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Palazzo dei Congressi, Rome, Italy, 7-11 October 2002

Centro Ricerche Portici

UNIVERSITA' DI NAPOLI FEDERICO II
Dipartimento di Scienze Fisiche

Analysis of optical degradation of photovoltaic modules

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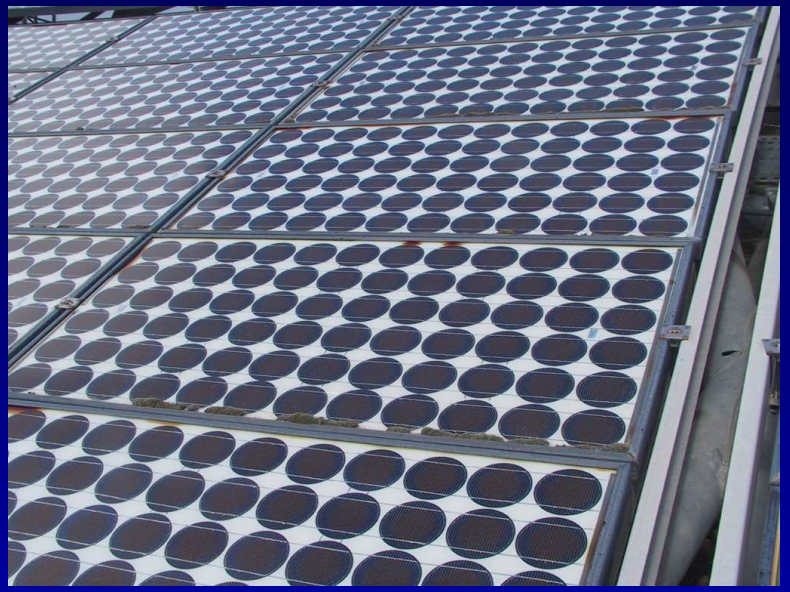
Department of Physics, University of Naples, Italy

Delphos plant

SECTION	**1st**	**2nd**
Rated power	**308 kWp**	3x100 kWp
Module type	**flat plane**	flat plane
Lay-out/tilt	**fixed single row/20°**	fixed parallel rows/30°
Configuration	**a) grid-connected** **b) stand-alone**	grid-connected
PV modules	**5760**	6700
Modules area	**3819 m2**	2700 m2
Occupation area	**4374 m2**	8500 m2
In operation	**August 1986**	January 1992

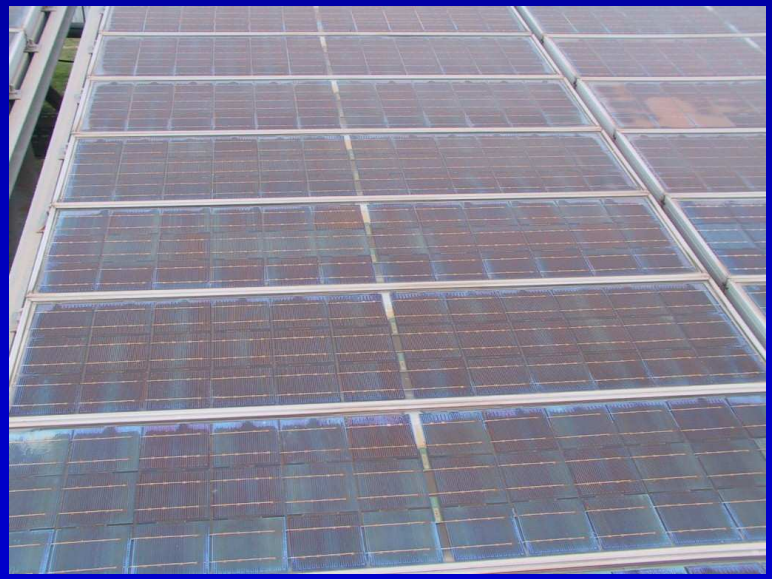
Delphos plant

Helios single-Si modules



Pragma single-Si modules

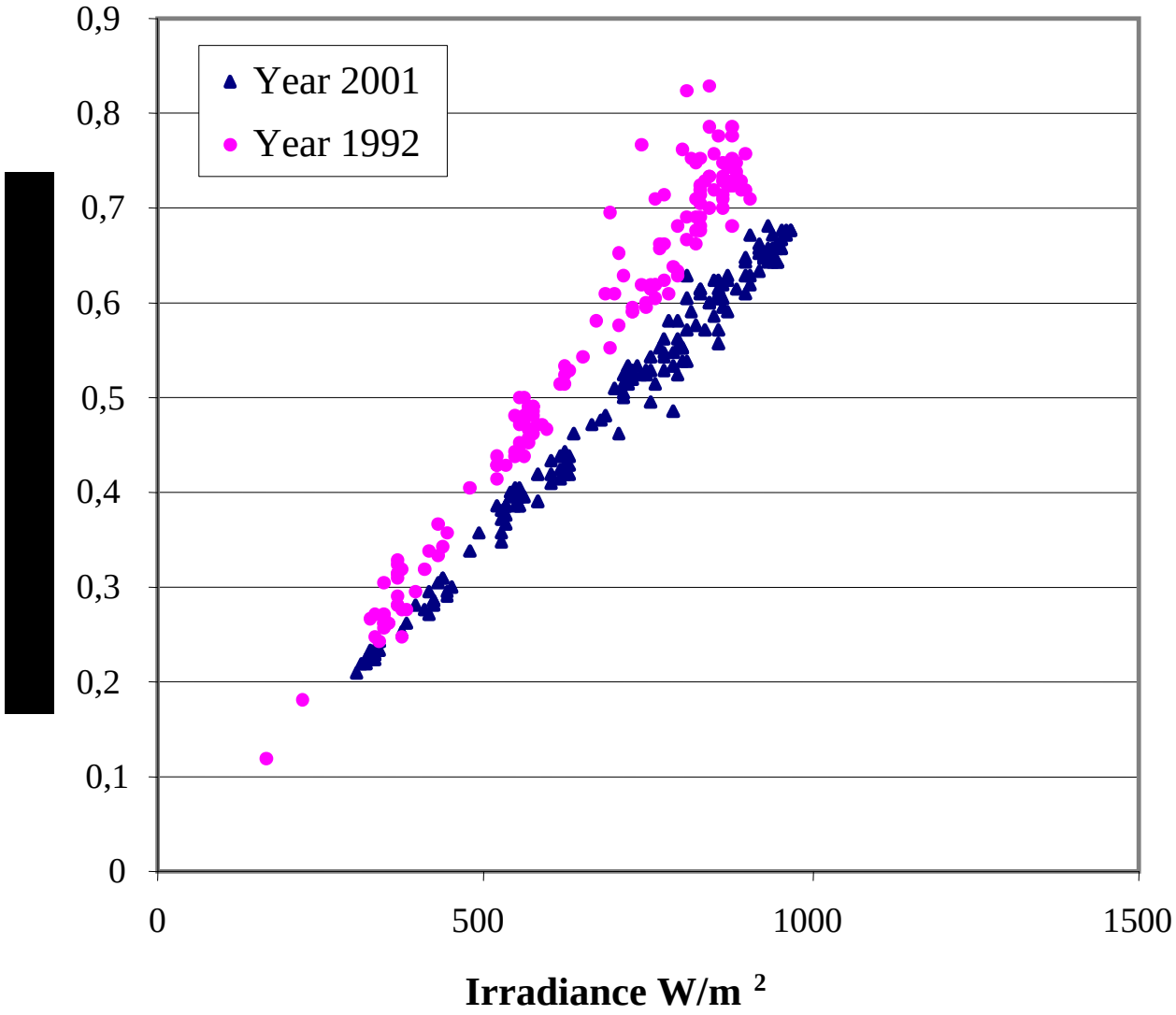
Pragma multi-Si modules



Ansaldo multi-Si modules

Delphos plant (1st section)

Power degradation diagram



$$\Delta t \approx 10\,years$$

$$\overline{\Delta P_S} \approx -16\%$$

Delphos plant (1st section)

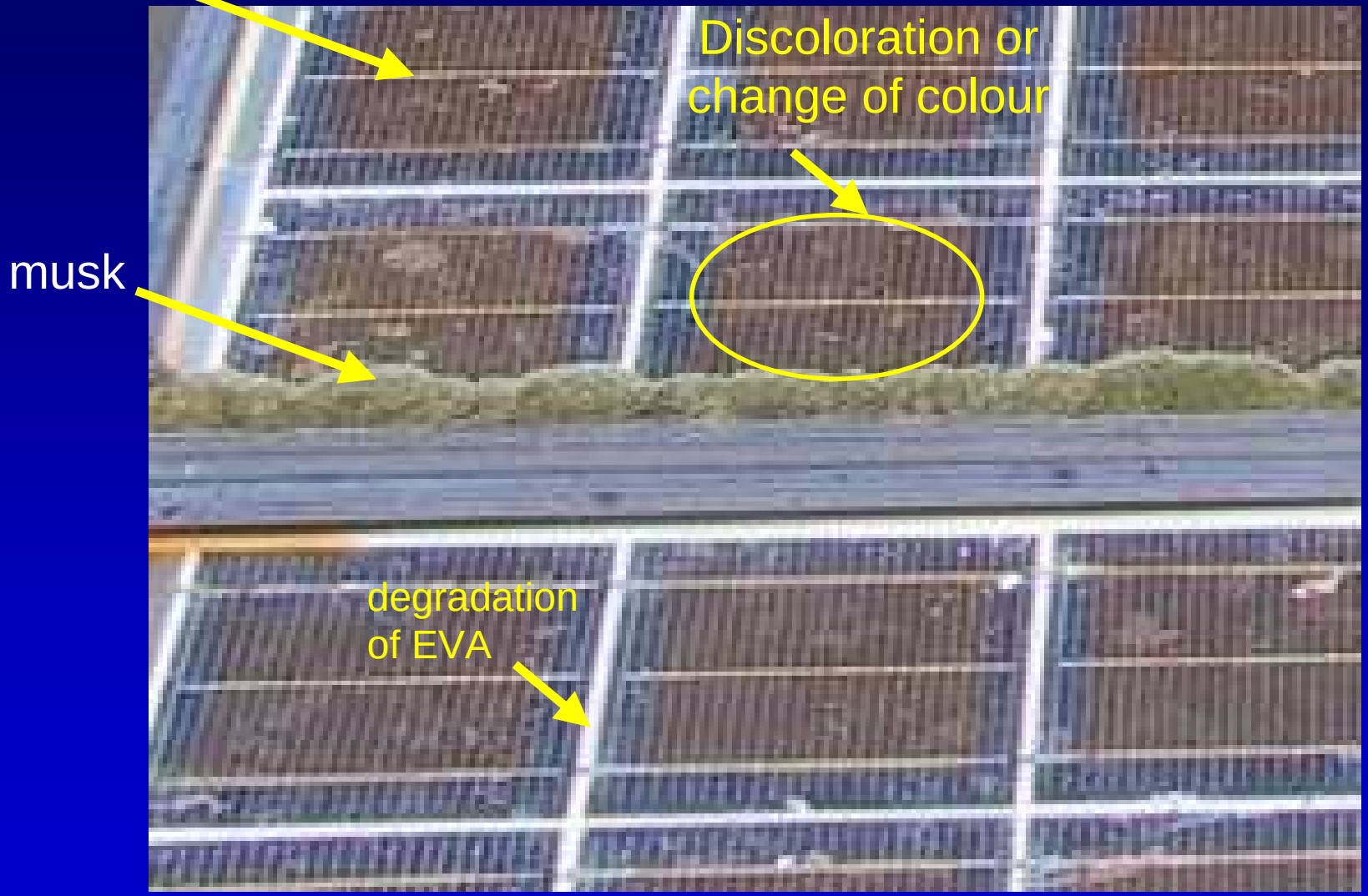
Single string degradation

Strings Measured/ Tot	Manufacturer / technology	**Power loss (%)**	**Isc loss (%)**	Equivalent by-passed modules / total	**Isc loss + Voltage lack loss (%)**	Annual V loss rate (%)	Annual Isc loss rate (%)
FIRST SECTION							
23/24	**Pragma mc-Si**	**21.6**	**14.25**	88/1380 (6.4%)	**20.65**	**0.53**	**1.36**
22/24	**Ansaldo mc-Si**	**18.7**	**14.07**	109/2640 (4.1%)	**18.17**	**0.36**	**1.36**
10/12	**Pragma c-Si**	**14.5**	**9.7**	27/600 (4.5%)	**14.2**	**0.40**	**0.95**
6/6	**Helios c-Si**	**11.4**	**9.4**	12/720 (1.7%)	**11.1**	**0.14**	**0.90**
SECOND SECTION							
13/26	Helios	3.9	2.3	18/1092		**0.18**	**0.25**
24/25	Eurosolare	2.6	1.8	17/2016		**0.09**	**0.20**
14/26	Eurosolare	3.5	1.9	20/1176		**0.19**	**0.21**

A. Parretta et al. *"Analysis of Delphos PV Generator Degradation"*, 17th EPSEC, Munich, 22-26 October 2001.

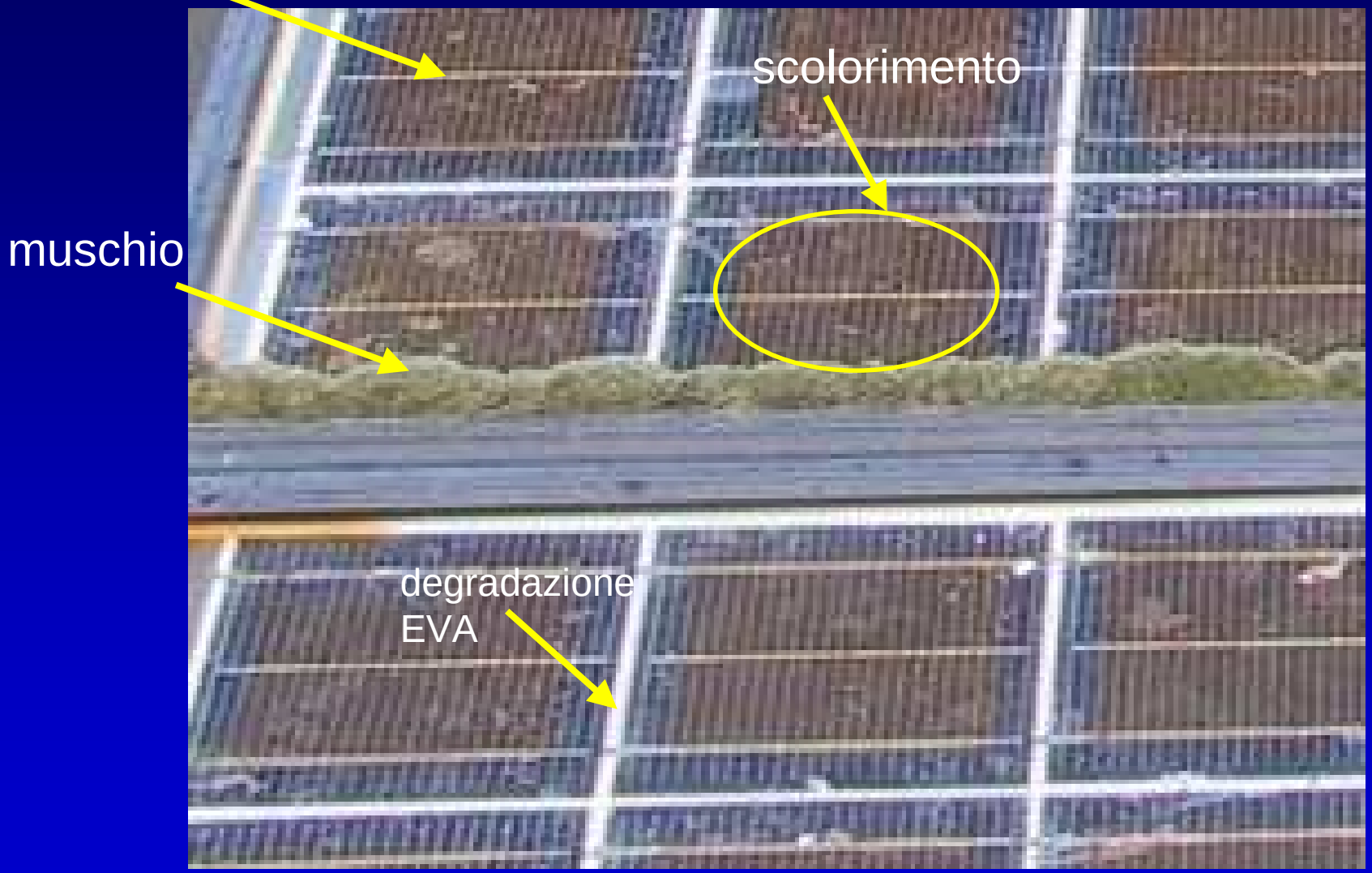
Delphos plant (1st section)

Visible ageing effects

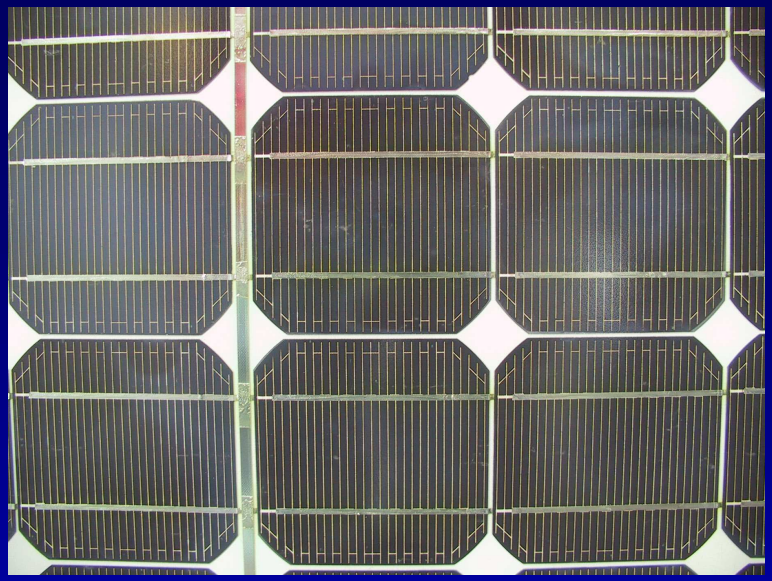


Impianto Delphos (1a sezione)

