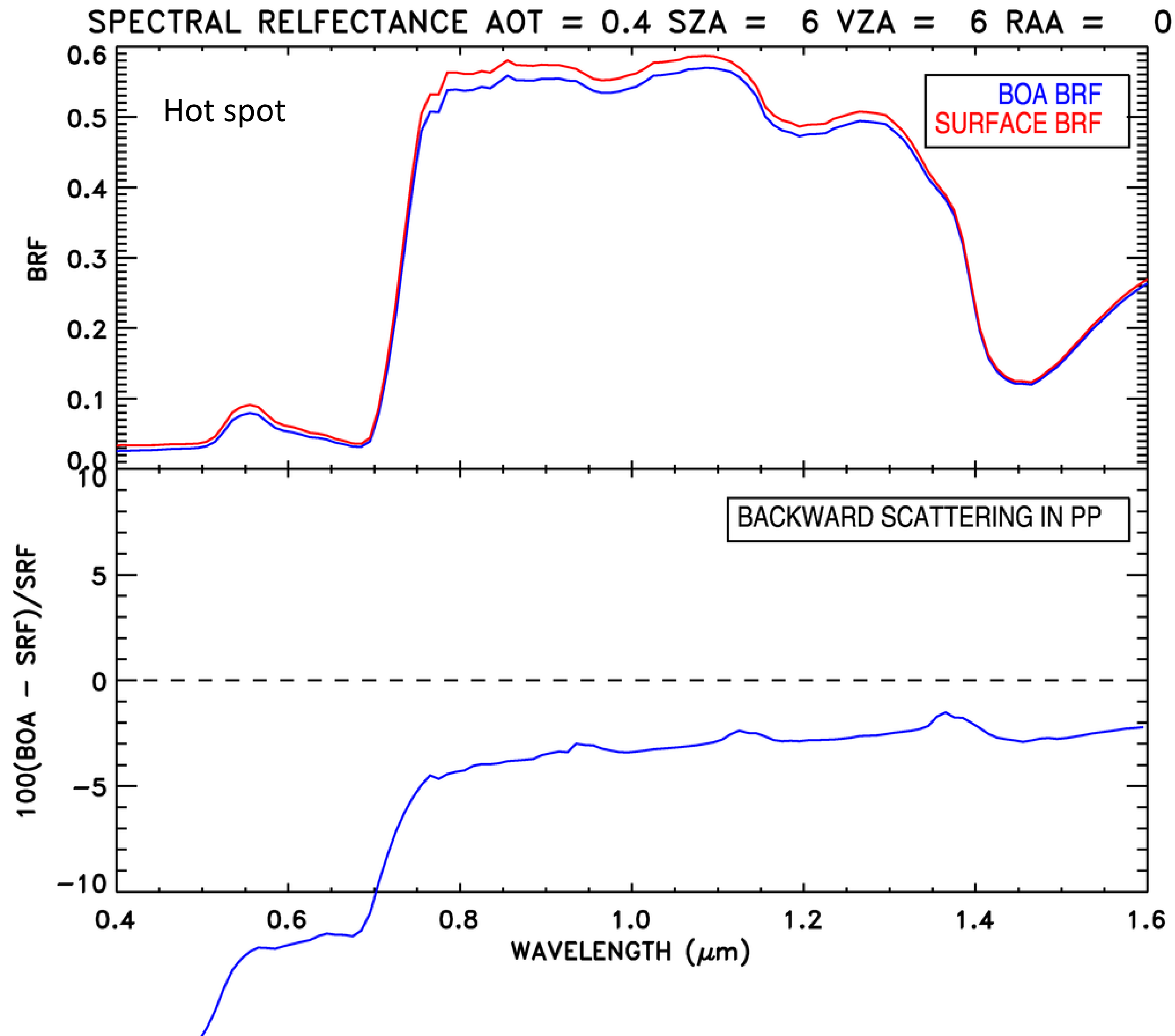


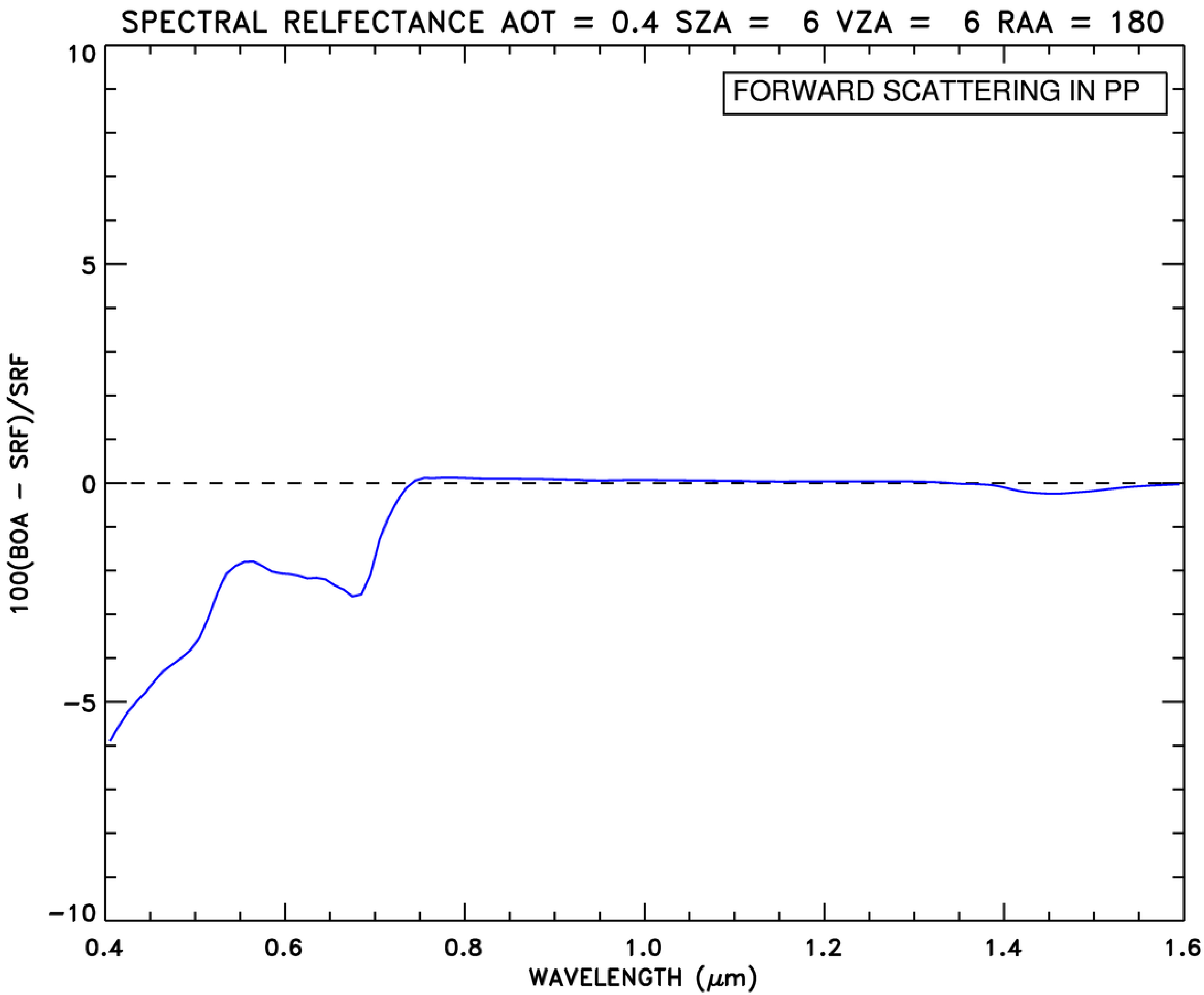
SRF – ATM INTERACTIONS

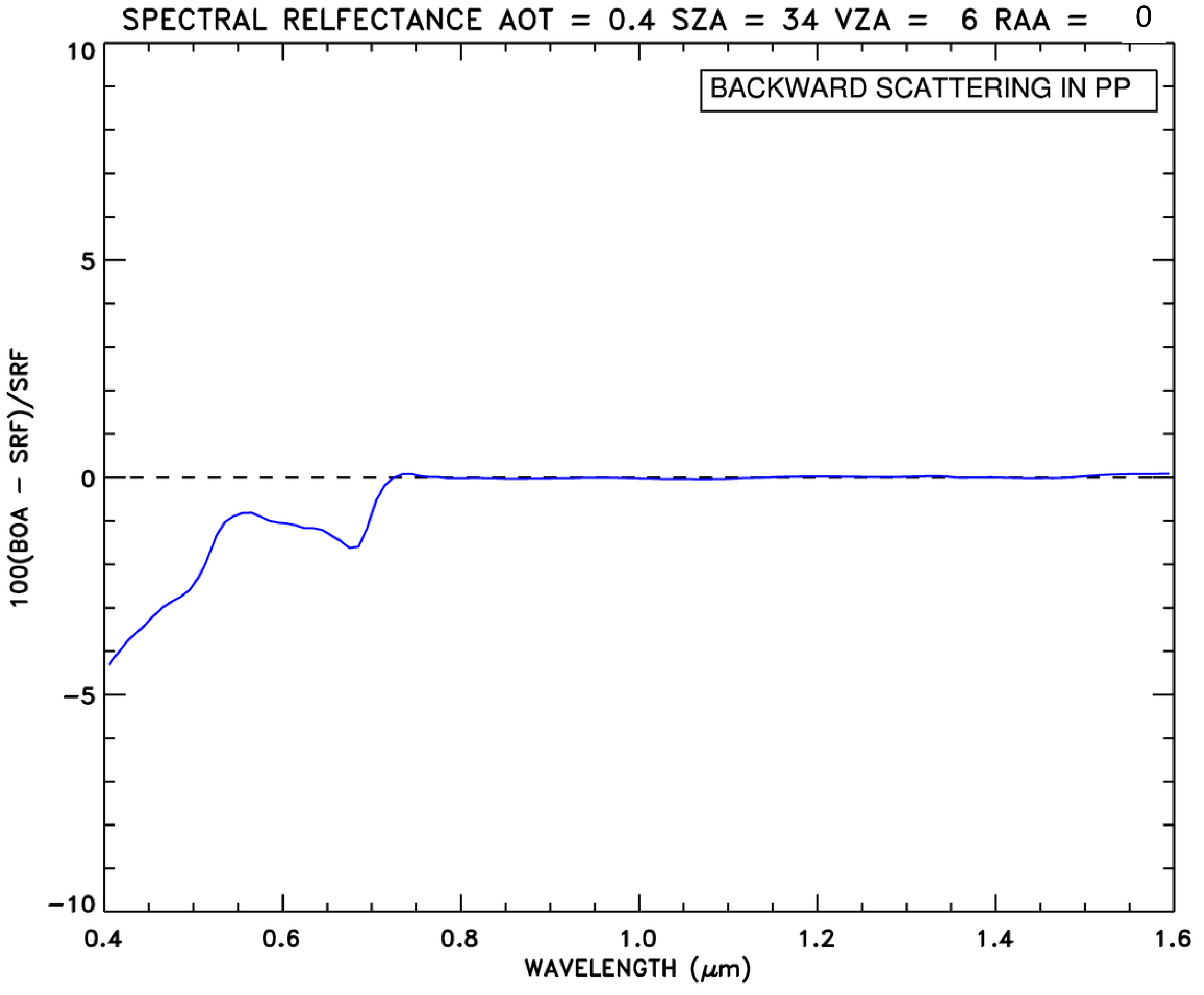
BOA /AF RELATIVE DIFFERENCE



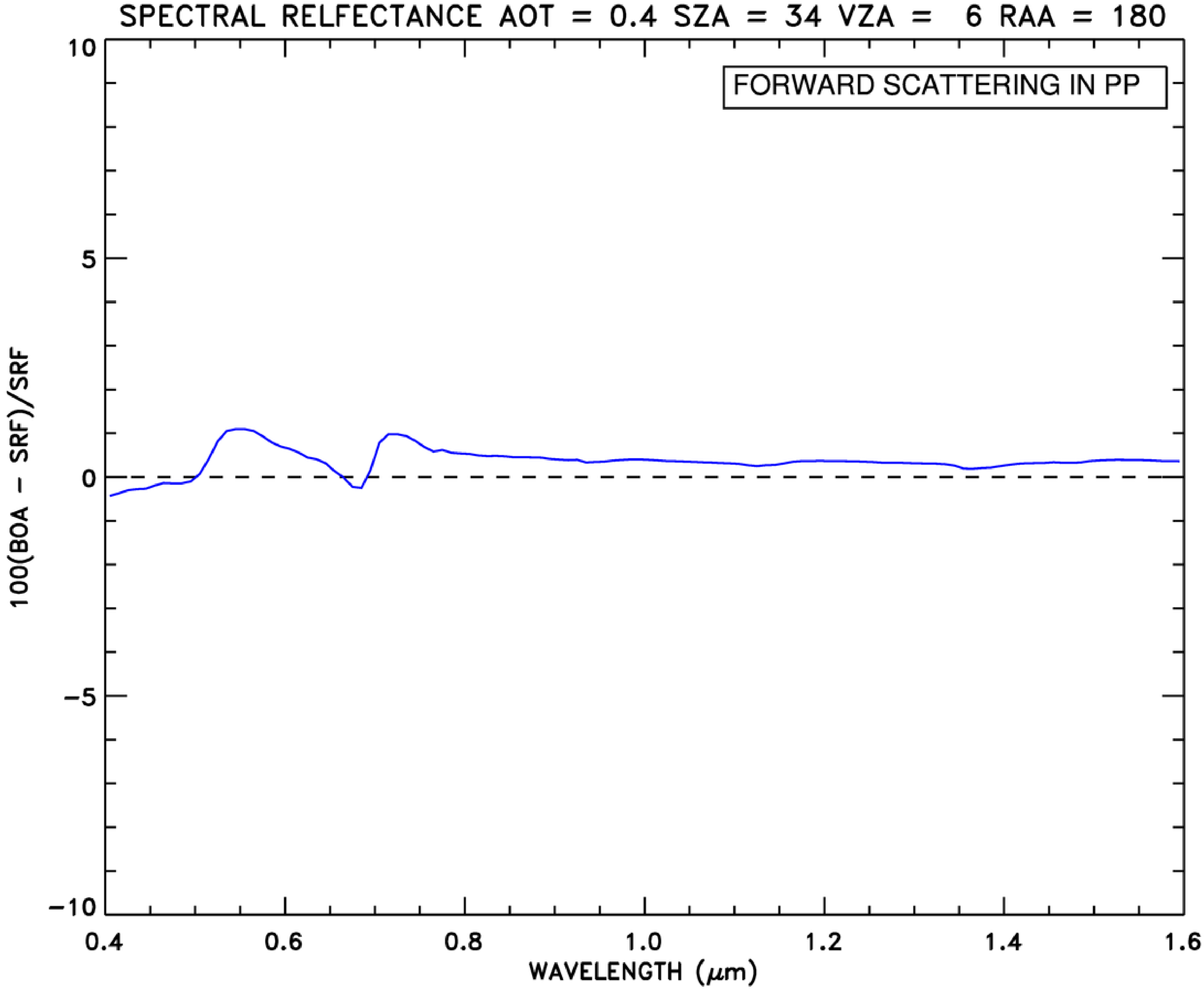
