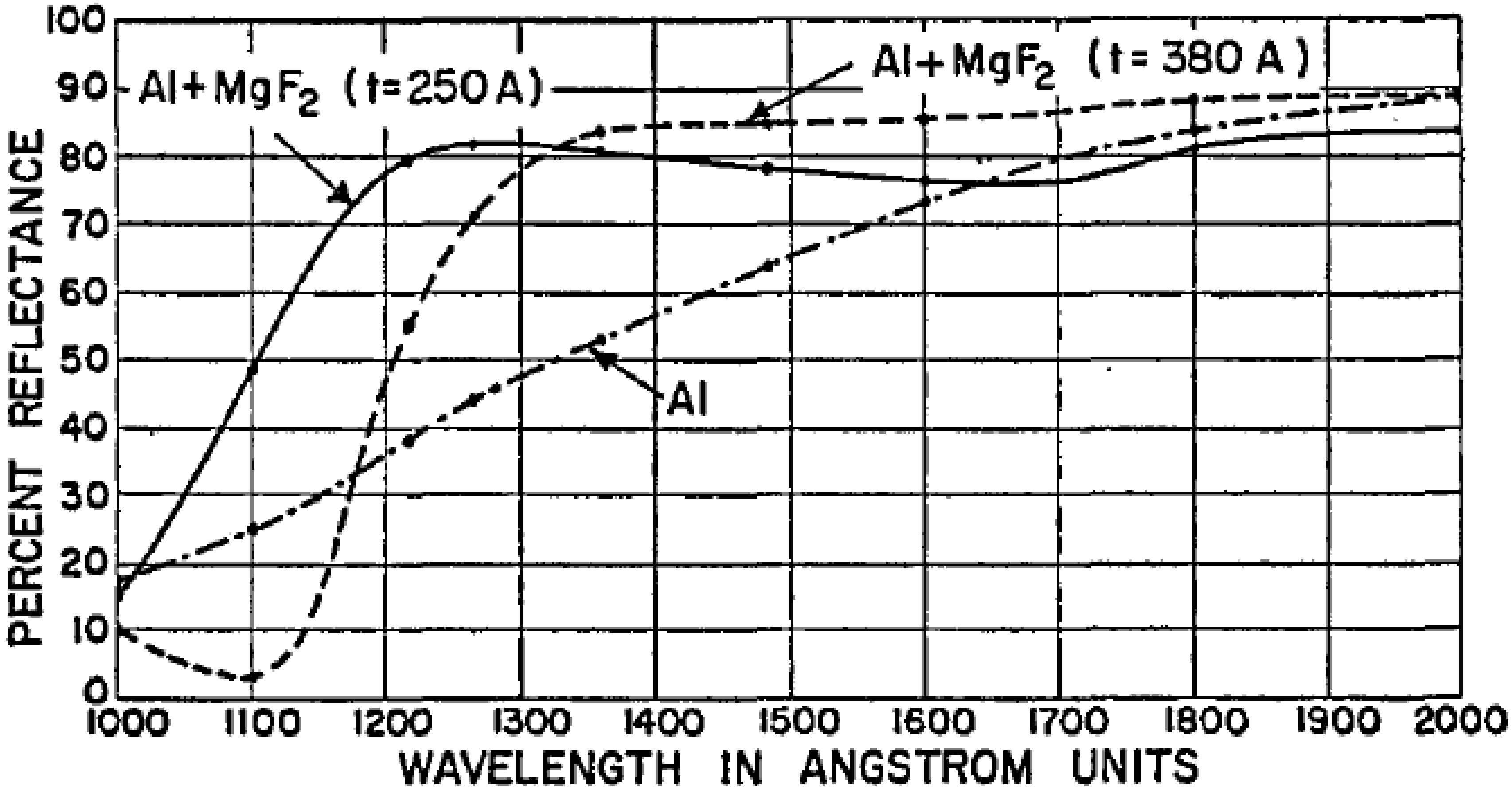
Coatings for the far UV

Juan Larruquert
GOLD- Instituto de Óptica, CSIC, Madrid
j.larruquert@csic.es

Outline

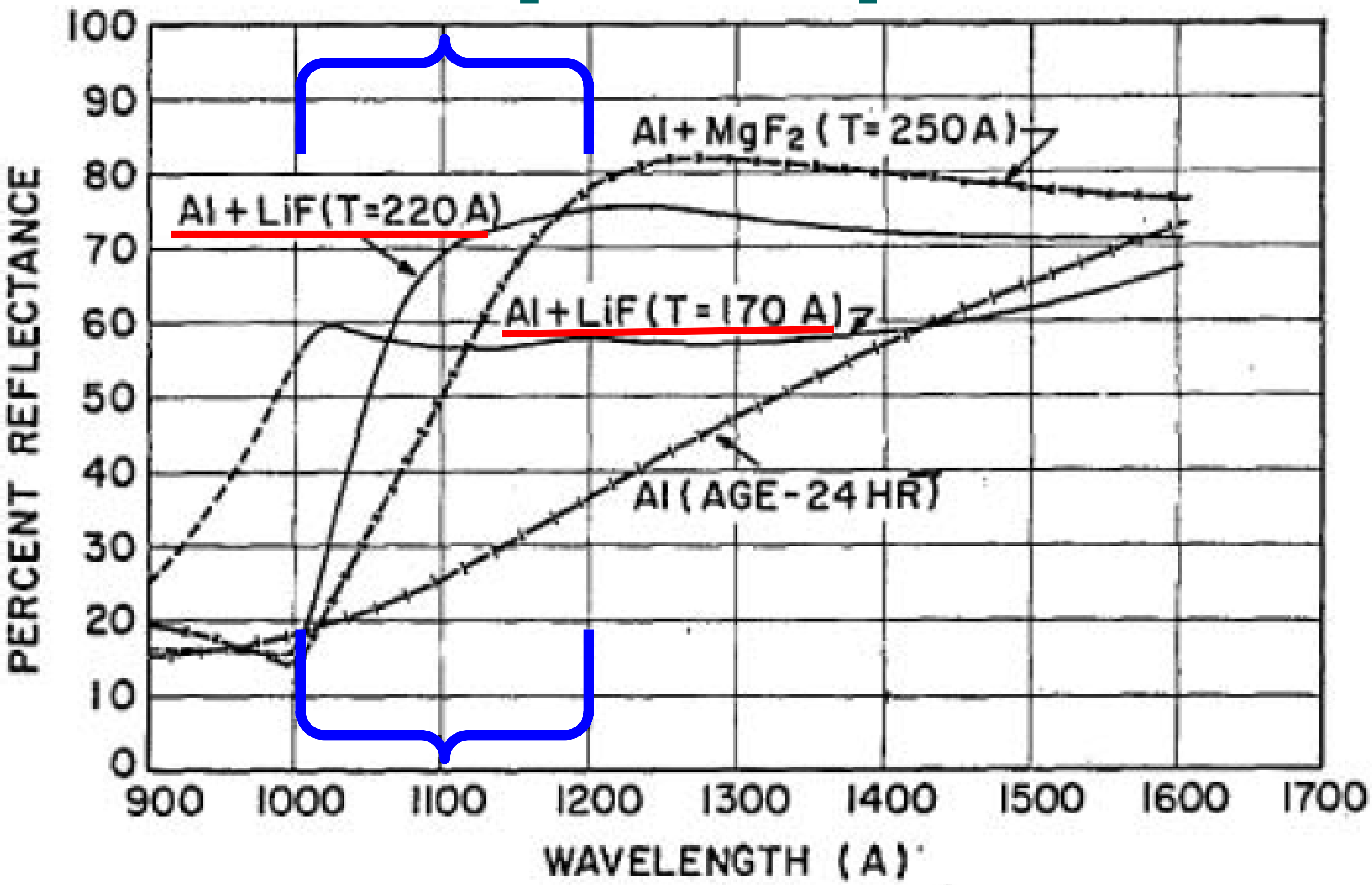
- Broadband mirrors at 100-1000 nm
    - ➢ Reflectance
    - ➢ Roughness
- Broadband mirrors down to $\lambda<100$ nm
- Narrowband mirrors centered at $\lambda>100$ nm
- Narrowband mirrors centered at $\lambda<100$ nm