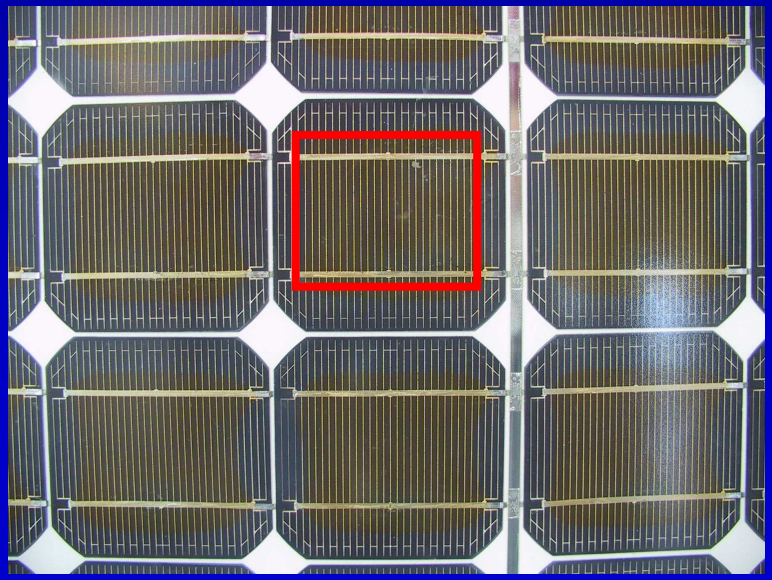
Effetti visibili dell'invecchiamento



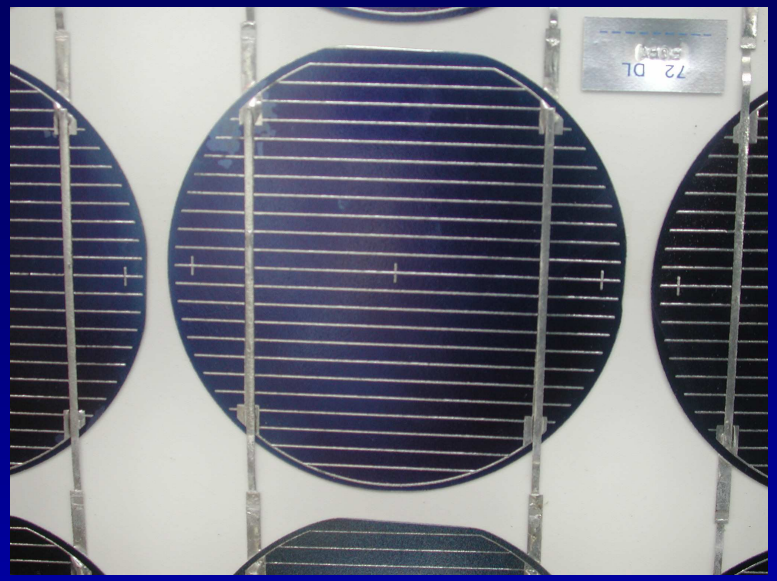
Helios single-Si (text)



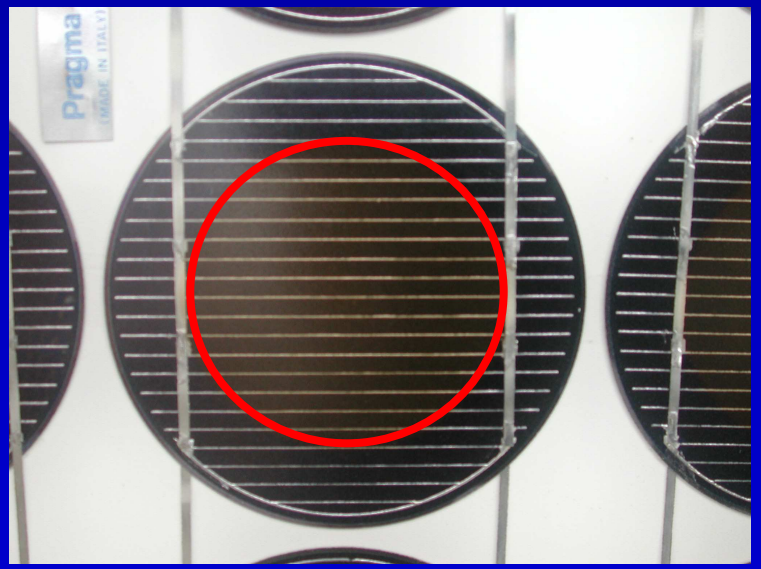
15 years



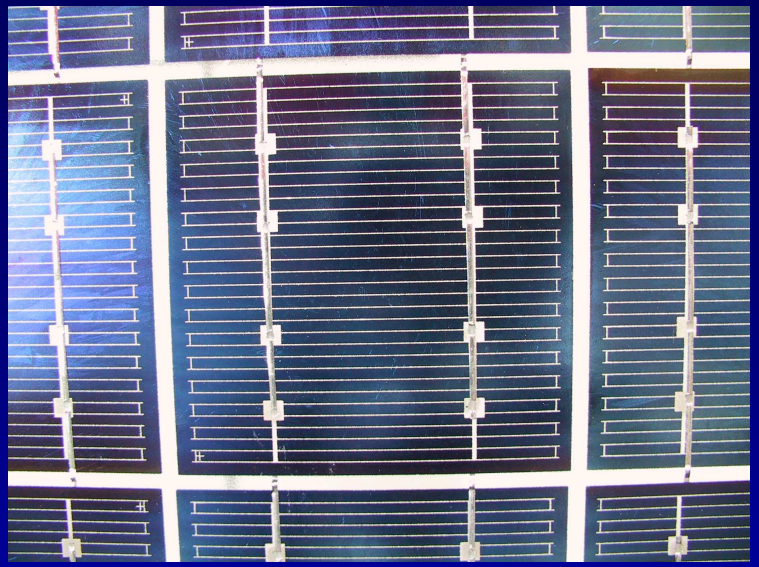
Pragma single-Si (ARC)



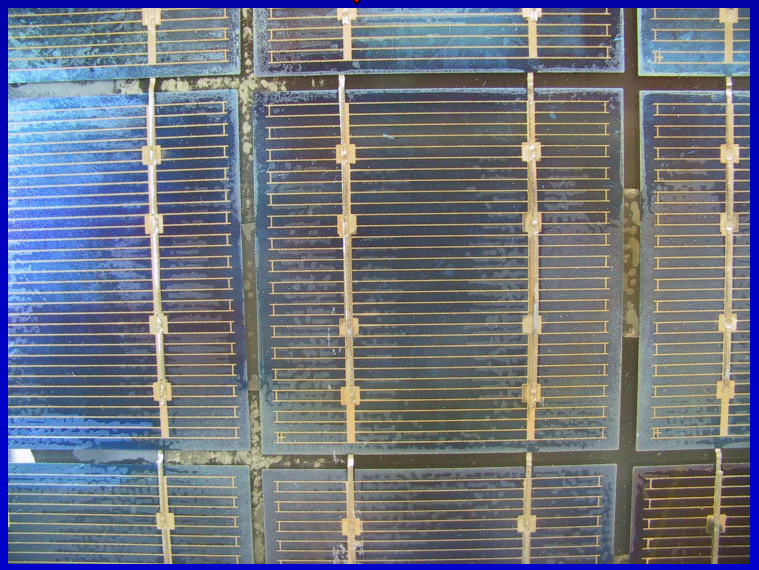
15 years



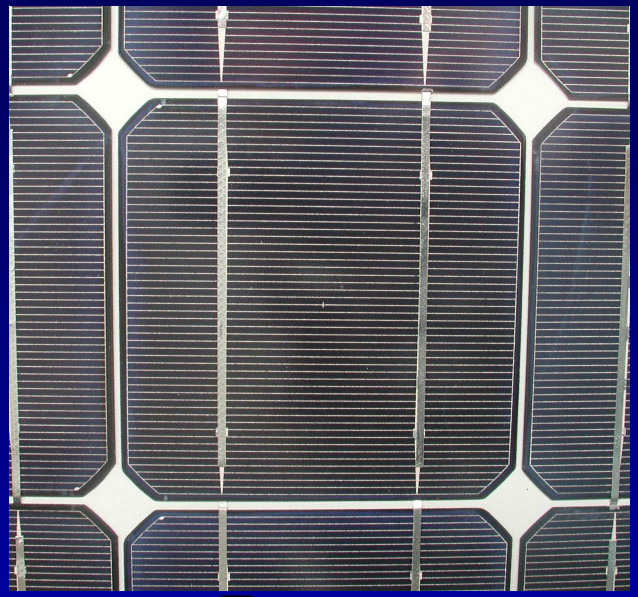
Ansaldo multi-Si (ARC)



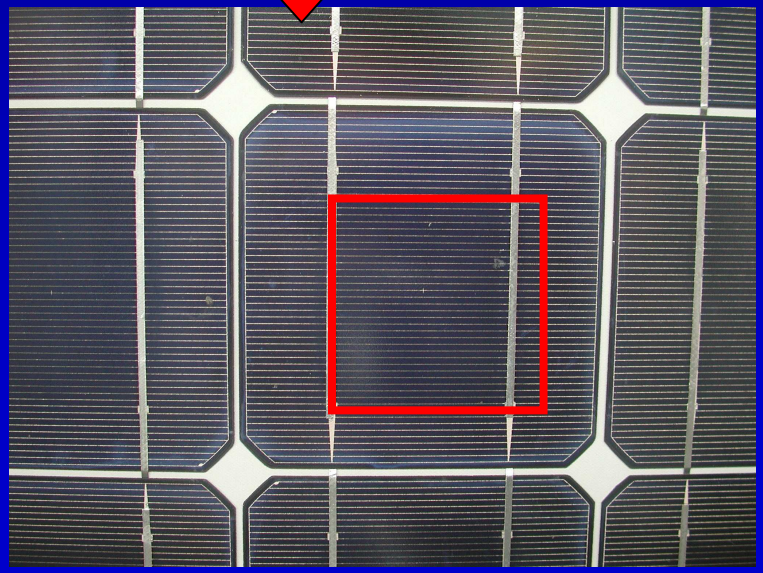
15 years



Siemens single-Si (texture, ARC)

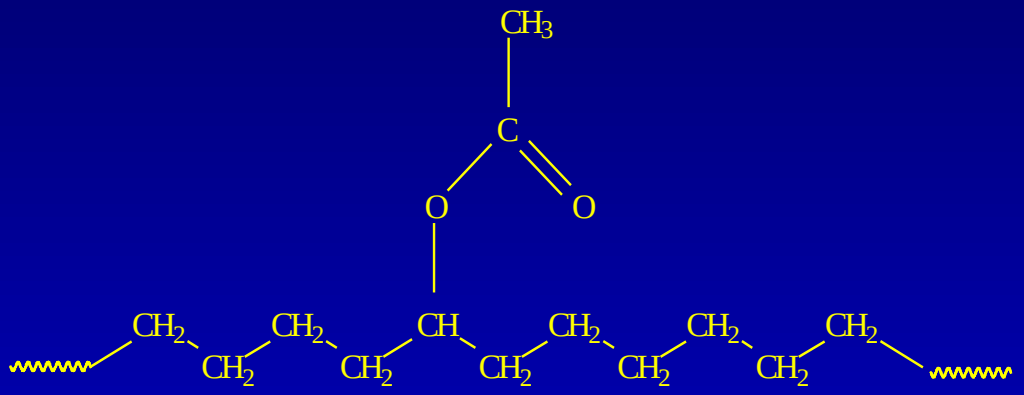


5 years



EVA

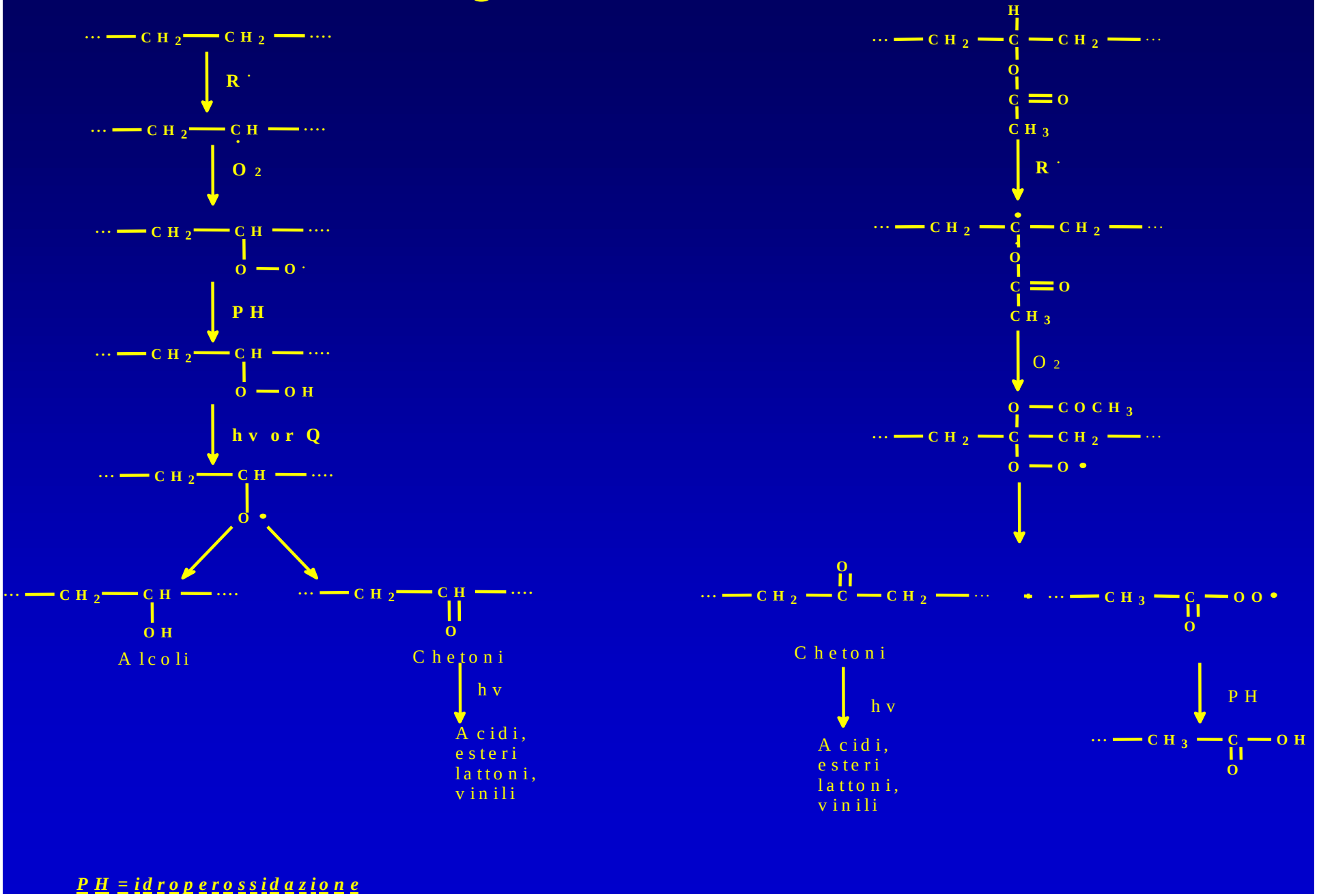
Ethylene –co- vinyl acetate copolymer



I prodotti di degradazione dell'EVA sono: lattoni, chetoni ed acetaldeidi.
L'ingiallimento è dovuto, sostanzialmente, alla formazione di polieni e carbonil-polieni.

Ingiallimento-Imbrunimento(marrone)- nero-trasparenza

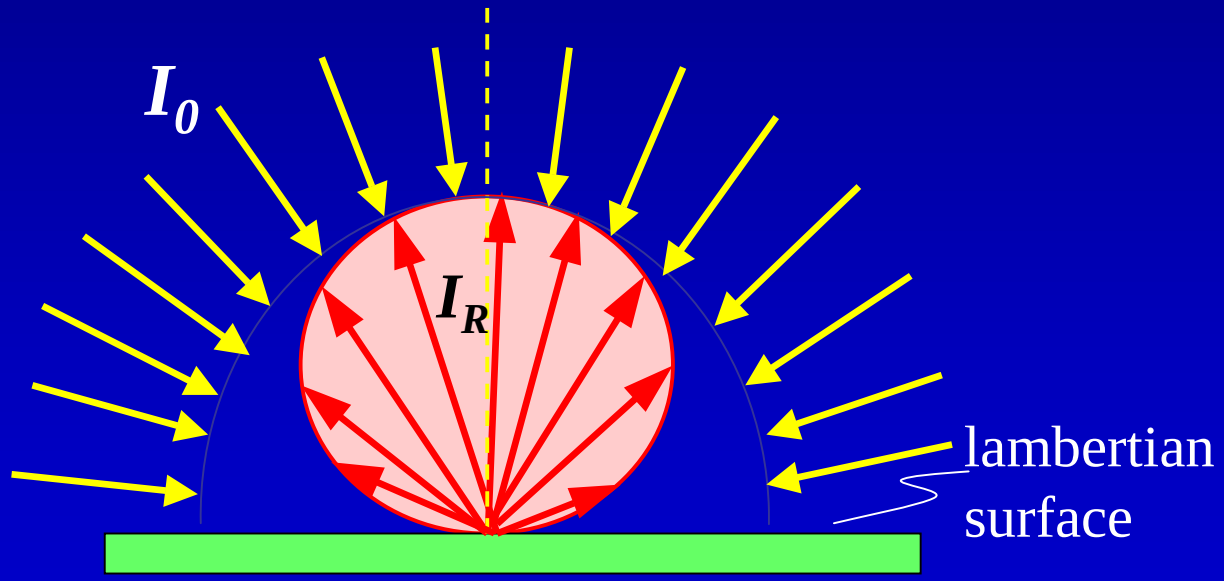
Degradazione dell'EVA



PH = idroperossidazione

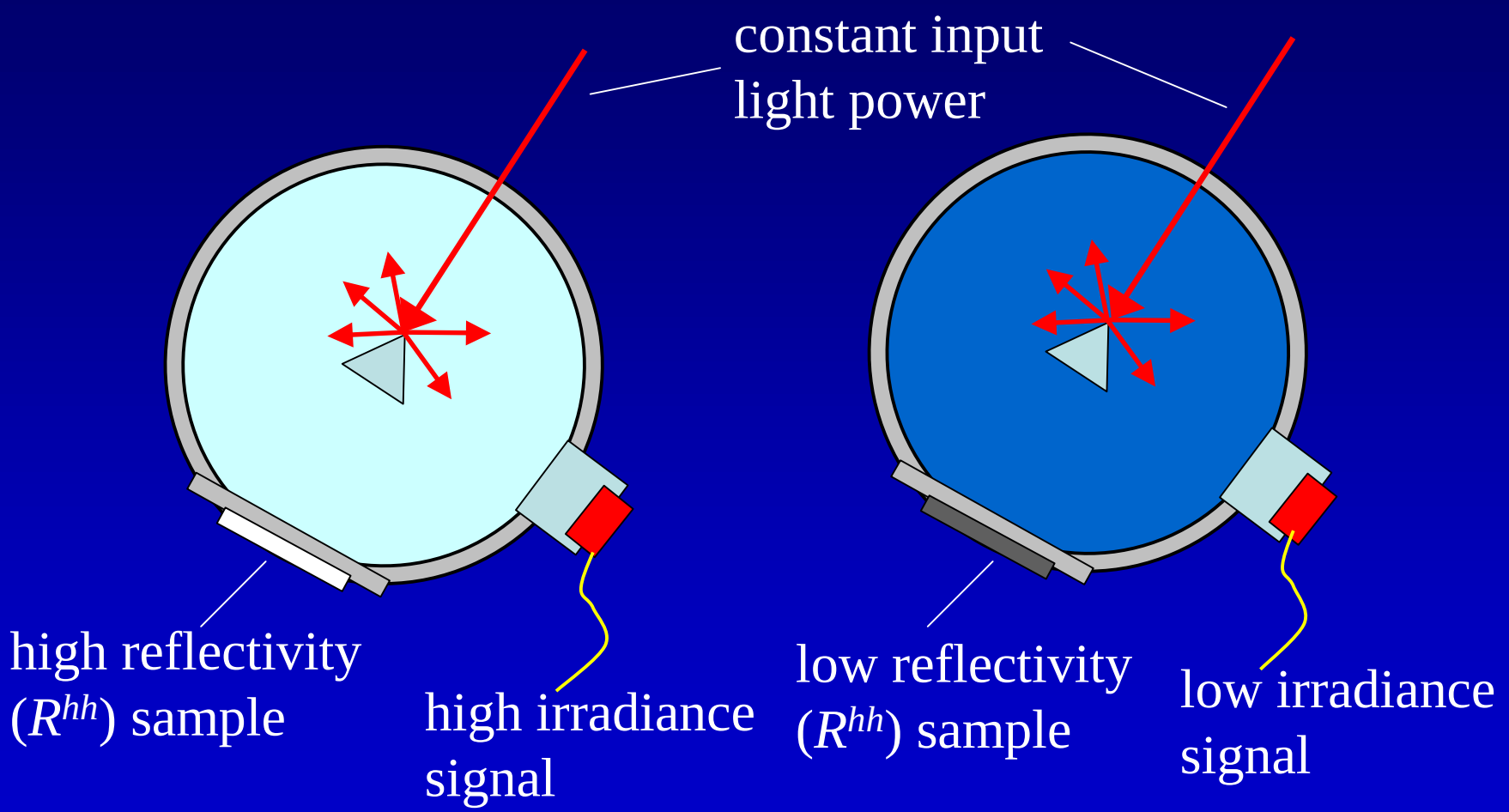
Reflectance measurements under diffuse light