NOW WITH CHANGING SURFACE CONDITIONS


SPECTRAL RELFECTANCE AOT = 0.4 SZA = 6 VZA = 6 RAA = 0
Hot spot
BOA BRF
SURFACE BRF
BRF
0.0
0.1
0.2
0.3
0.4
0.5
0.6
BACKWARD SCATTERING IN PP
100(BOA − SRF)/SRF
−10
−5
0
5
10
0.4
0.6
0.8
1.0
1.2
1.4
1.6
WAVELENGTH (μm)

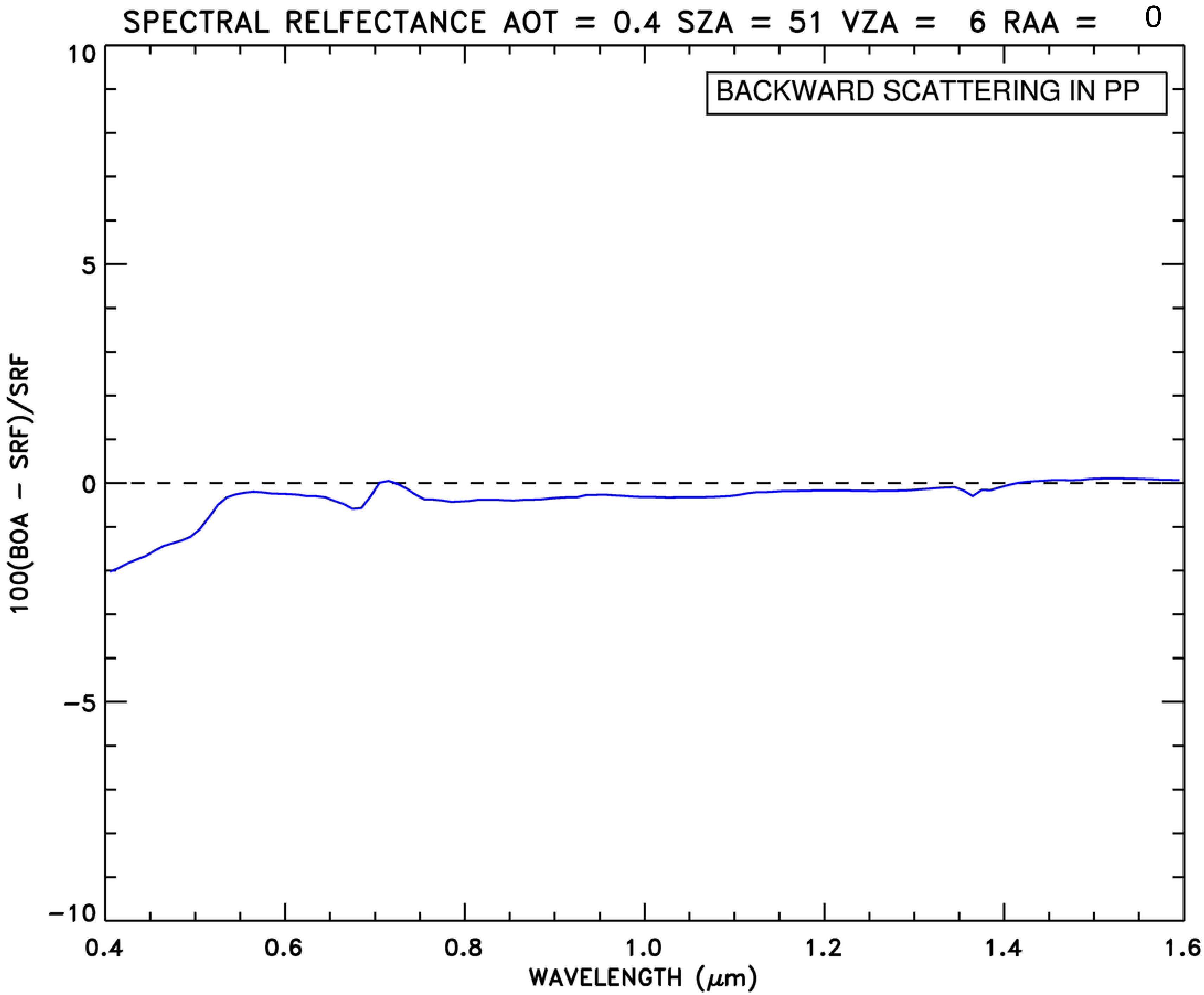

SPECTRAL RELFECTANCE AOT = 0.4 SZA = 6 VZA = 6 RAA = 180
FORWARD SCATTERING IN PP
100(BOA - SRF)/SRF
10
5
0
−5
−10
0.4
0.6
0.8
1.0
1.2
1.4
1.6
WAVELENGTH (μm)