Apparatus "HERE":
"HEmispherical / HEmispherical REflectometer"

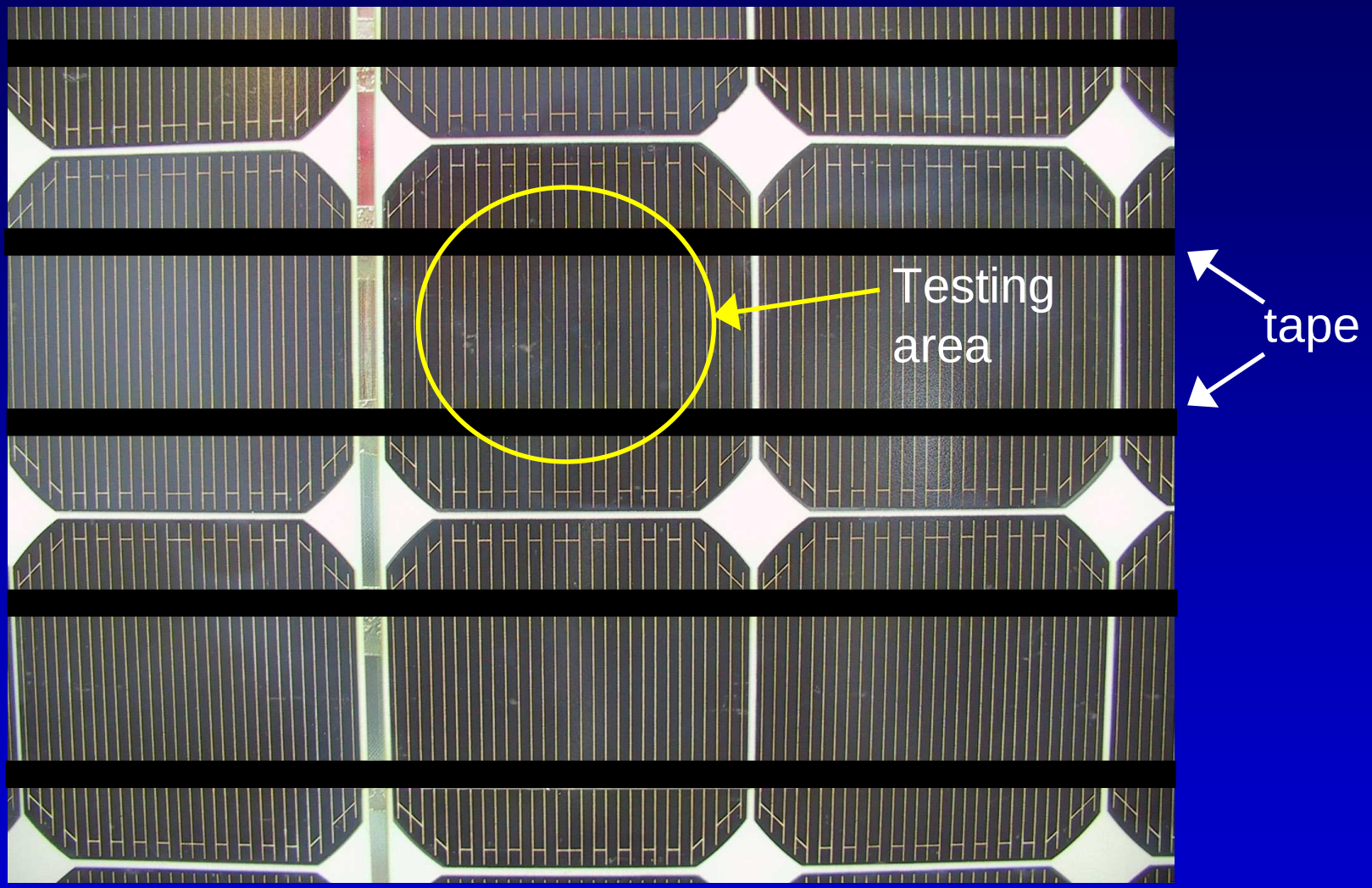


Hemispherical / hemispherical reflectance, R^{hh}

Method for R^{hh} measurements

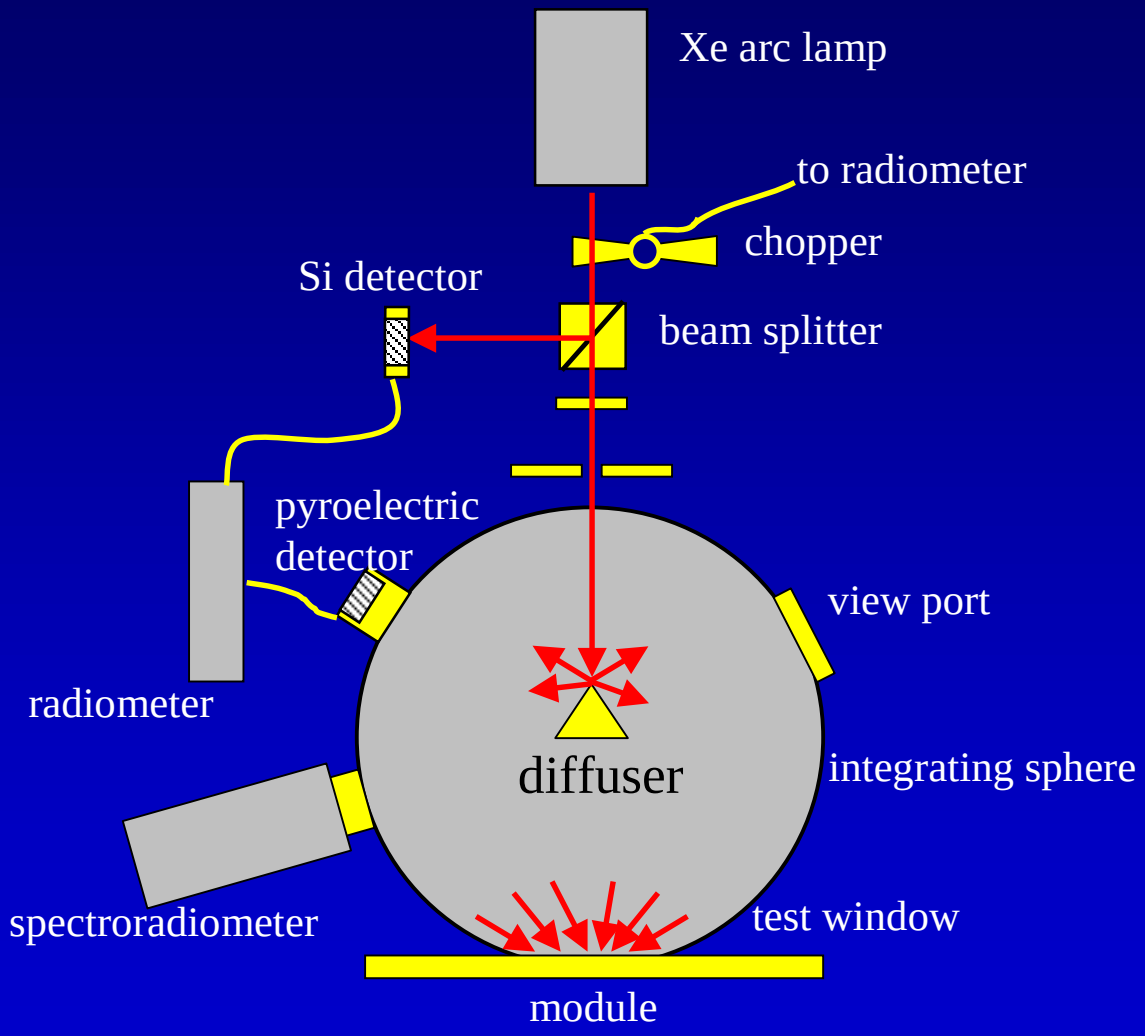


R^{hh} measurements



REFLECTOMETER "HERE"

"HEmispherical / HEmispherical REflectometer"



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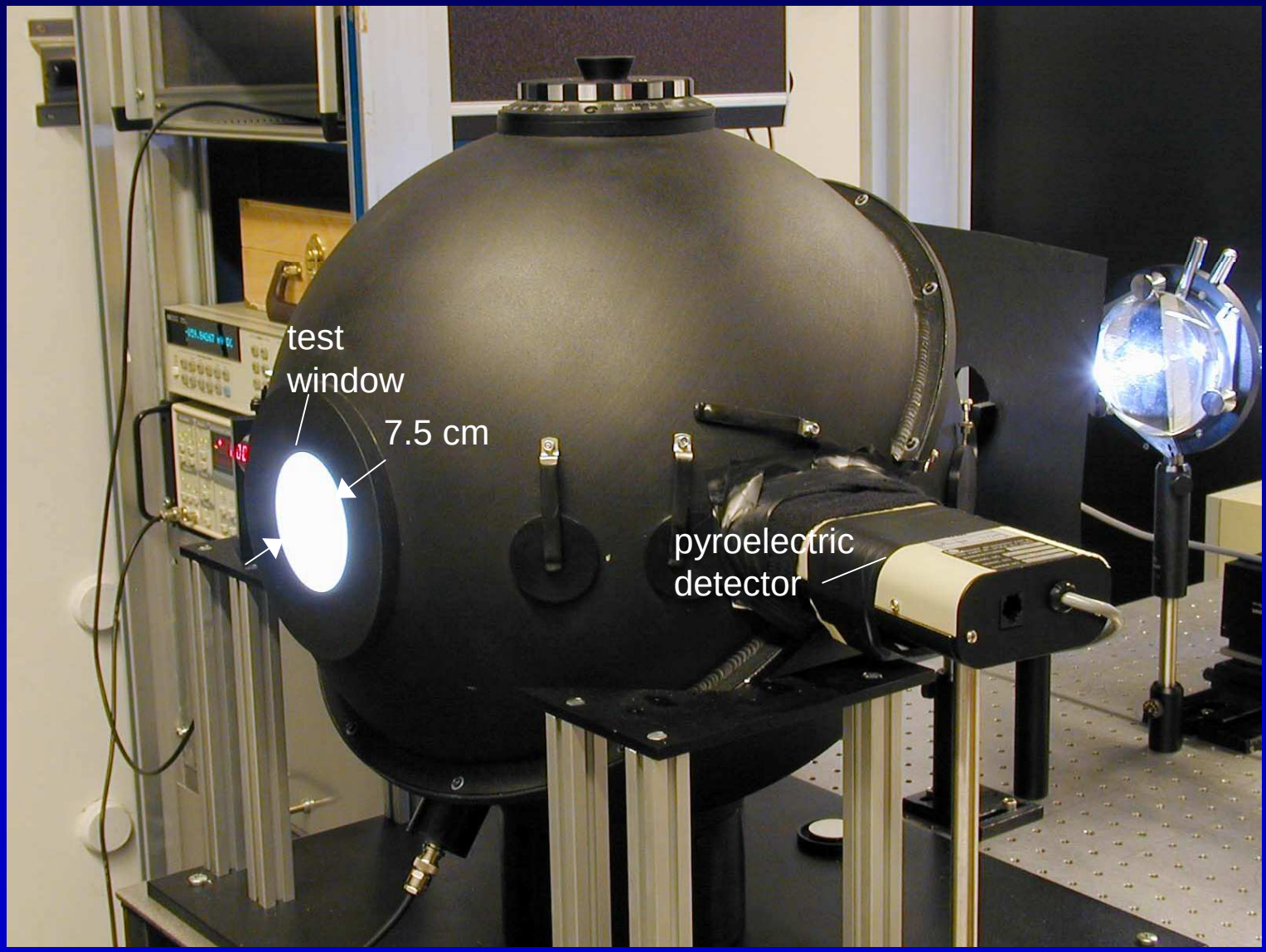
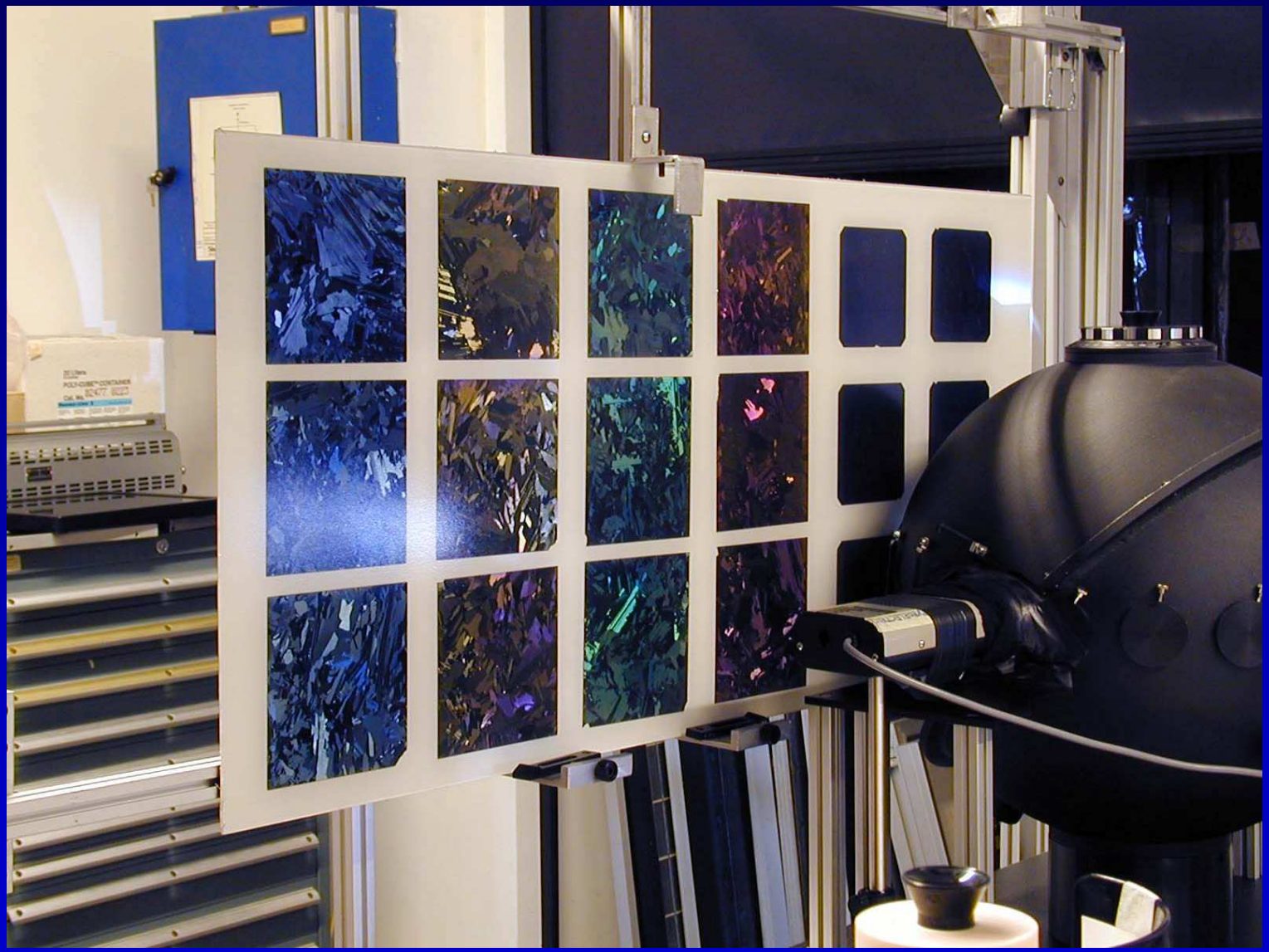
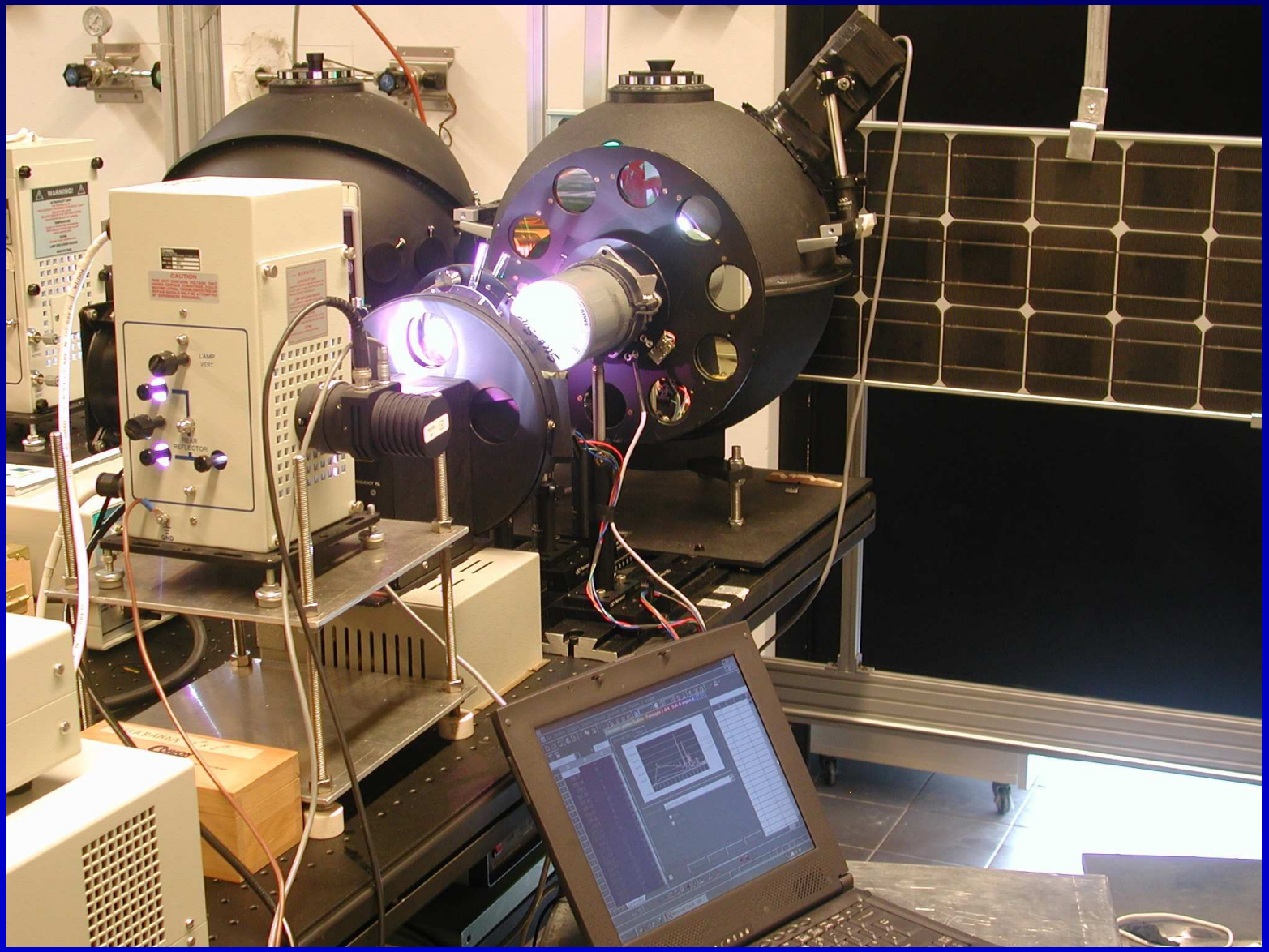


REFLECTOMETER “HERE”



REFLECTOMETER “HERE”

Compact configuration



Delphos plant (1st section)

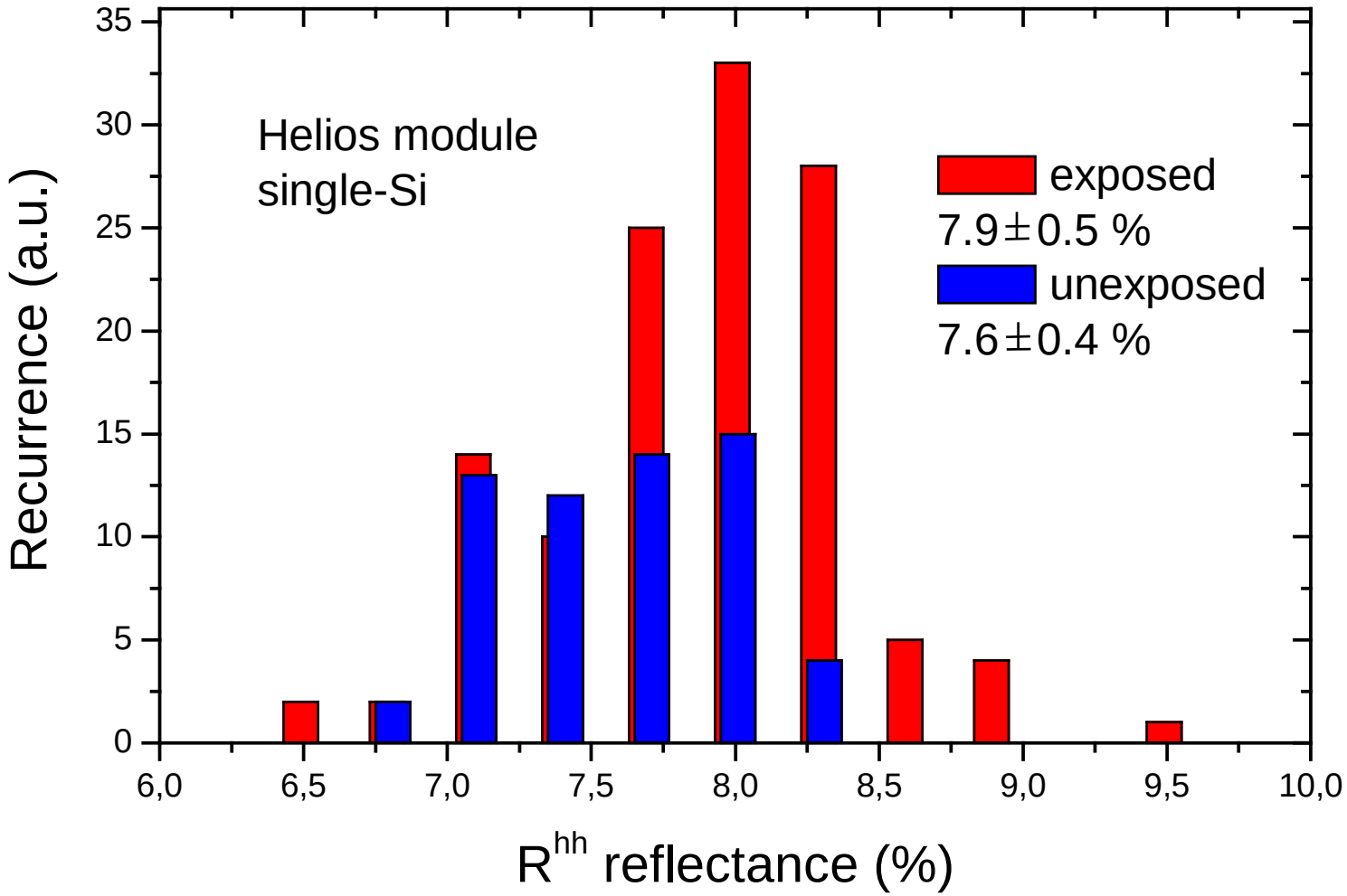
Optical reflectance of single modules under diffuse light

Cleaned modules (excluded dust effects)

Module	Exposition Time (years)	R^{hh} (%)	Standard deviation (%)	ΔR^{hh} (%)	Cell efficiency (%)
Helios single c-Si	15				
Unexposed		**7.6**	0.4		12.5
Exposed		**7.9**	0.5	+ 0.3	
Pragma single c-Si	15				
Unexposed		**10.2**	0.4		11.7
Exposed		**11.0**	0.8	+ 0.8	
Pragma multi c-Si	15				
Unexposed		**8.8**	0.8		9.5
Exposed		**10.3**	0.9	+ 1.5	
Ansaldo multi c-Si	15				
Unexposed		**8.8**	0.7		9.6
Exposed		**10.6**	2.1	+ 1.8	

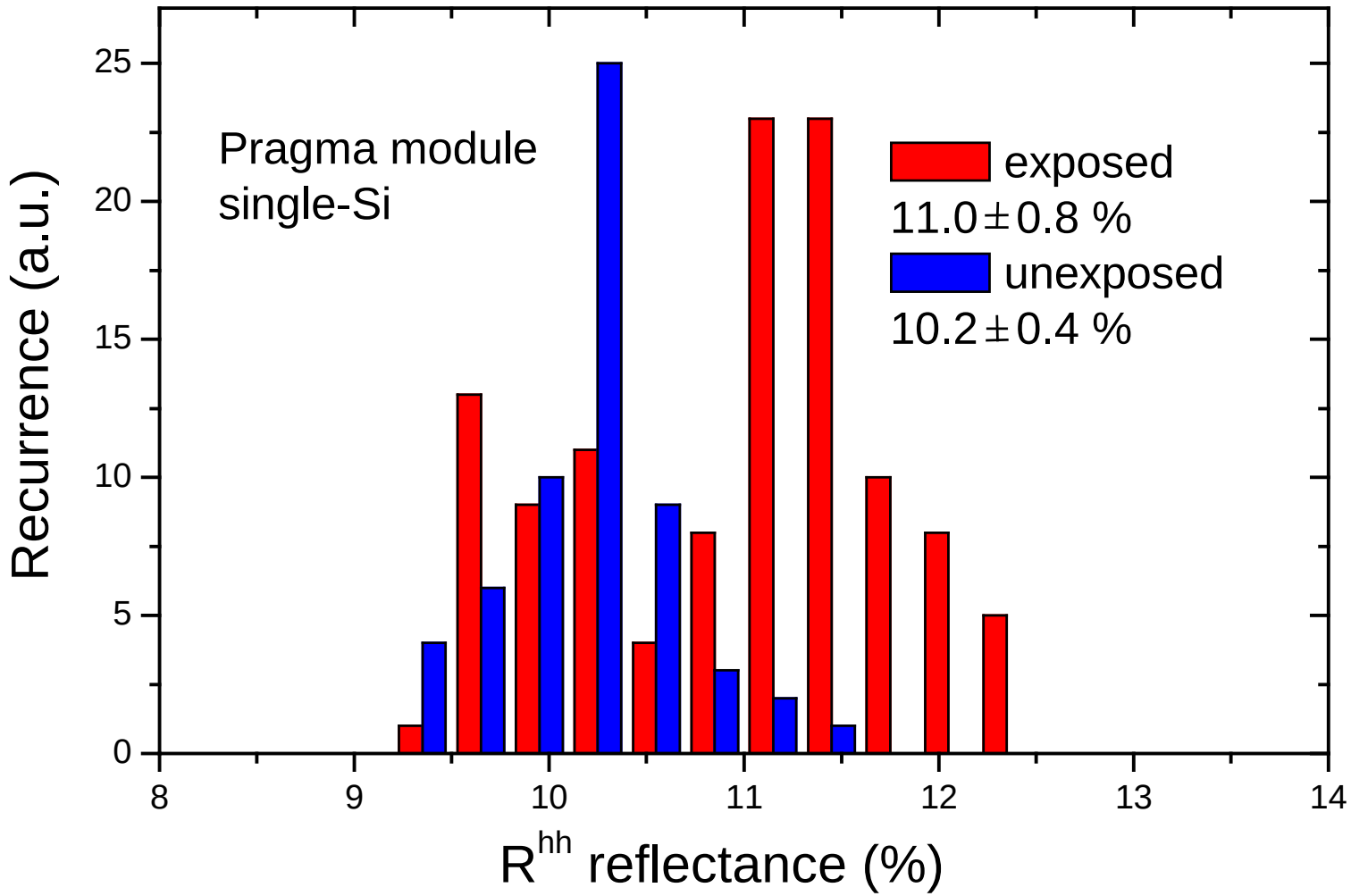
Hemispherical / hemispherical reflectance

HELIOS module (single-Si)



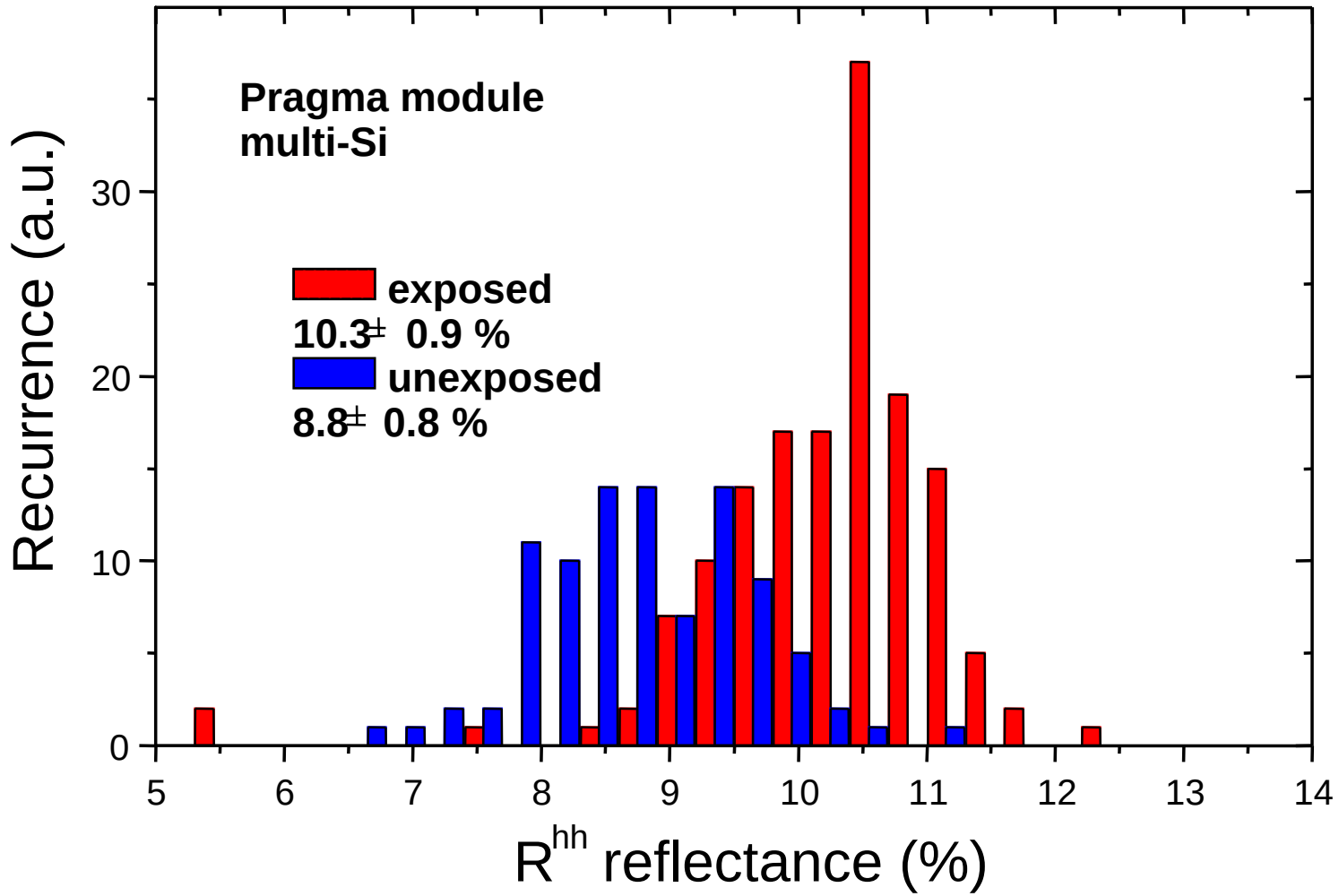
Hemispherical / hemispherical reflectance

PRAGMA module (single-Si)



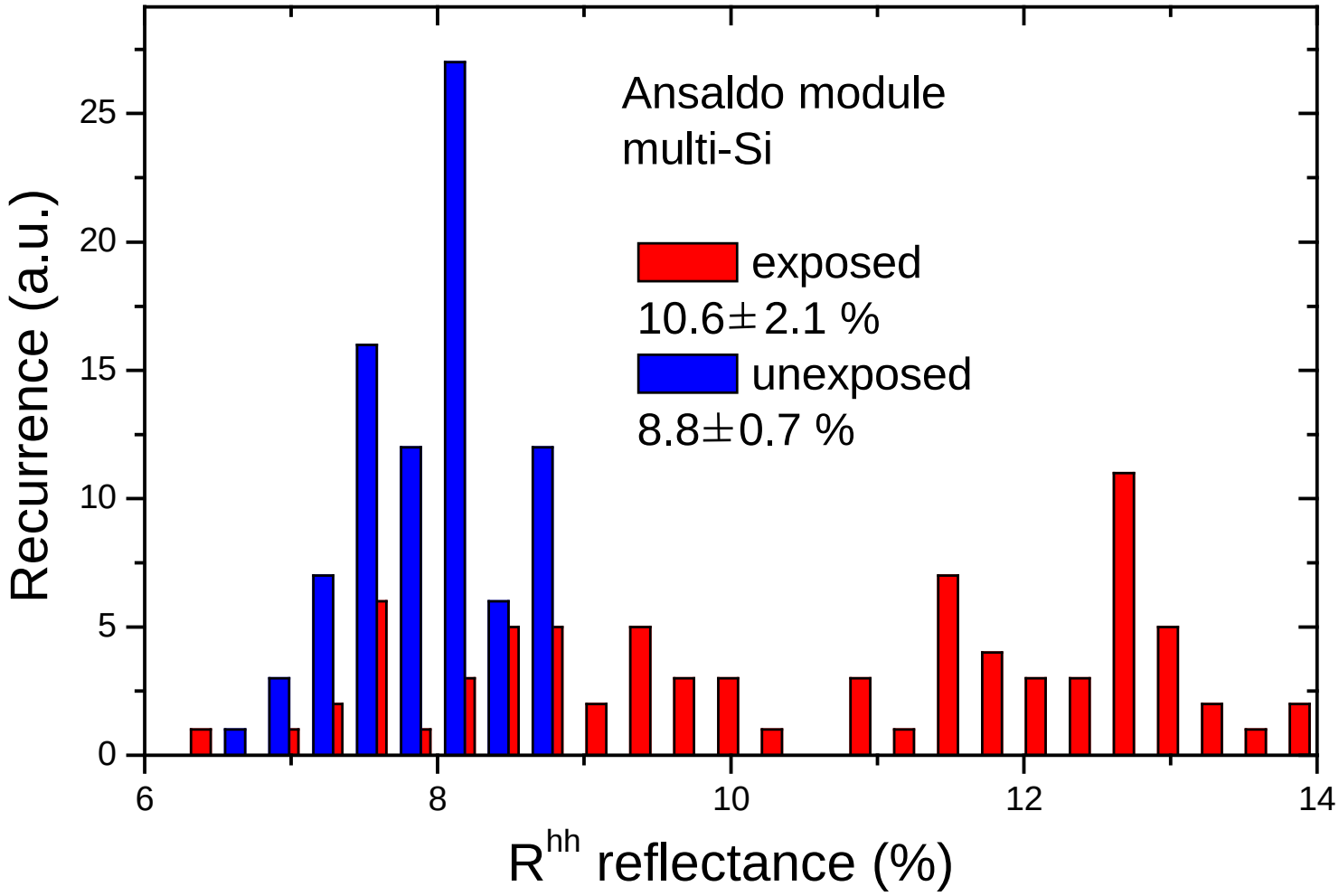
Hemispherical / hemispherical reflectance

PRAGMA module (multi-Si)