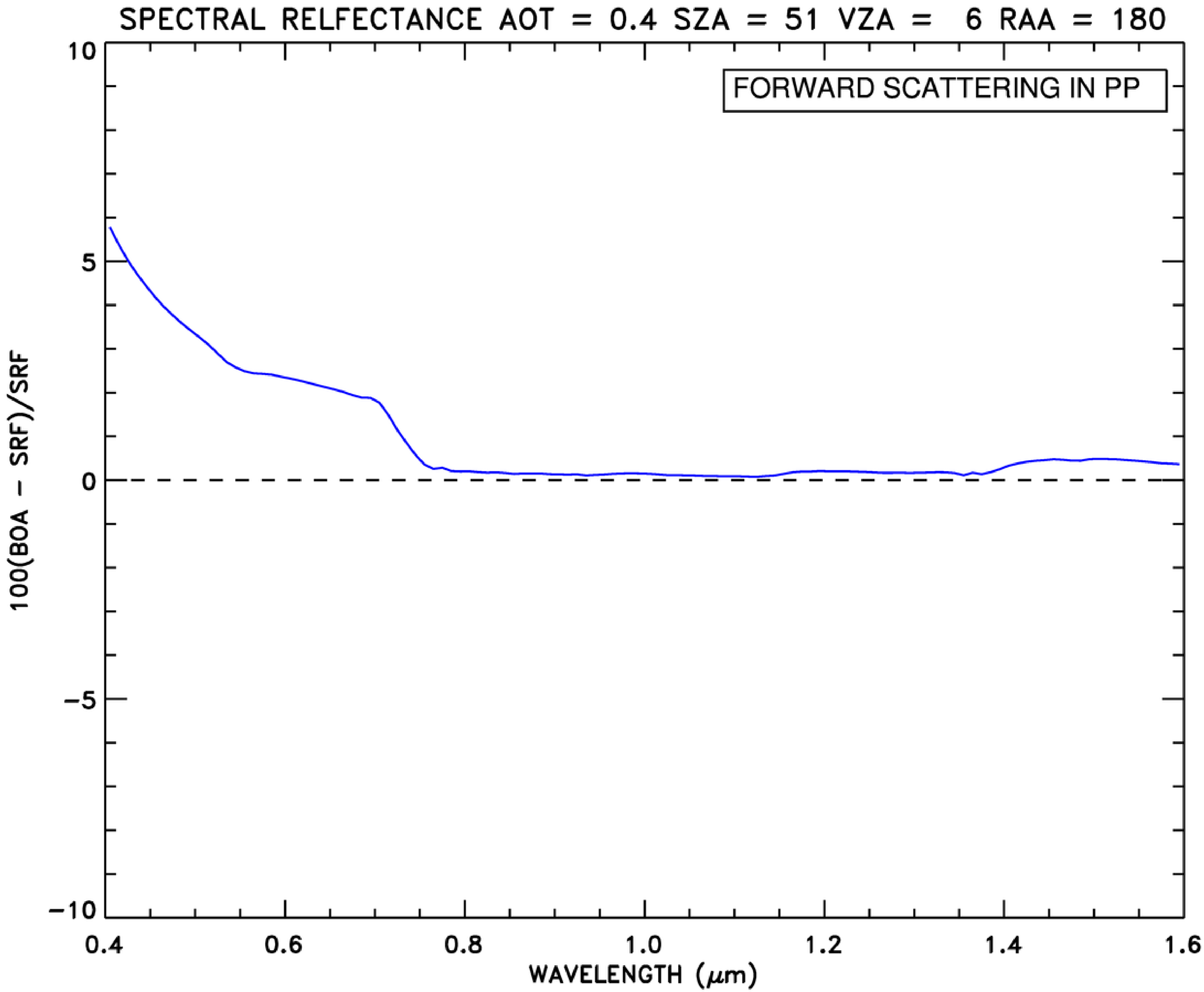


SPECTRAL RELFECTANCE AOT = 0.4 SZA = 34 VZA = 6 RAA = 0
BACKWARD SCATTERING IN PP
100(BOA - SRF)/SRF
WAVELENGTH (μm)
10
5
0
−5
−10
0.4
0.6
0.8
1.0
1.2
1.4
1.6



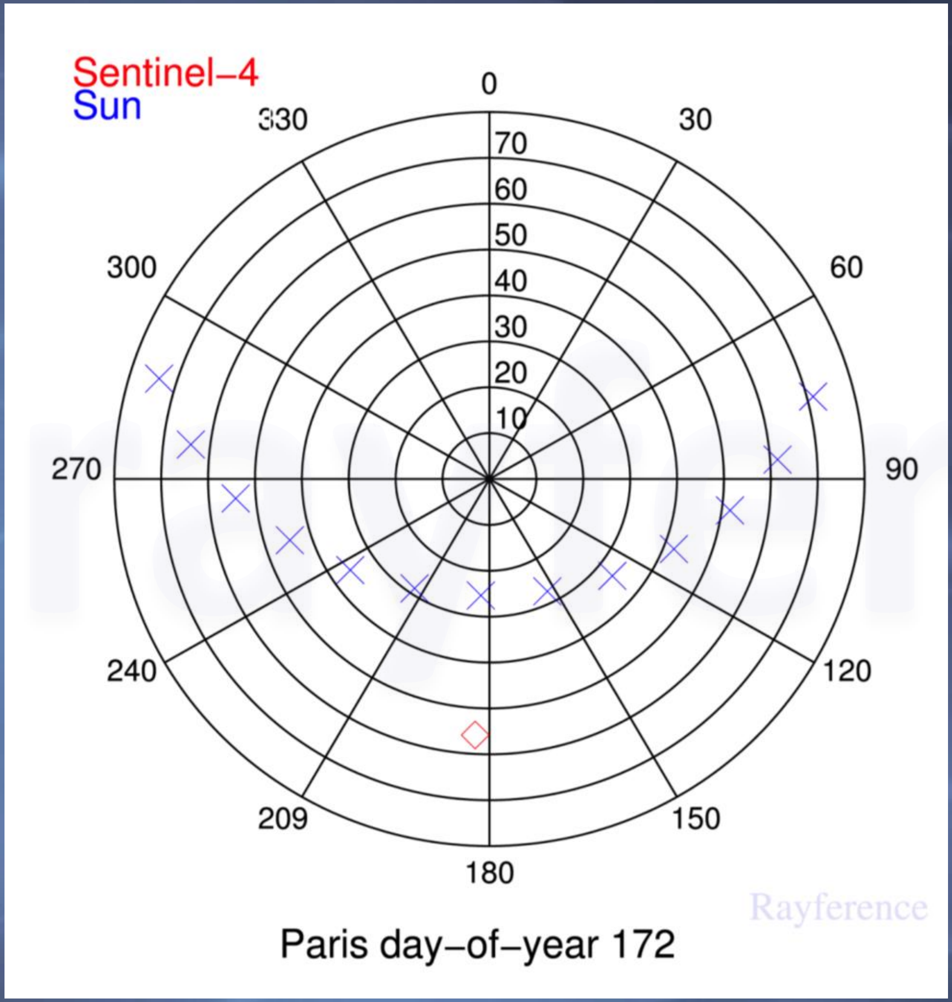
SPECTRAL RELFECTANCE AOT = 0.4 SZA = 34 VZA = 6 RAA = 180
FORWARD SCATTERING IN PP
10
5
0
−5
−10
100(BOA − SRF)/SRF
0.4
0.6
0.8
1.0
1.2
1.4
1.6
WAVELENGTH (μm)


SPECTRAL RELFECTANCE AOT = 0.4 SZA = 51 VZA = 6 RAA = 0
BACKWARD SCATTERING IN PP
10
5
0
−5
−10
100(BOA − SRF)/SRF
0.4
0.6
0.8
1.0
1.2
1.4
1.6
WAVELENGTH (μm)


SPECTRAL RELFECTANCE AOT = 0.4 SZA = 51 VZA = 6 RAA = 180
FORWARD SCATTERING IN PP
100(BOA − SRF)/SRF
10
5
0
−5
−10
0.4
0.6
0.8
1.0
1.2
1.4
1.6
WAVELENGTH (μm)