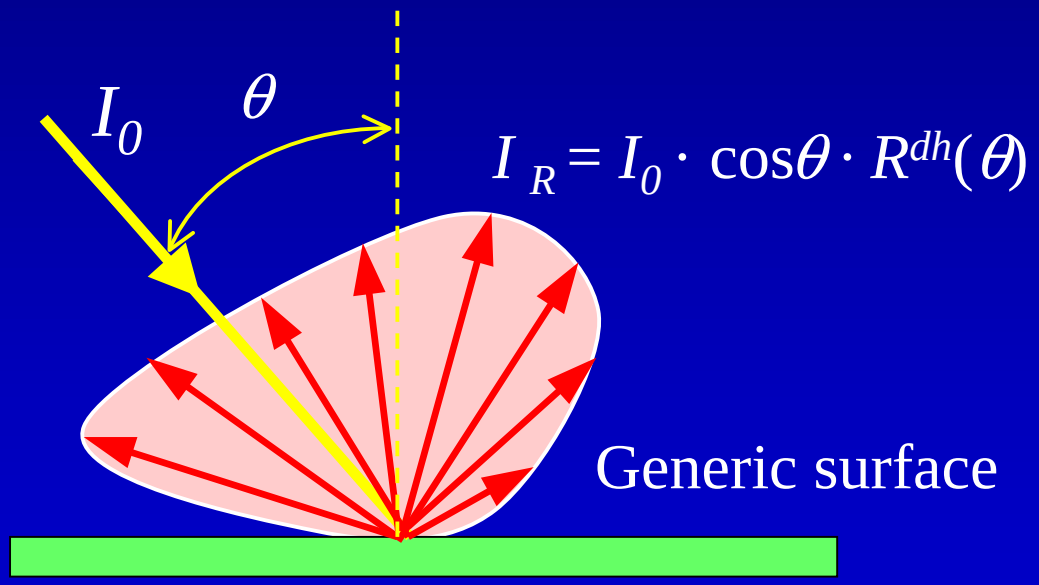
Hemispherical / hemispherical reflectance

ANSALDO module (multi-Si)



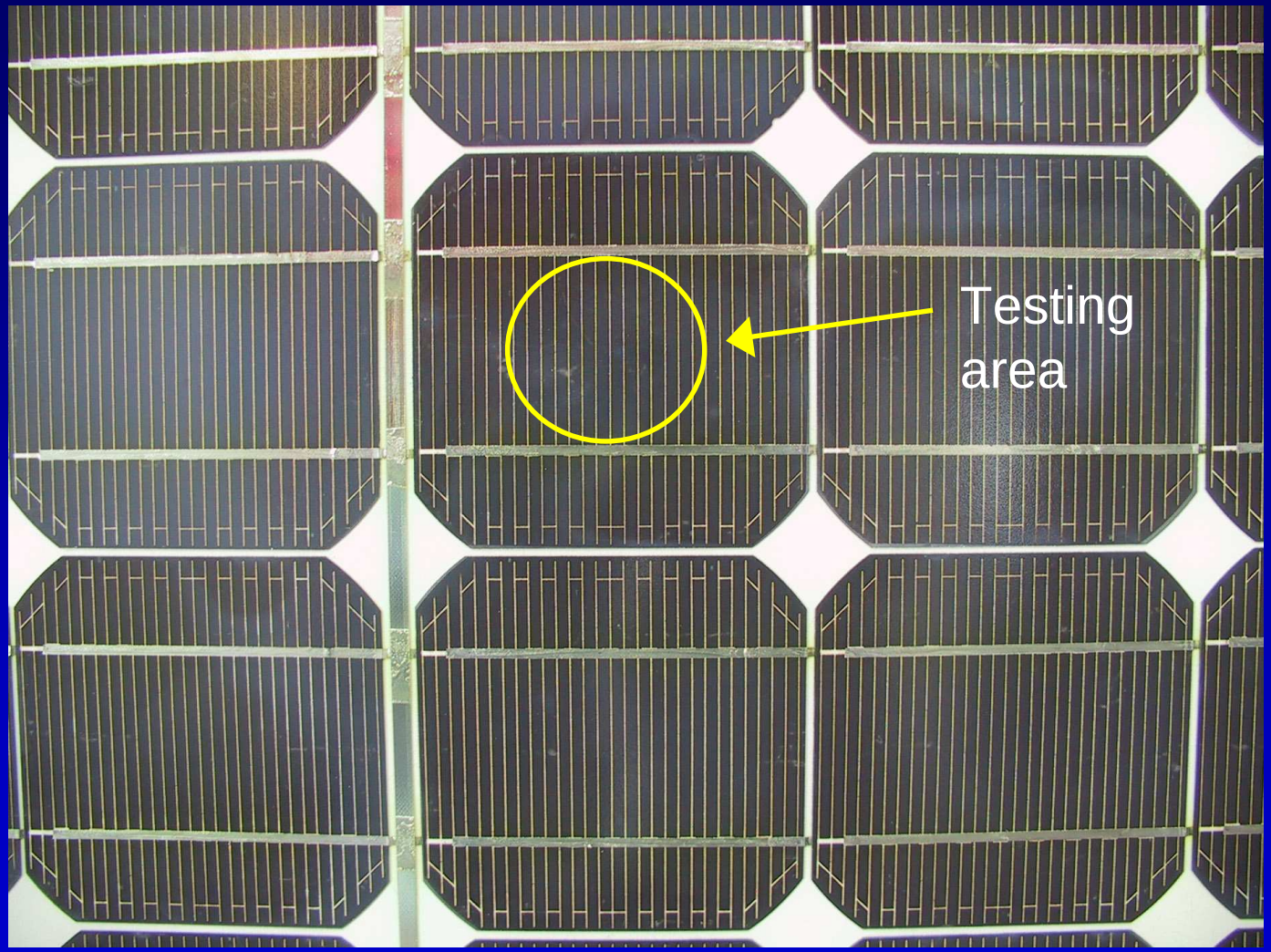
Spectral reflectance measurements under direct light (10° incidence)

Apparatus "ROSE":
"Reflectometer for Optical measurements
In Solar Energy"

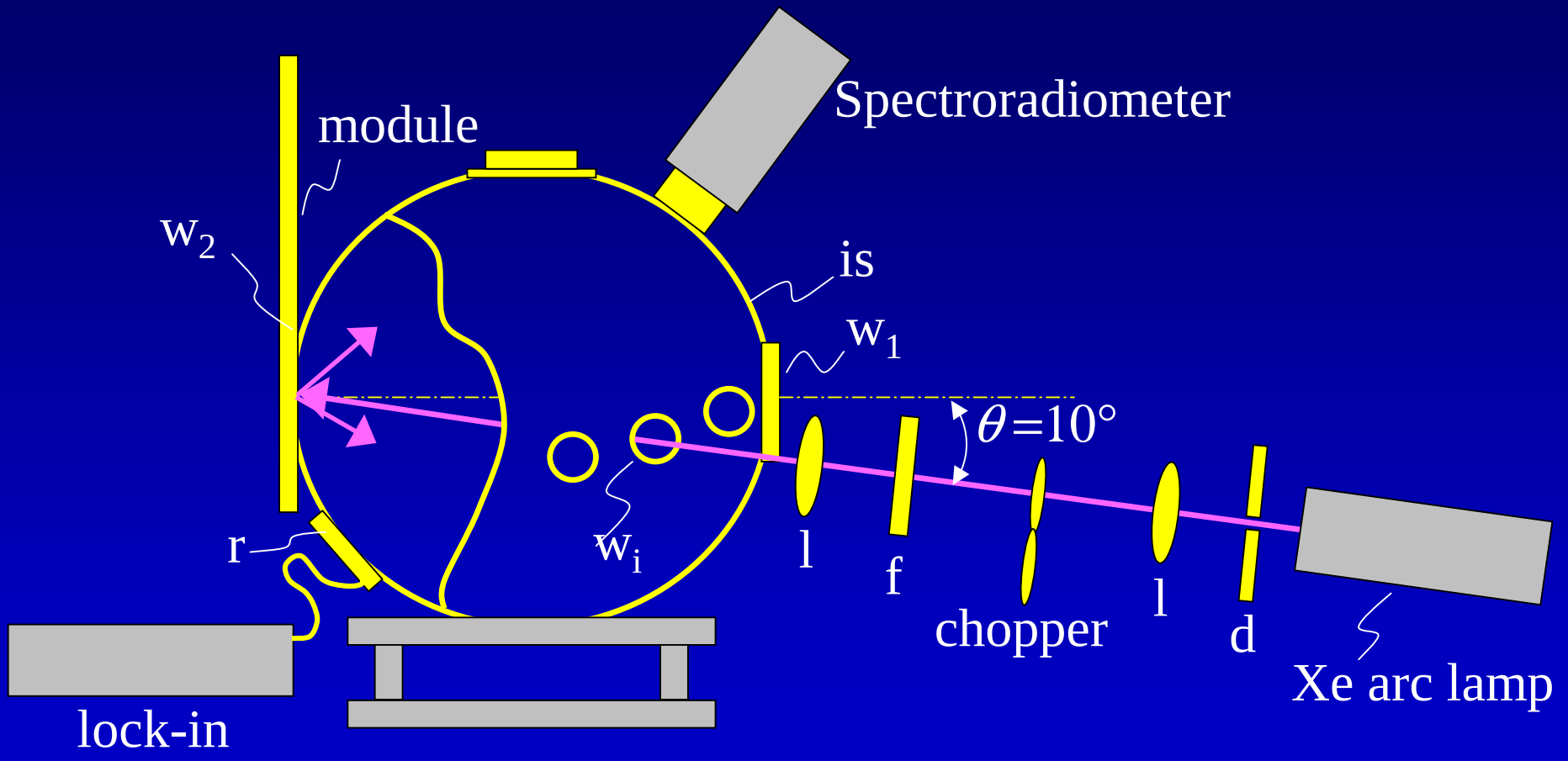


Directional / hemispherical reflectance, R^{dh}

$R^{dh}(10°, \lambda)$ measurements



REFLECTOMETER "ROSE"



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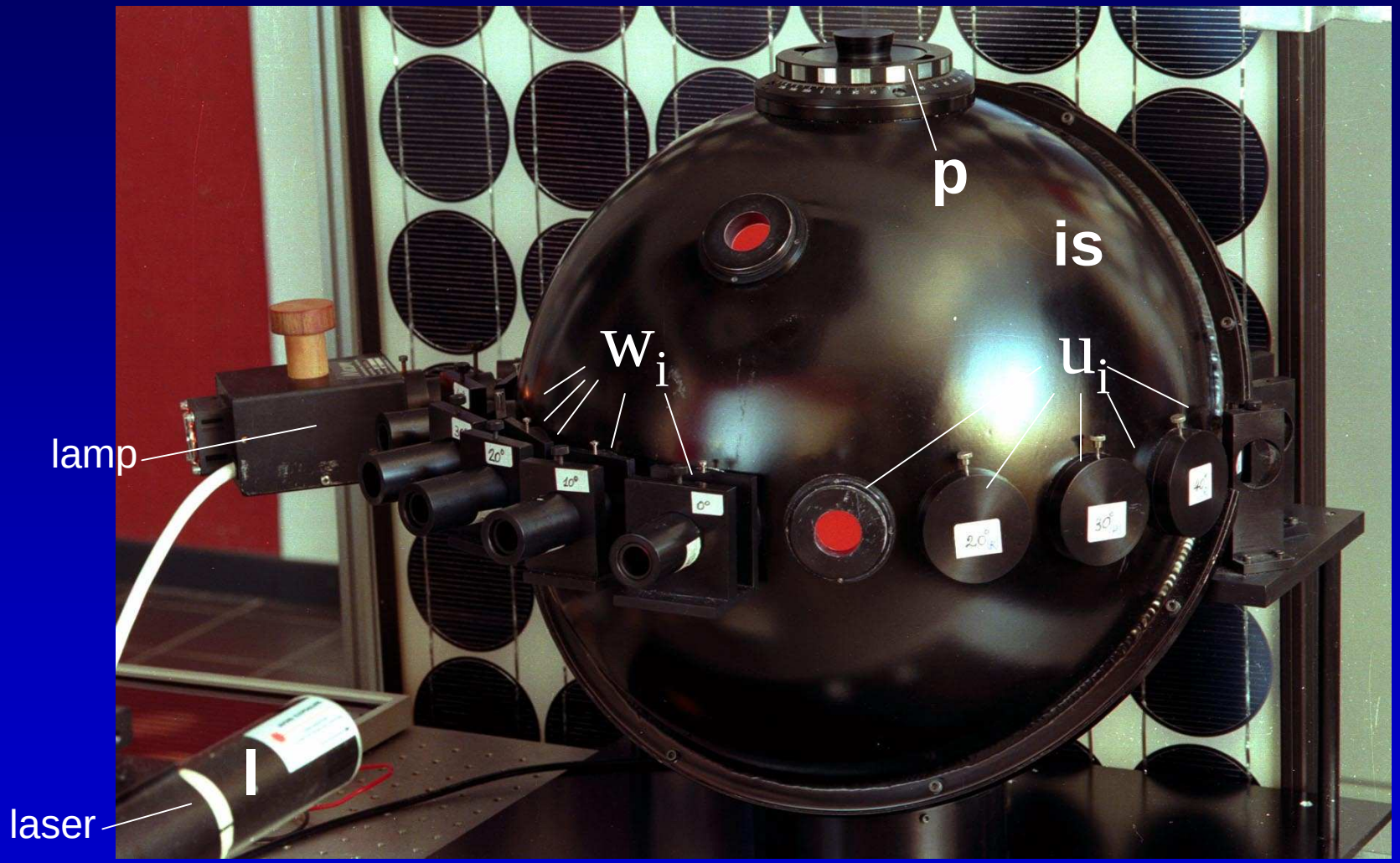
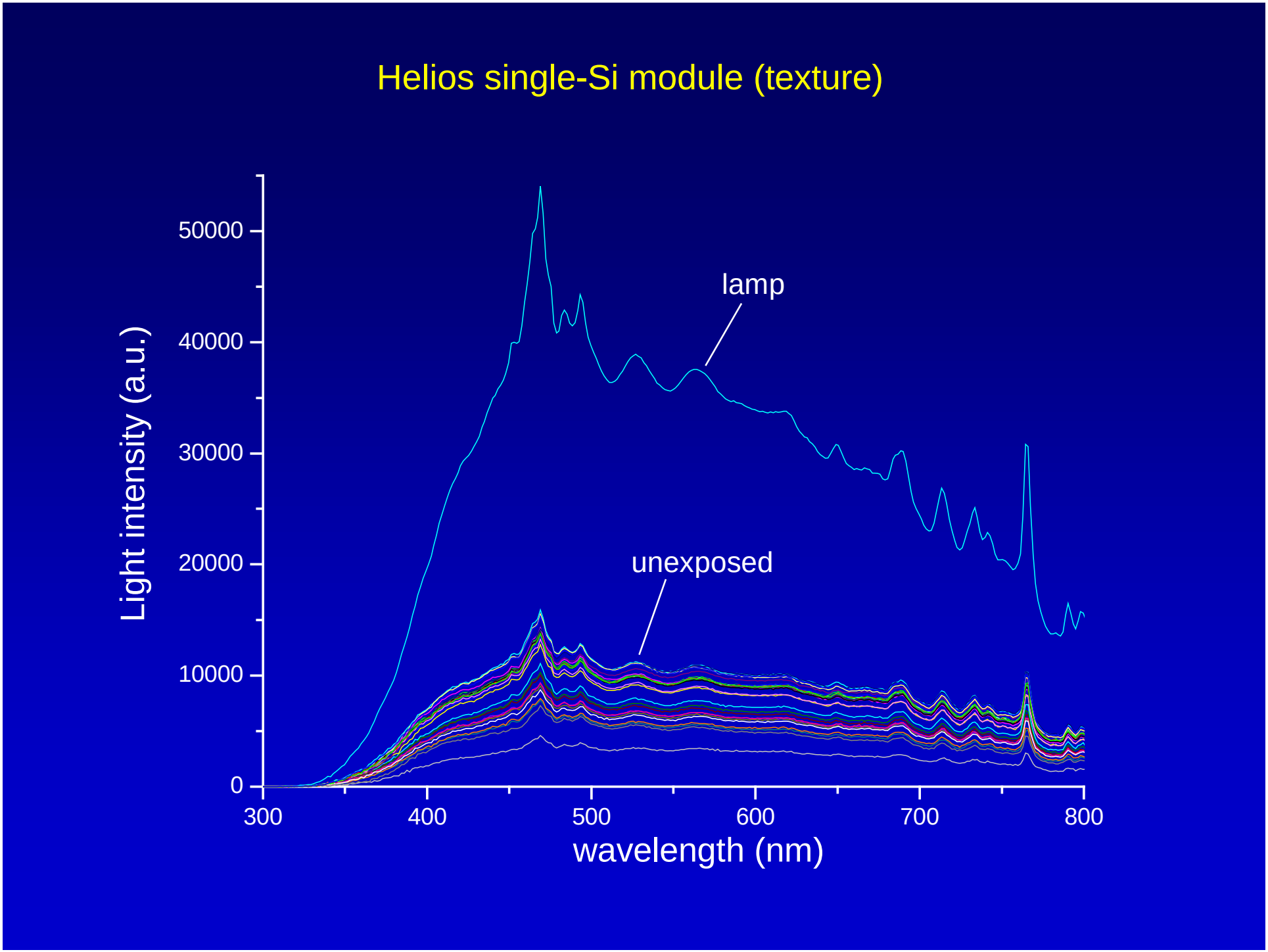
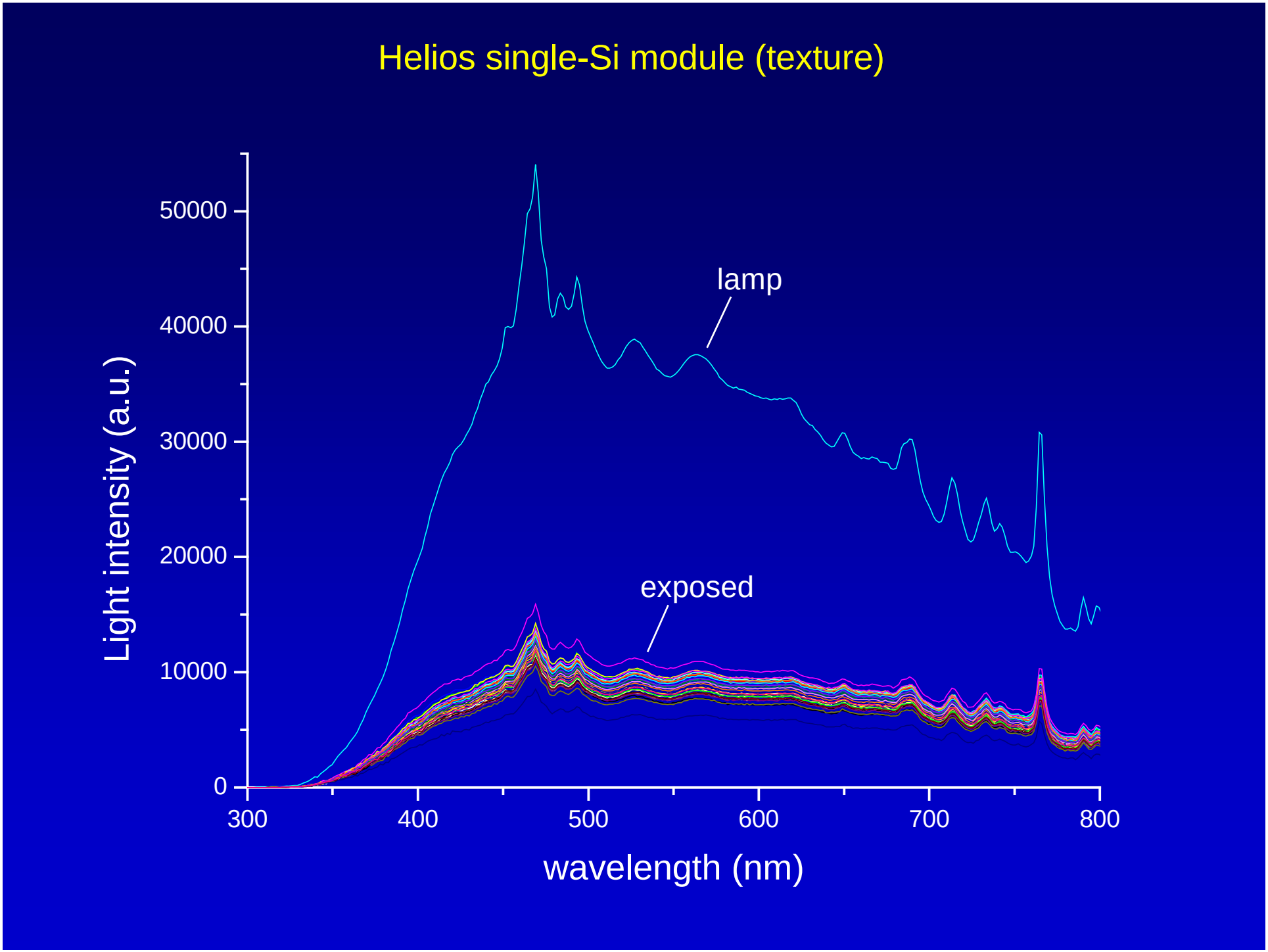


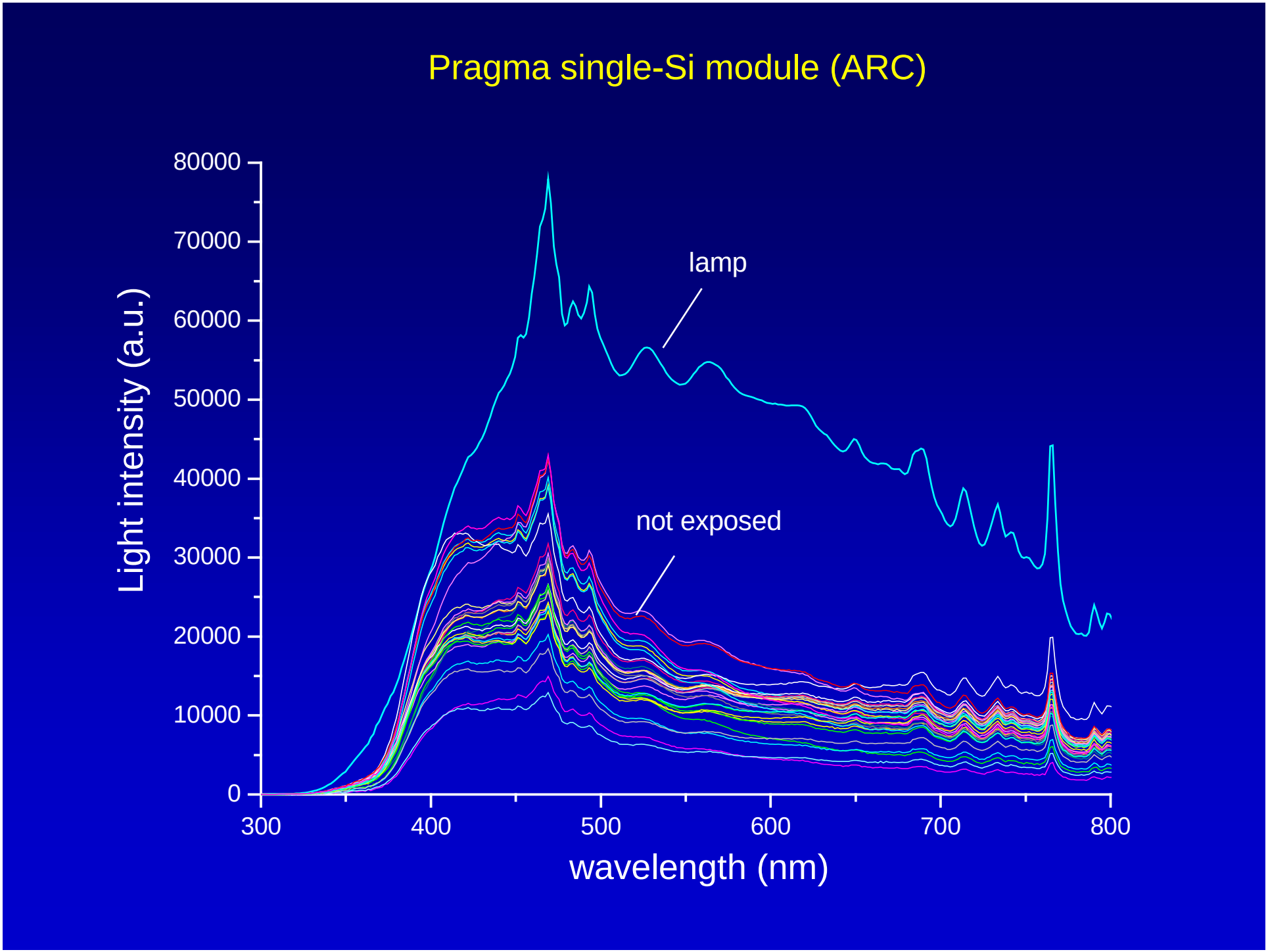
Measurements of $R(\Theta, \lambda)$ on large-area samples:
PV modules, glasses, Fresnel lenses

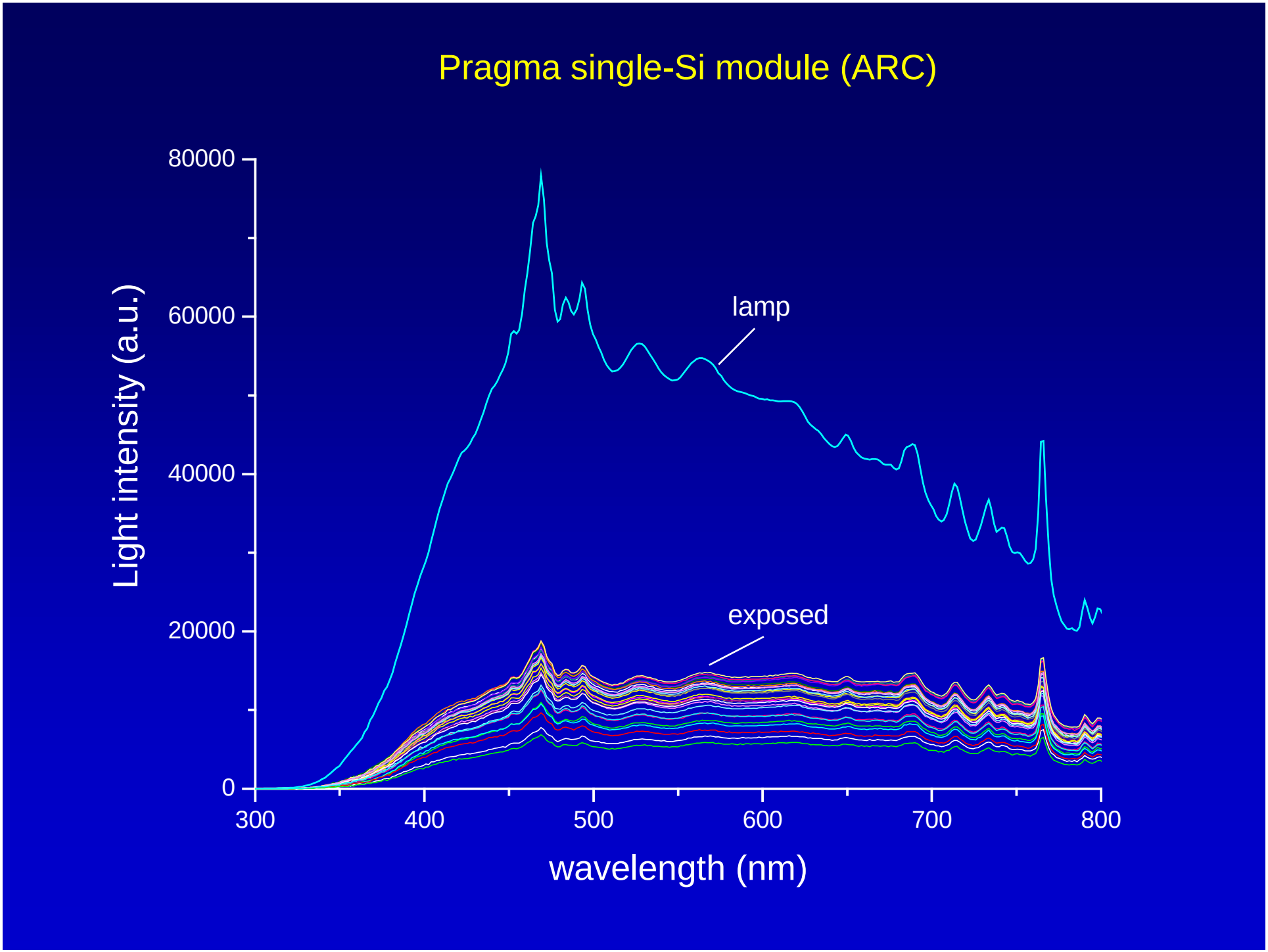
REFLECTOMETER “ROSE”

REFLECTOMETER “ROSE”

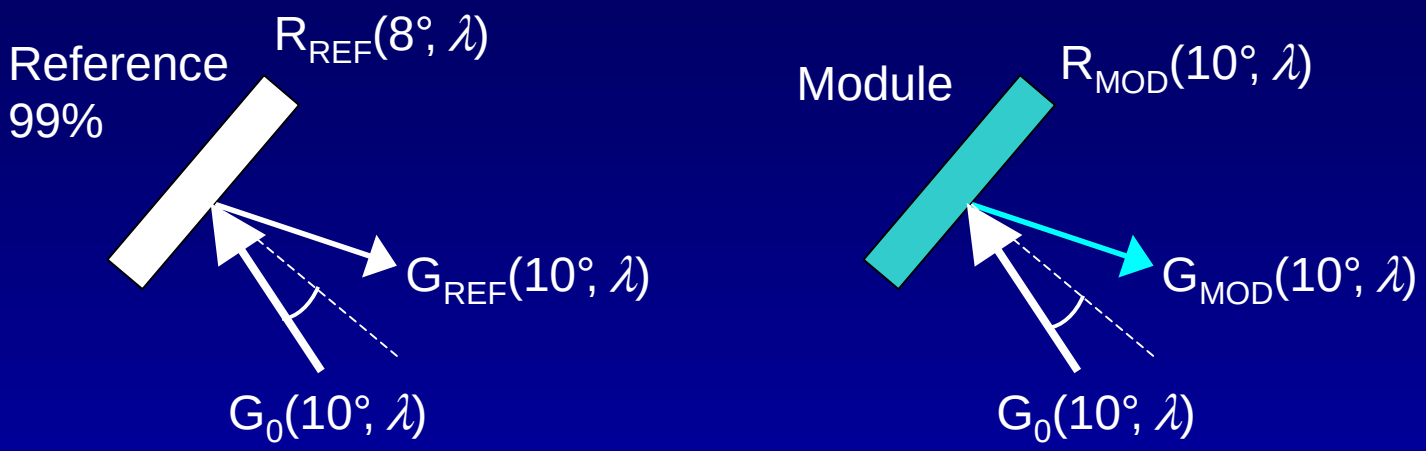

Helios single-Si module (texture)
Light intensity (a.u.)
50000
40000
30000
20000
10000
0
300
400
500
600
700
800
wavelength (nm)
lamp
unexposed


Helios single-Si module (texture)
Light intensity (a.u.)
50000
40000
30000
20000
10000
0
300
400
500
600
700
800
wavelength (nm)
lamp
exposed


Pragma single-Si module (ARC)
Light intensity (a.u.)
80000
70000
60000
50000
40000
30000
20000
10000
0
300
400
500
600
700
800
wavelength (nm)
lamp
not exposed


Pragma single-Si module (ARC)
Light intensity (a.u.)
80000
60000
40000
20000
0
lamp
exposed
300
400
500
600
700
800
wavelength (nm)

Spectral reflectance calculation

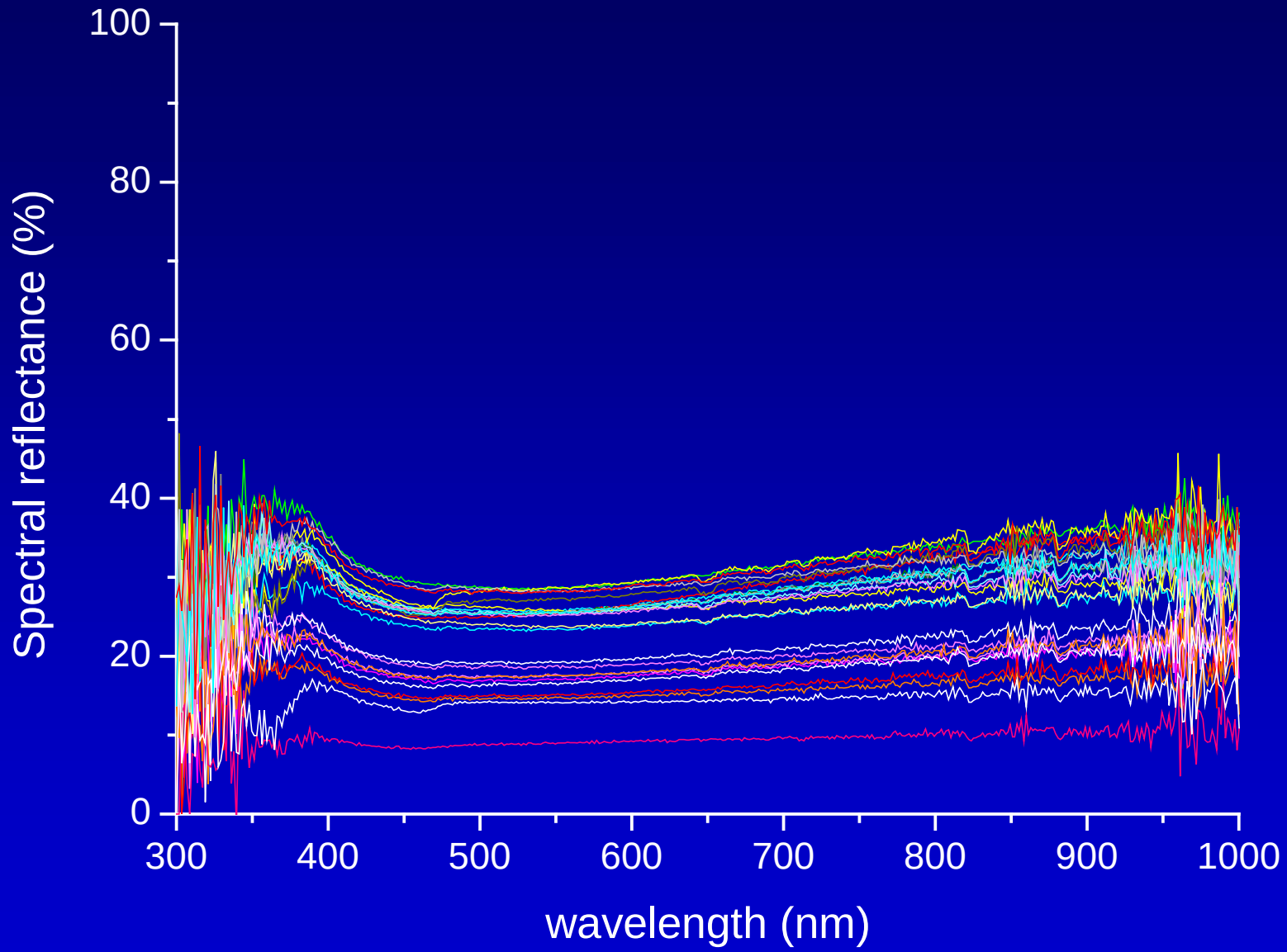


$$G_{REF}(10°,\lambda) = G_0(10°,\lambda)\cdot R_{REF}(10°,\lambda) \approx G_0(10°,\lambda)\cdot R_{REF}(8°,\lambda)$$

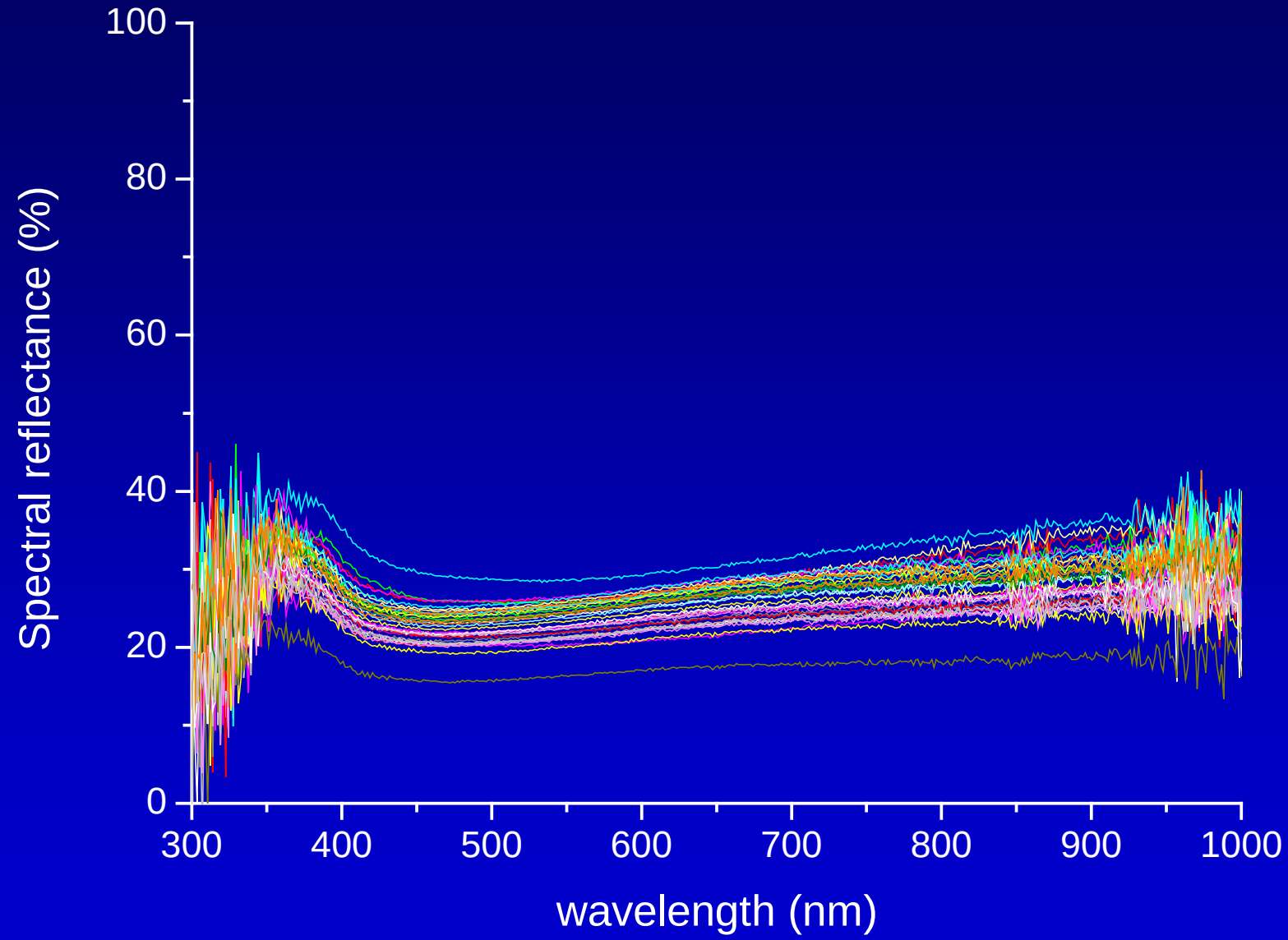
$$G_{MOD}(10°,\lambda) = G_0(10°,\lambda)\cdot R_{MOD}(10°,\lambda)$$