PRACTICAL SENTINEL-4 EXAMPLE

PARIS EXAMPLE



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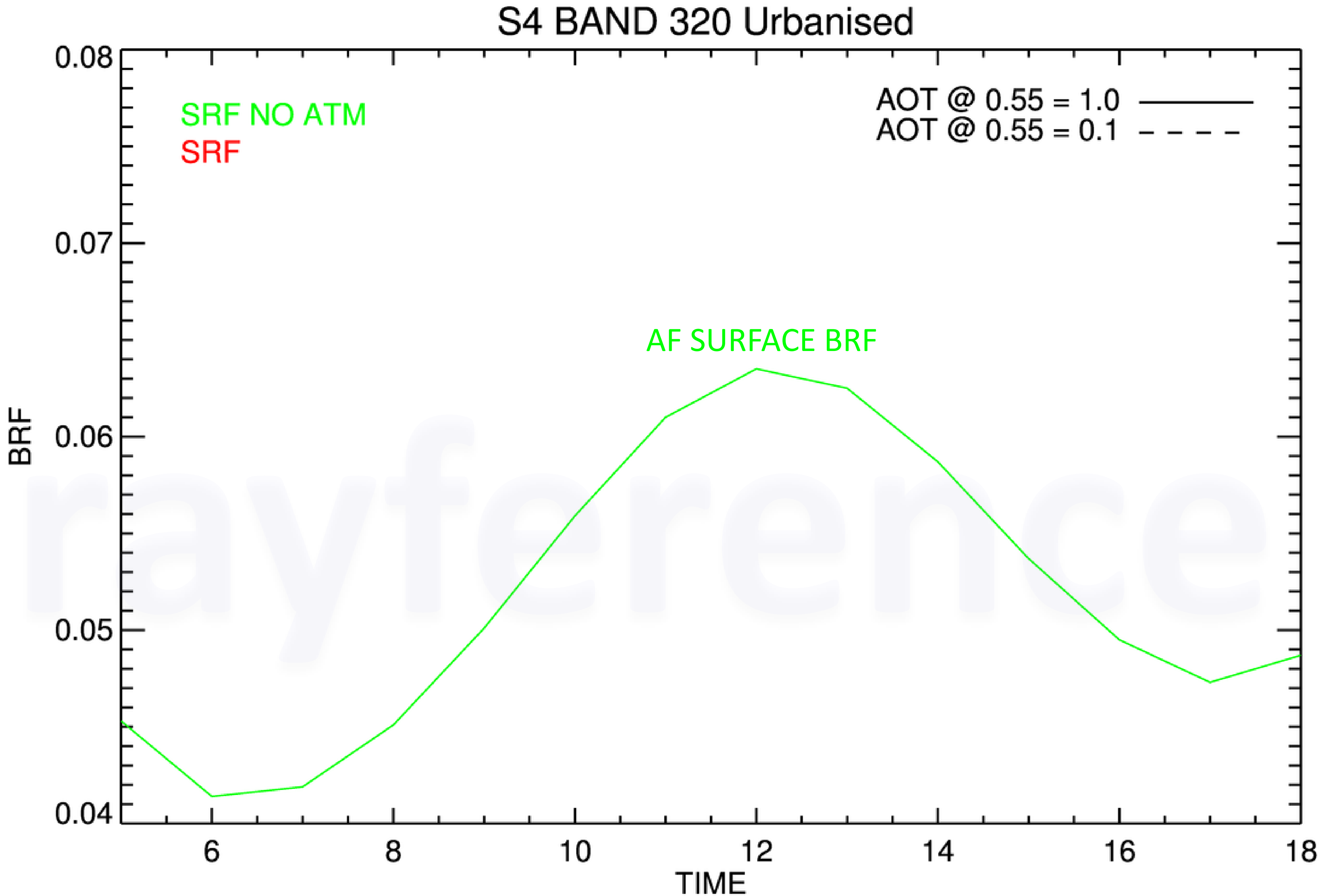
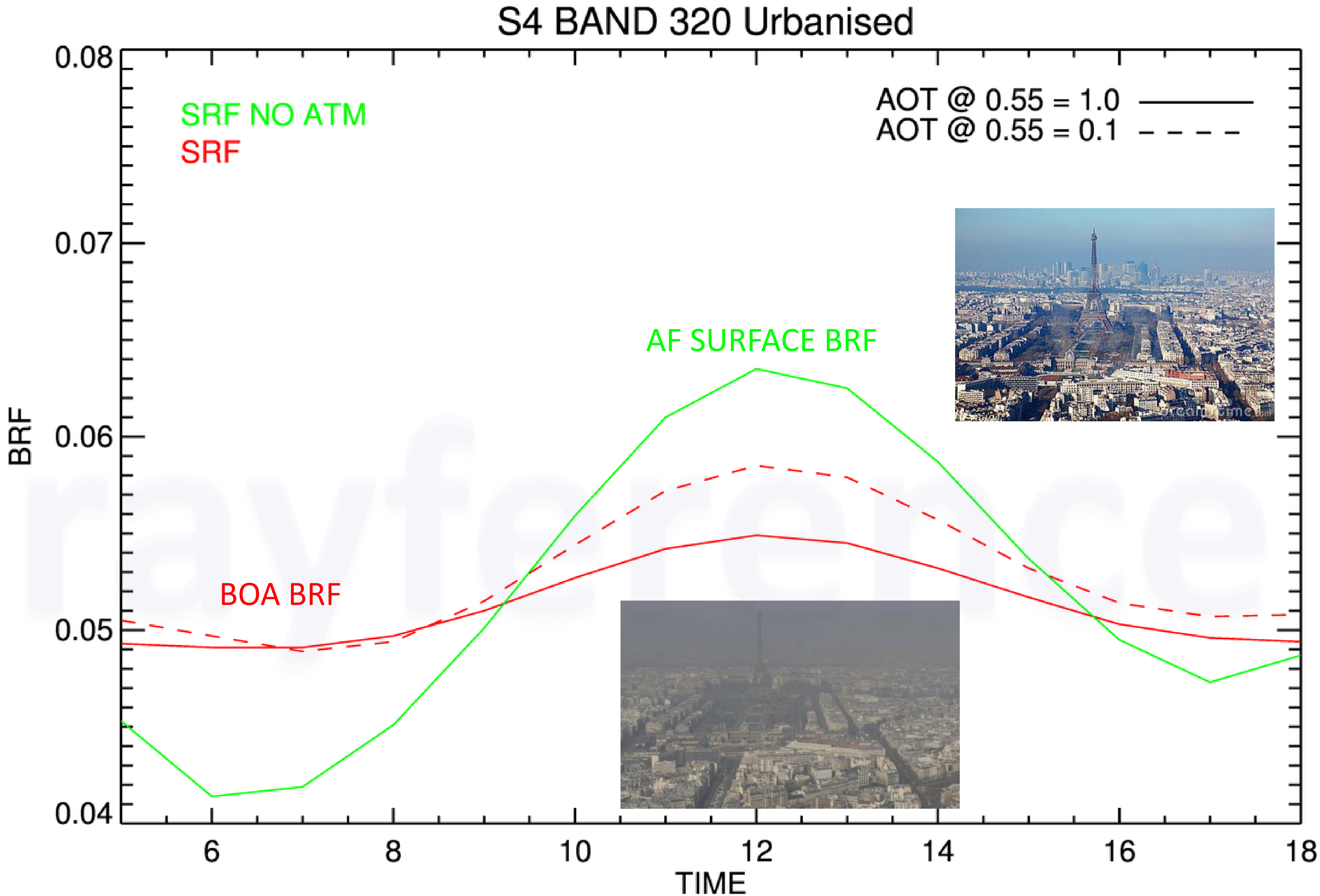

S4 BAND 320 Urbanised
SRF NO ATM
SRF
AOT @ 0.55 = 1.0
AOT @ 0.55 = 0.1
AF SURFACE BRF
BRF
0.08
0.07
0.06
0.05
0.04
6
8
10
12
14
16
18
TIME