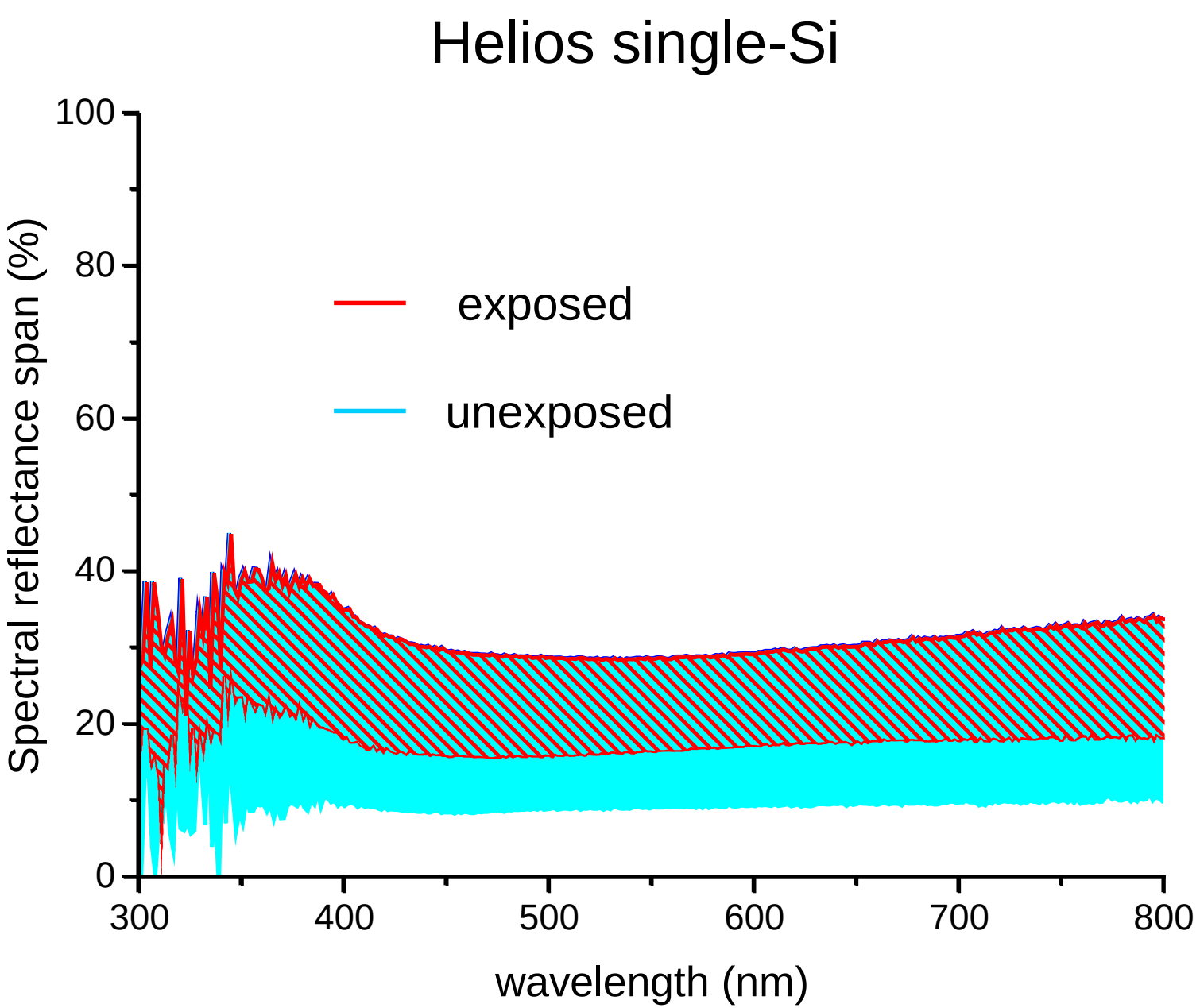
$$R_{MOD}(10°,\lambda) \approx \frac{G_{MOD}(10°,\lambda)\cdot R_{REF}(8°,\lambda)}{G_{REF}(10°,\lambda)}$$

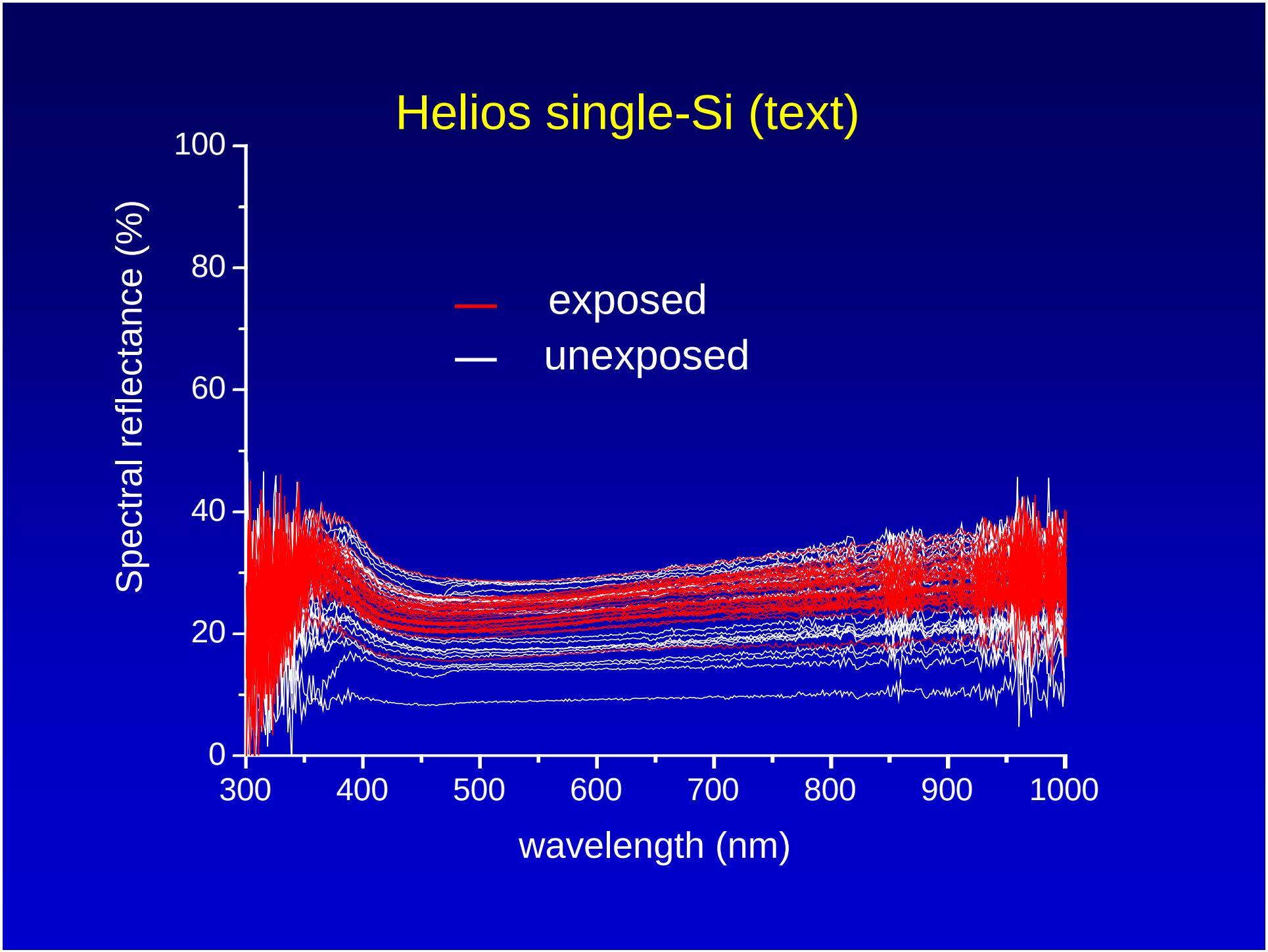
Helios single-Si **unexposed**

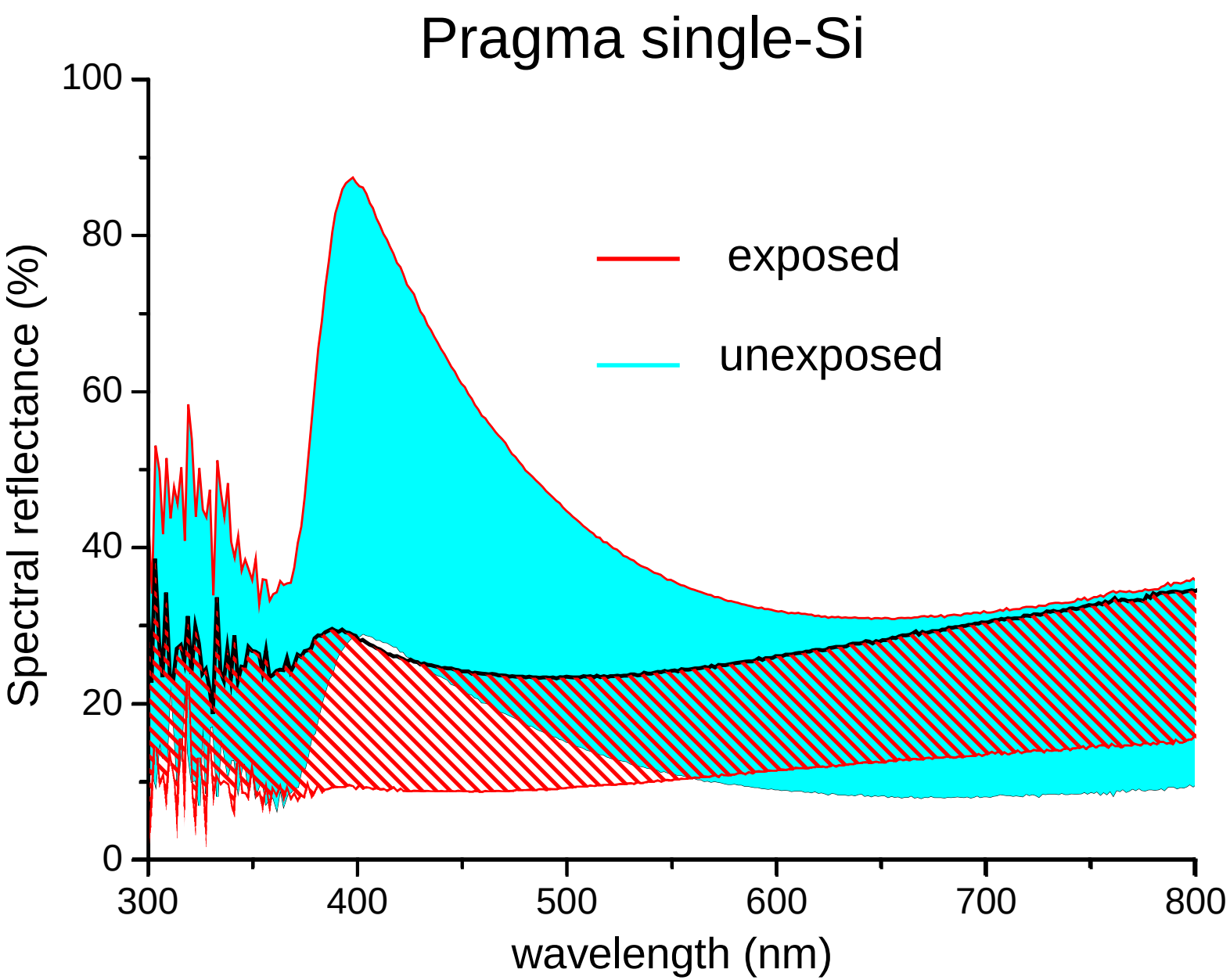


Helios single-Si **exposed**

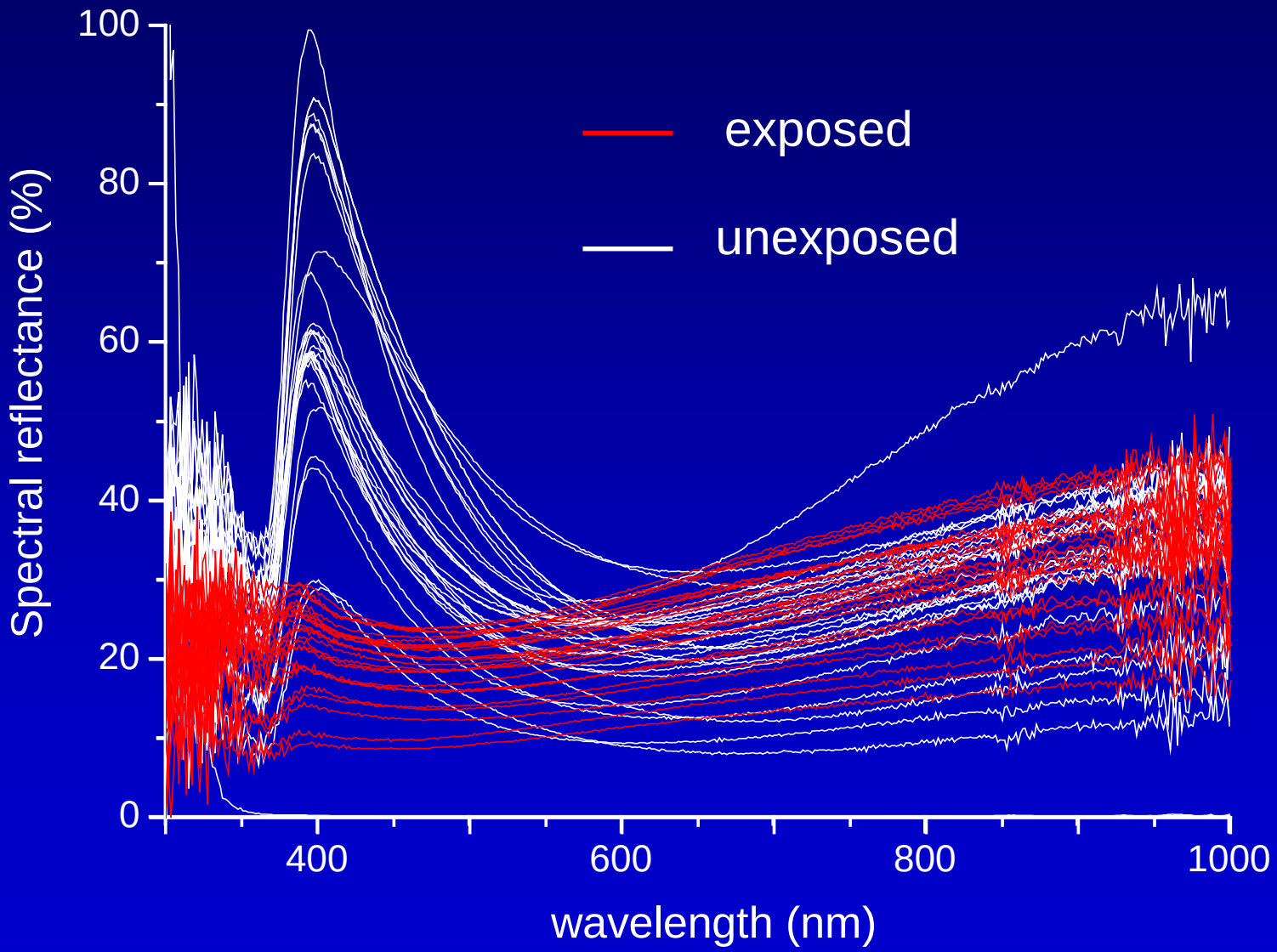


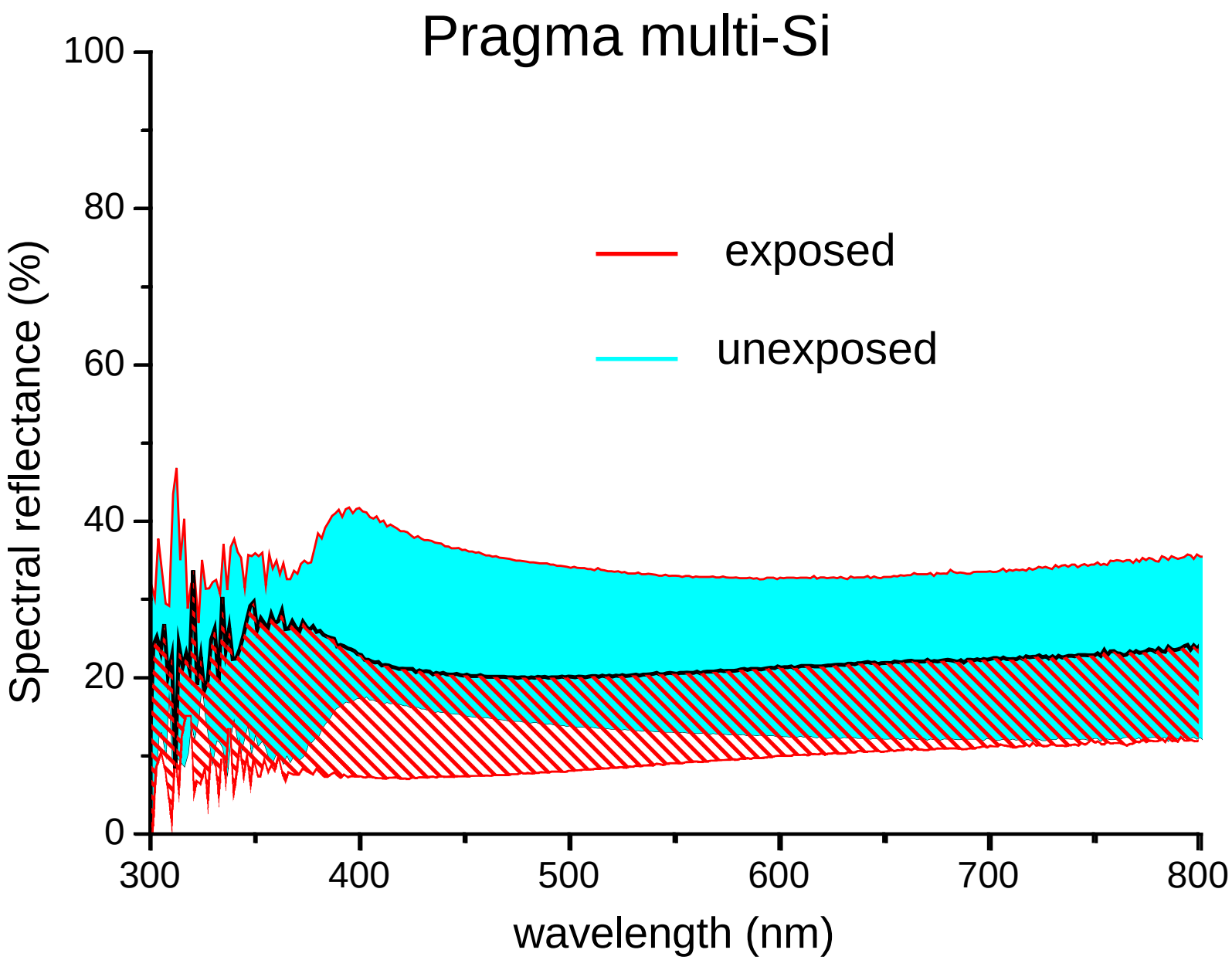

Helios single-Si
Spectral reflectance span (%)
100
80
60
40
20
0
exposed
unexposed
300
400
500
600
700
800
wavelength (nm)