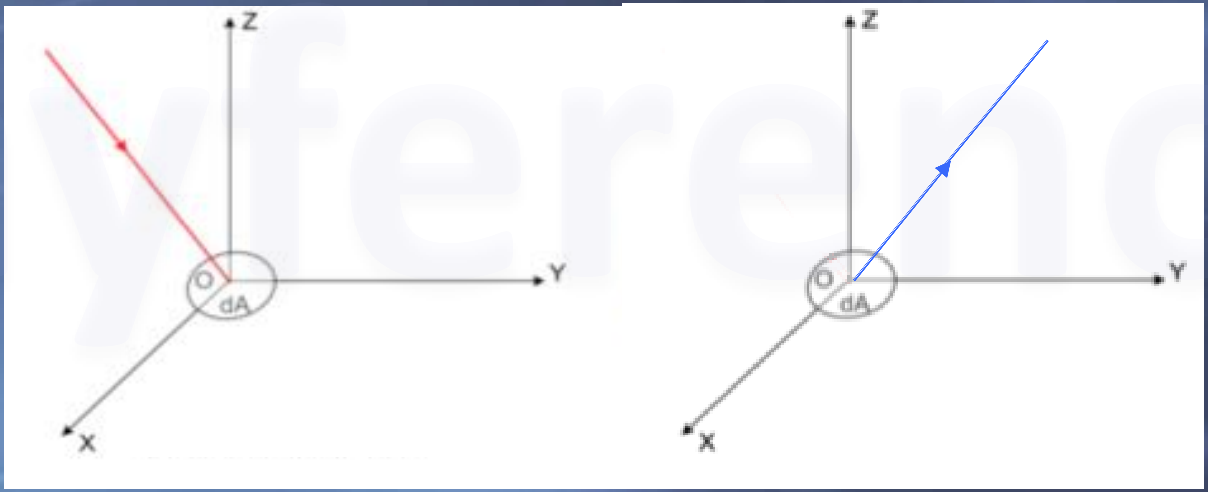
rayference


S4 BAND 320 Urbanised
SRF NO ATM
SRF
AOT @ 0.55 = 1.0
AOT @ 0.55 = 0.1
AF SURFACE BRF
BOA BRF
BRF
0.08
0.07
0.06
0.05
0.04
6
8
10
12
14
16
18
TIME

FROM AF BRF TO LER

Method 1: LER = AF BRF

$$\text{LER}(t) = f(\Omega_s(t), \Omega_v; p_i)$$



This approximation could be used in case of low optical thickness, *e.g.*, in the NIR spectral region.

Provides the exact solution for the single scattering.

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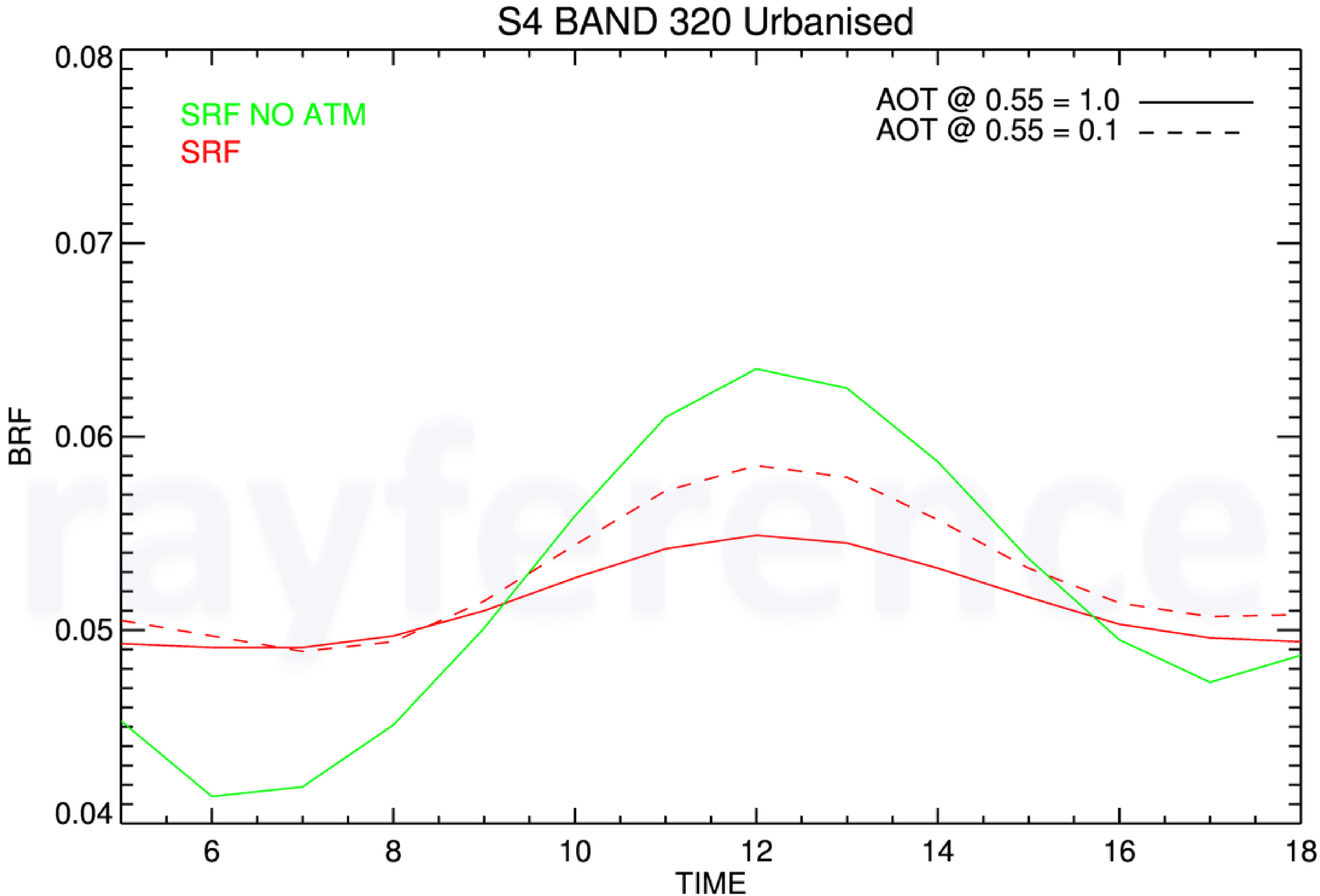
S4 BAND 320 Urbanised
SRF NO ATM
SRF
AOT @ 0.55 = 1.0
AOT @ 0.55 = 0.1
BRF
0.08
0.07
0.06
0.05
0.04
6
8
10
12
14
16
18
TIME

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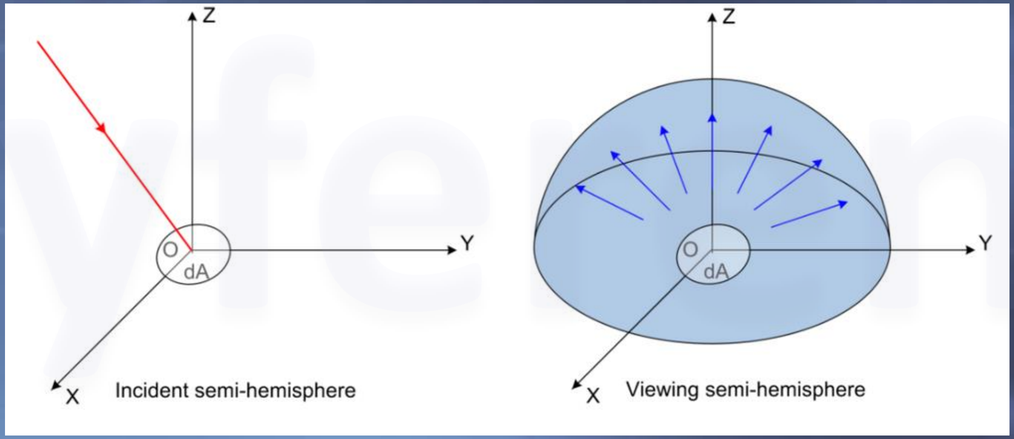
FROM AF BRF TO LER

Method 2: LER = AF DHR (black sky)

$$\mathrm{LER}(t) = DHR(\Omega_s(t); p_i)$$

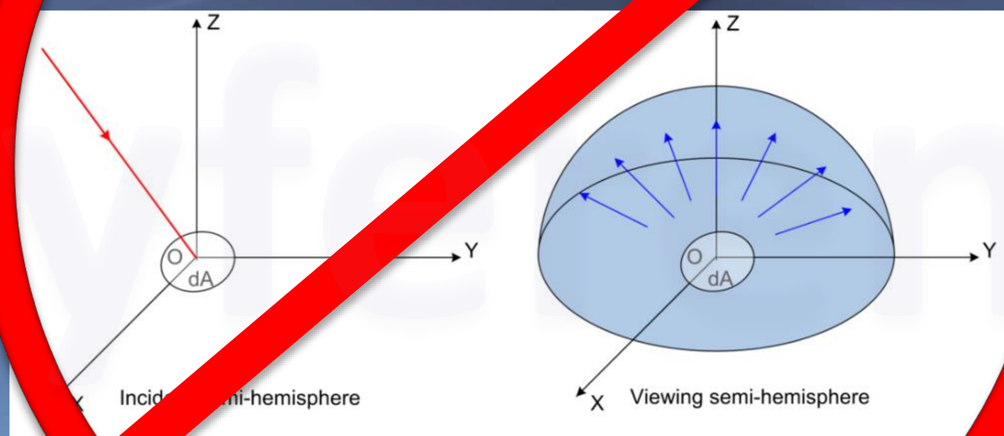


This approximation is pretty meaningless as it does not respect the S4 illumination of viewing conditions.

FROM AF BRF TO LER

Method 2: LER = AF DHR

$$\text{LER}(t) = DHR(\Omega_{0}(t); p_i)$$

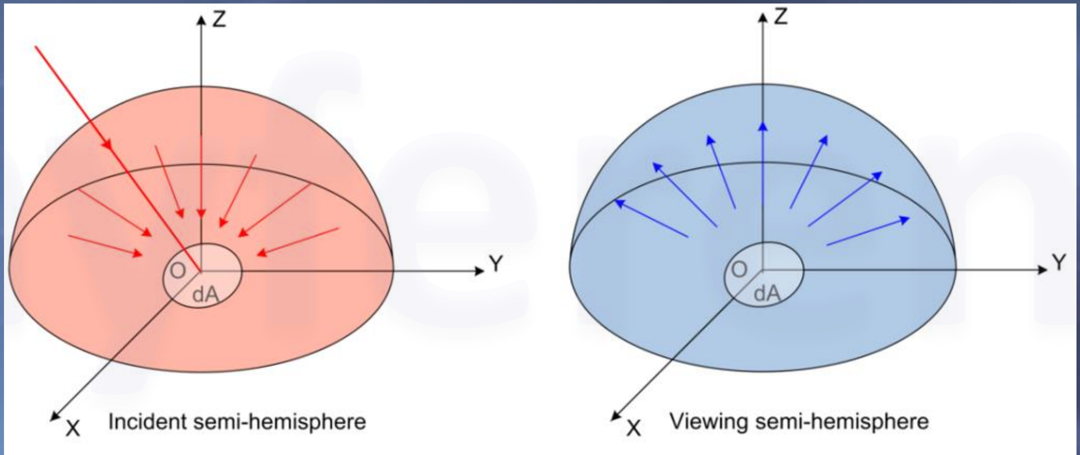


This approximation is pretty meaningless as it does not respect the S4 illumination of viewing conditions.

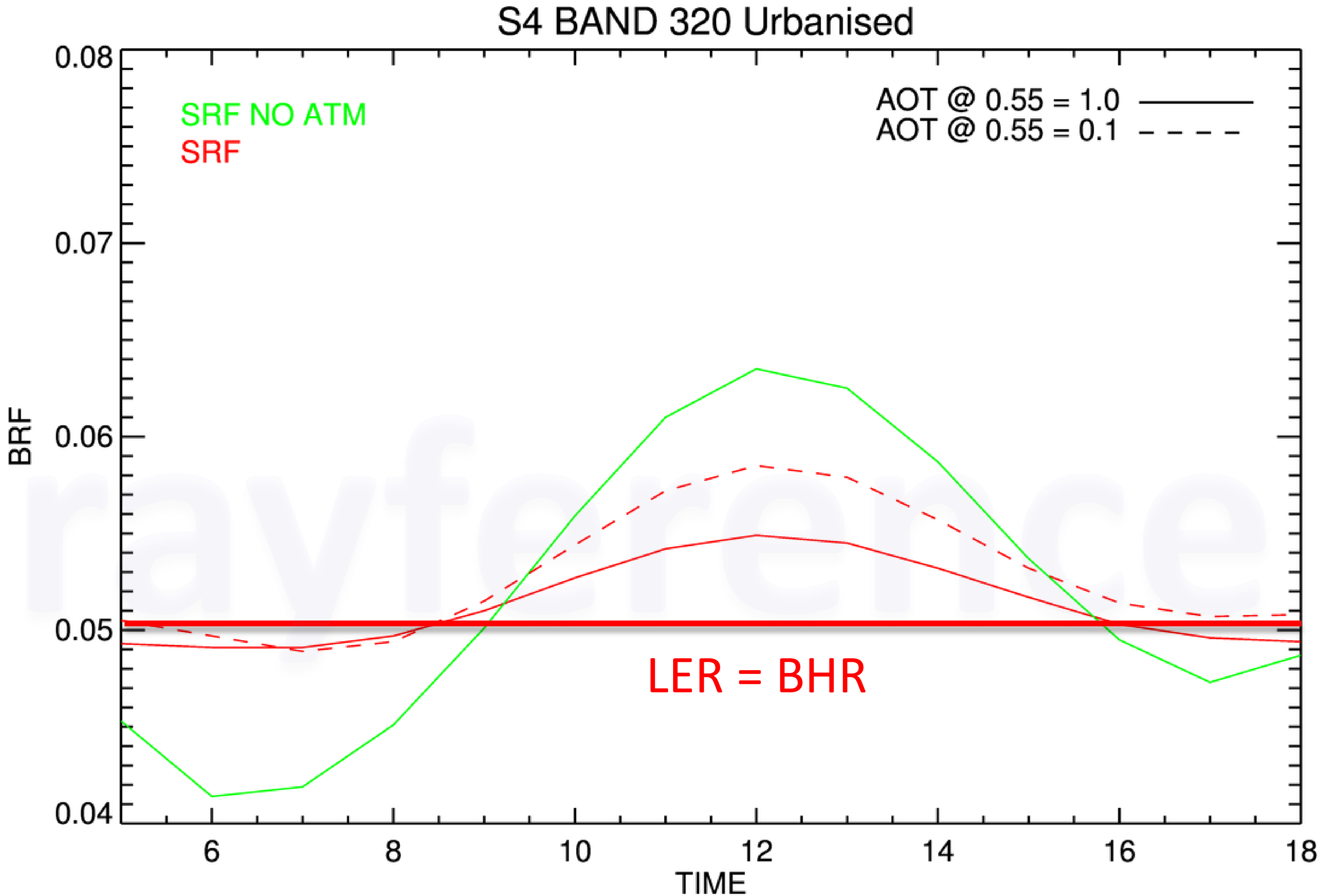
FROM AF BRF TO LER

Method 3: LER = Diffuse BHR (white sky)