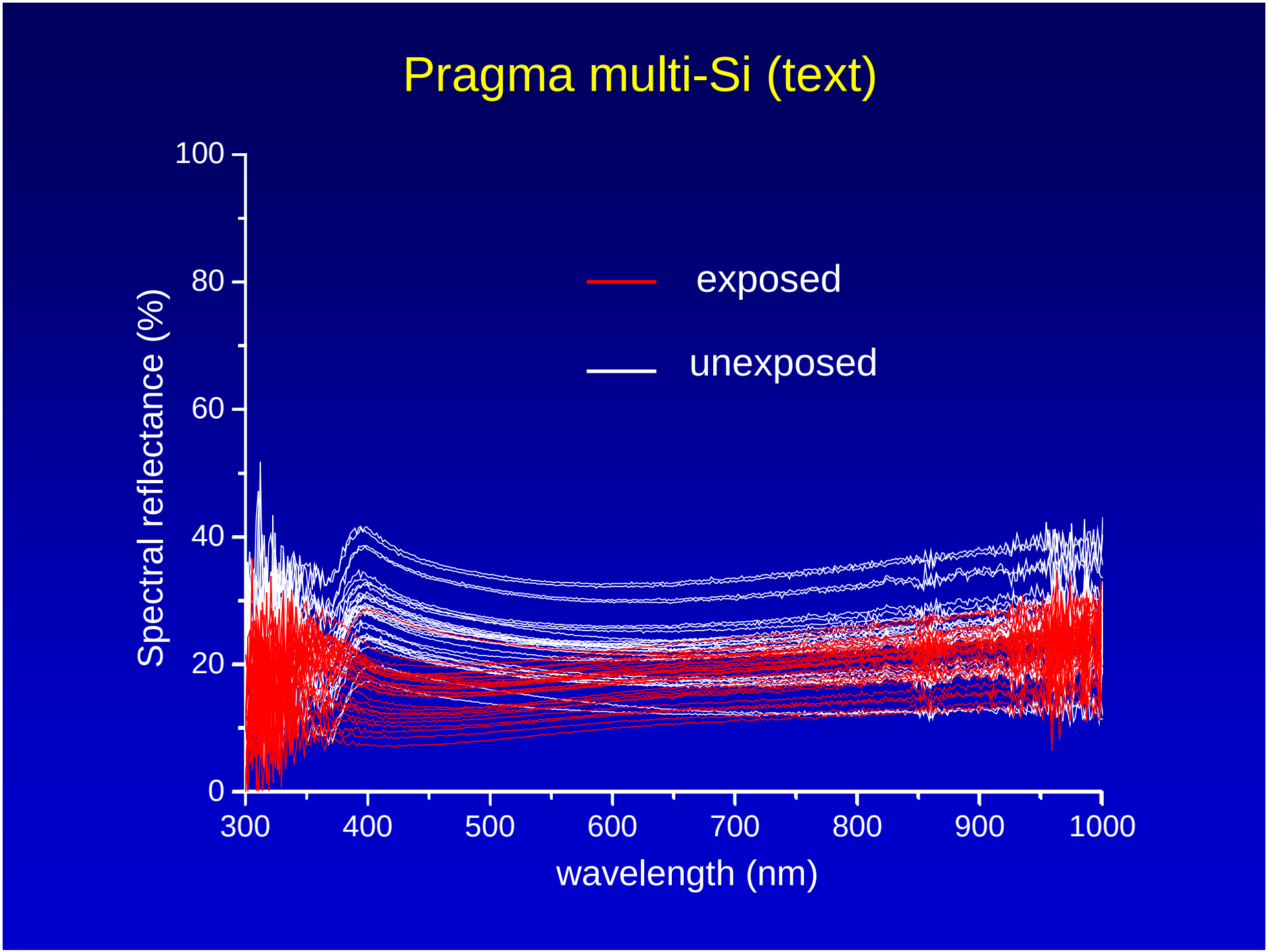

Helios single-Si (text)
Spectral reflectance (%)
100
80
60
40
20
0
exposed
unexposed
300
400
500
600
700
800
900
1000
wavelength (nm)

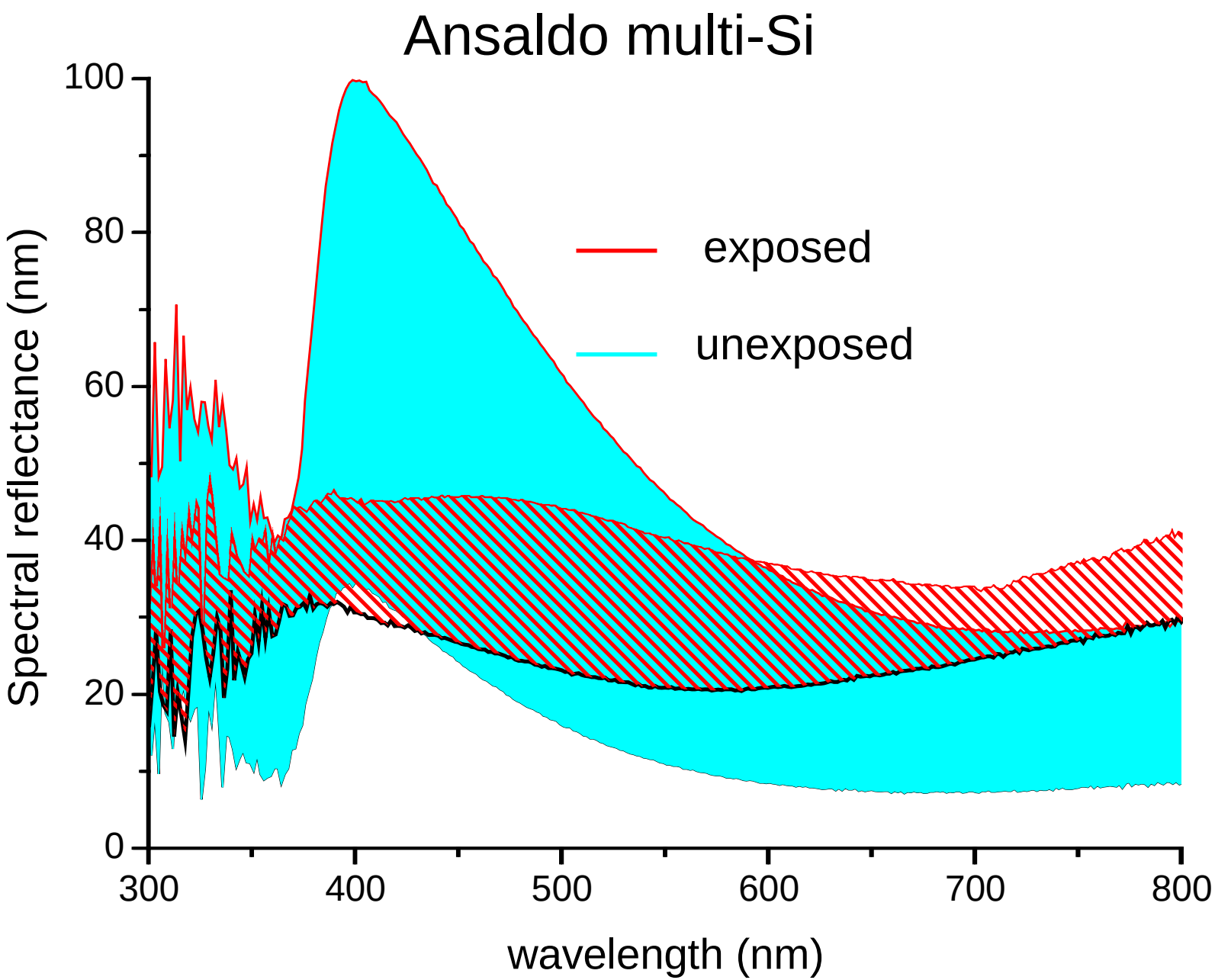

Pragma single-Si
exposed
unexposed
Spectral reflectance (%)
100
80
60
40
20
0
300
400
500
600
700
800
wavelength (nm)

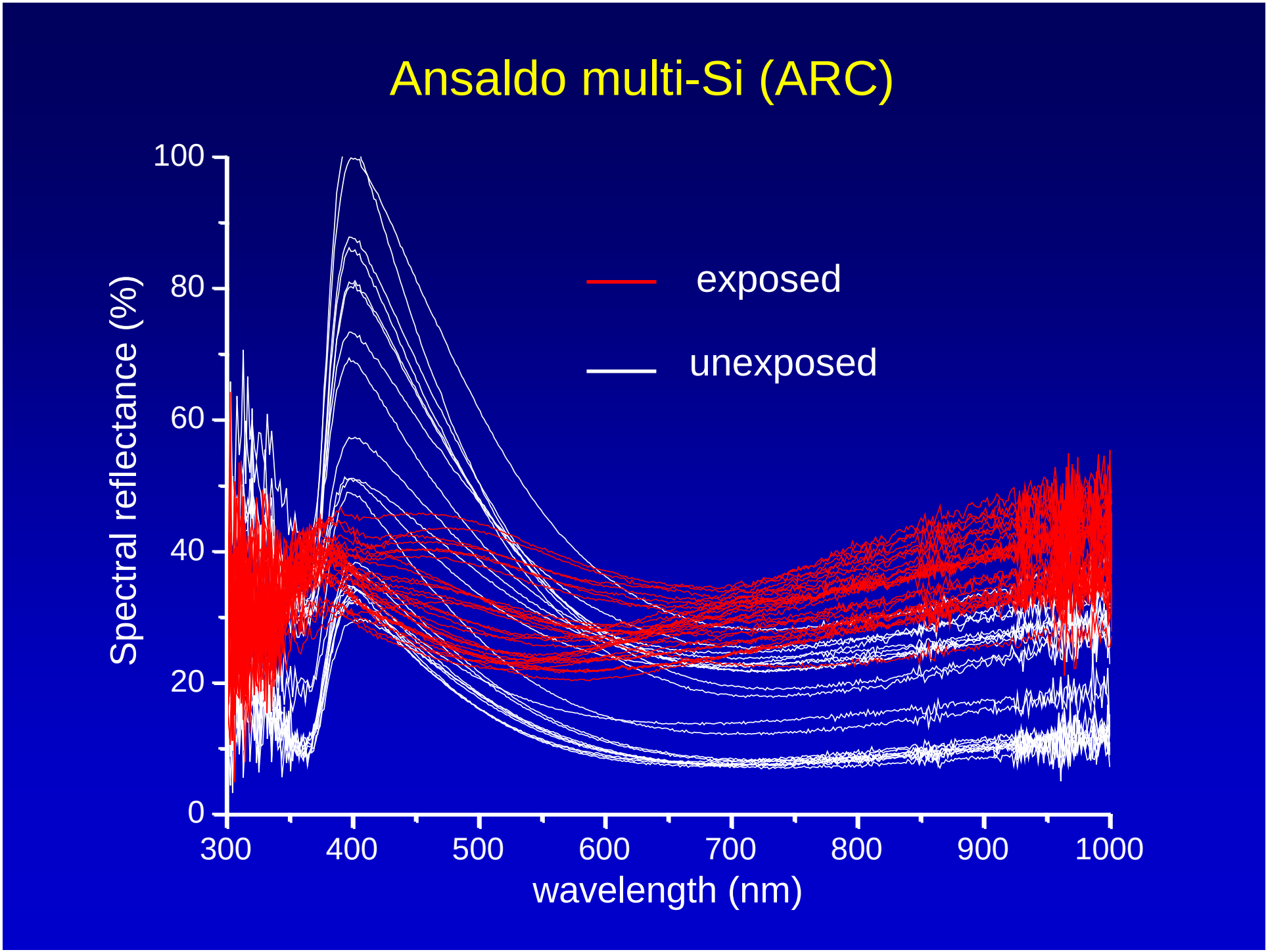
Pragma single-Si (ARC)

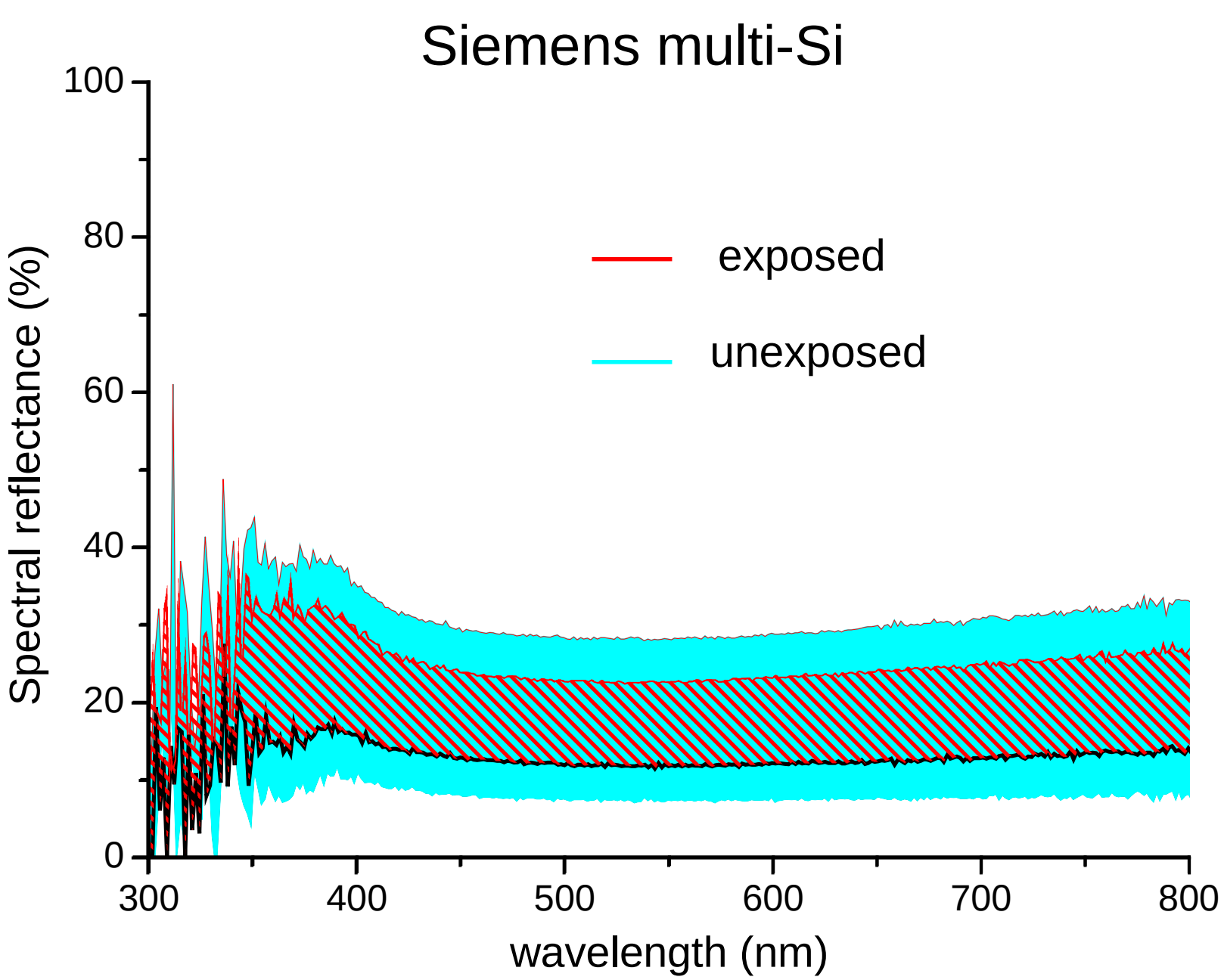



Pragma multi-Si
exposed
unexposed
Spectral reflectance (%)
100
80
60
40
20
0
300
400
500
600
700
800
wavelength (nm)


Pragma multi-Si (text)
Spectral reflectance (%)
100
80
60
40
20
0
300
400
500
600
700
800
900
1000
wavelength (nm)
exposed
unexposed


Ansaldo multi-Si
Spectral reflectance (nm)
100
80
60
40
20
0
300
400
500
600
700
800
wavelength (nm)
exposed
unexposed


Ansaldo multi-Si (ARC)
exposed
unexposed
Spectral reflectance (%)
100
80
60
40
20
0
300
400
500
600
700
800
900
1000
wavelength (nm)


Siemens multi-Si
exposed
unexposed
Spectral reflectance (%)
100
80
60
40
20
0
300
400
500
600
700
800
wavelength (nm)

CONCLUSIONS

- The optical properties of cleaned c-Si PV modules are strongly modified by long-term (15 years) exposition outdoors.

- Visible modifications are the discoloration (browning) of the central region of the cells or the appearance of large stains distributed over the module surface.

- All the degraded modules show a slight increase of reflectance under diffuse light, particularly the multi-Si modules.

- The spectral reflectance under direct light is strongly reduced in modules with ARC in the 400-500 nm interval (blue), due to the discoloration of the ARC layer.

CONCLUSIONS

- The degradation tends to level the optical properties under direct light of modules.

- Discrepancy between reflectances under direct and diffuse light could be due to a degradation of EVA. This investigation is in progress.

- The method HERE for reflectance measurements under diffuse light is proposed for evaluating the optical loss of a module under outdoor conditions. The method HERE is fast and suitable for heterogeneous samples (multi-Si modules).