$$\text{LER} = BHR(p_i)$$



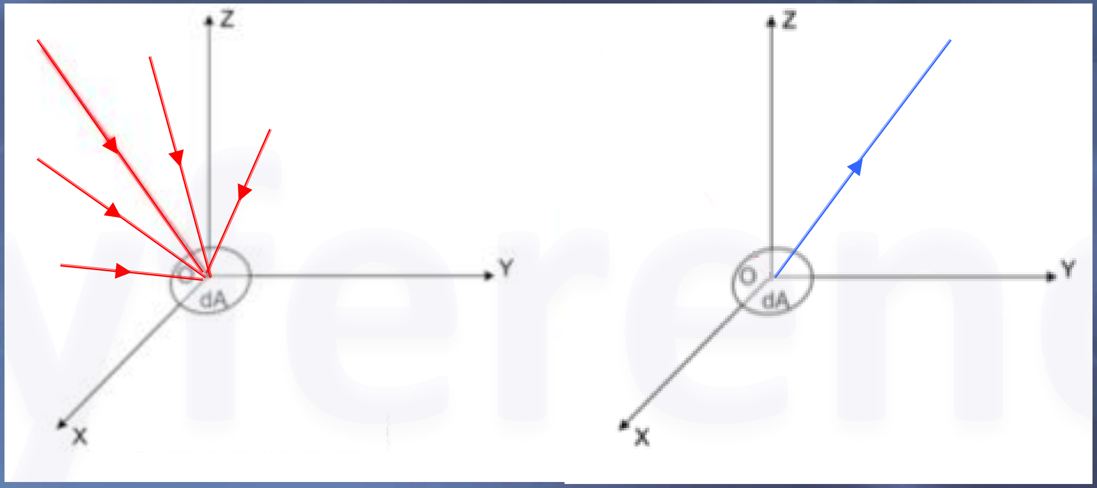
This approximation could be used in case of high scattering optical thickness, e.g., in the UV region.


S4 BAND 320 Urbanised
SRF NO ATM
SRF
AOT @ 0.55 = 1.0
AOT @ 0.55 = 0.1
BRF
0.08
0.07
0.06
0.05
0.04
6
8
10
12
14
16
18
TIME
LER = BHR

FROM AF BRF TO LER

Method 4: LER = BOA BRF

$$\text{LER}(t, \tau) = g(\Omega_s(t), \Omega_v; p_i, \tau(t))$$



This approximation is the best choice but requires the knowledge of $\tau(t)$ and the irradiance field at the surface.

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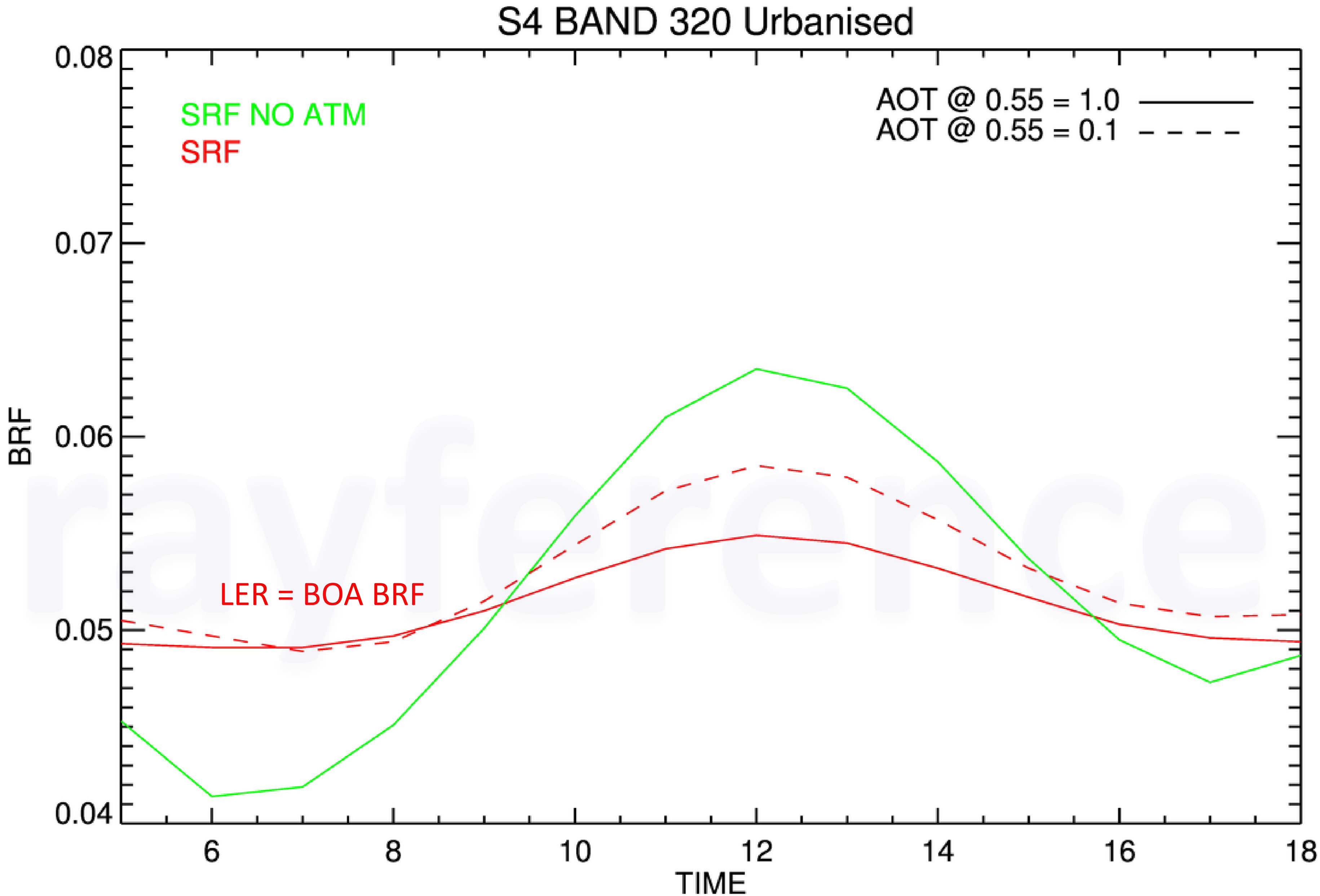
S4 BAND 320 Urbanised
SRF NO ATM
SRF
AOT @ 0.55 = 1.0
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LER = BOA BRF
BRF
0.08
0.07
0.06
0.05
0.04
6
8
10
12
14
16
18
TIME

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CONCLUSIONS (1)

- Sky radiation plays an important role in shaping surface BRF;
- BOA BRF and atmospheric free BRF are often mixed though they might exhibit important differences
  - In the blue-NIR spectral region;
  - When the scattering optical thickness is important;
  - In the hot spot conditions;
- These differences might have an important impact for lower atmosphere trace gas retrieval over land surfaces.