Al protected with MgF_2: the paradigm



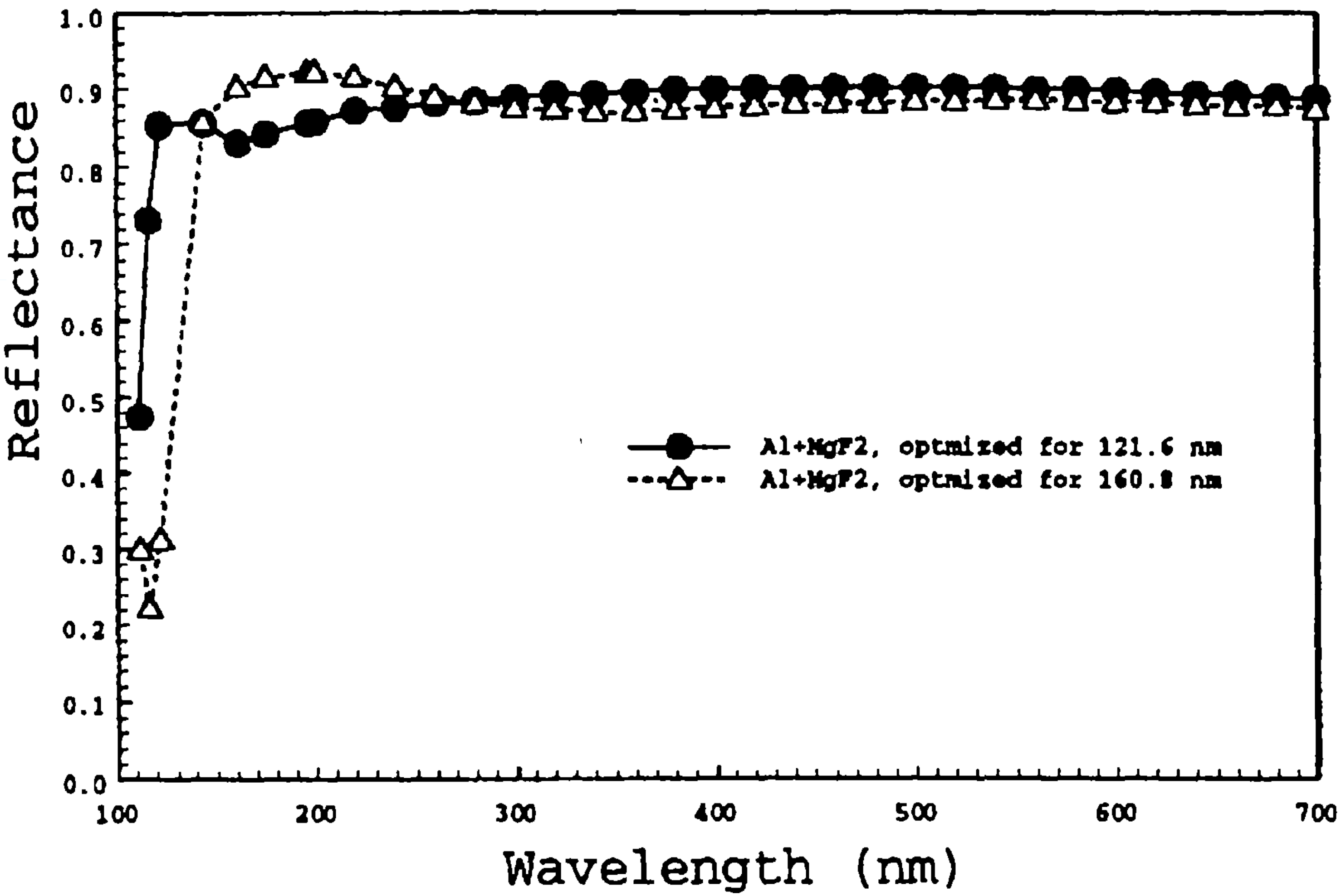
Hass & Tousey, J. Opt. Soc. Am. **49**, 593 (**1959**)

Al protected with LiF: the paradigm at $\lambda \in [100-120]$ nm



Angel et al. J. Opt. Soc. Am. **51**, 913 (**1961**)

Al/ MgF_2: improved Refl. due to cleaner techniques



Keski-Kuha et al., ASP Conf. Ser. **164**, 406 (1999)

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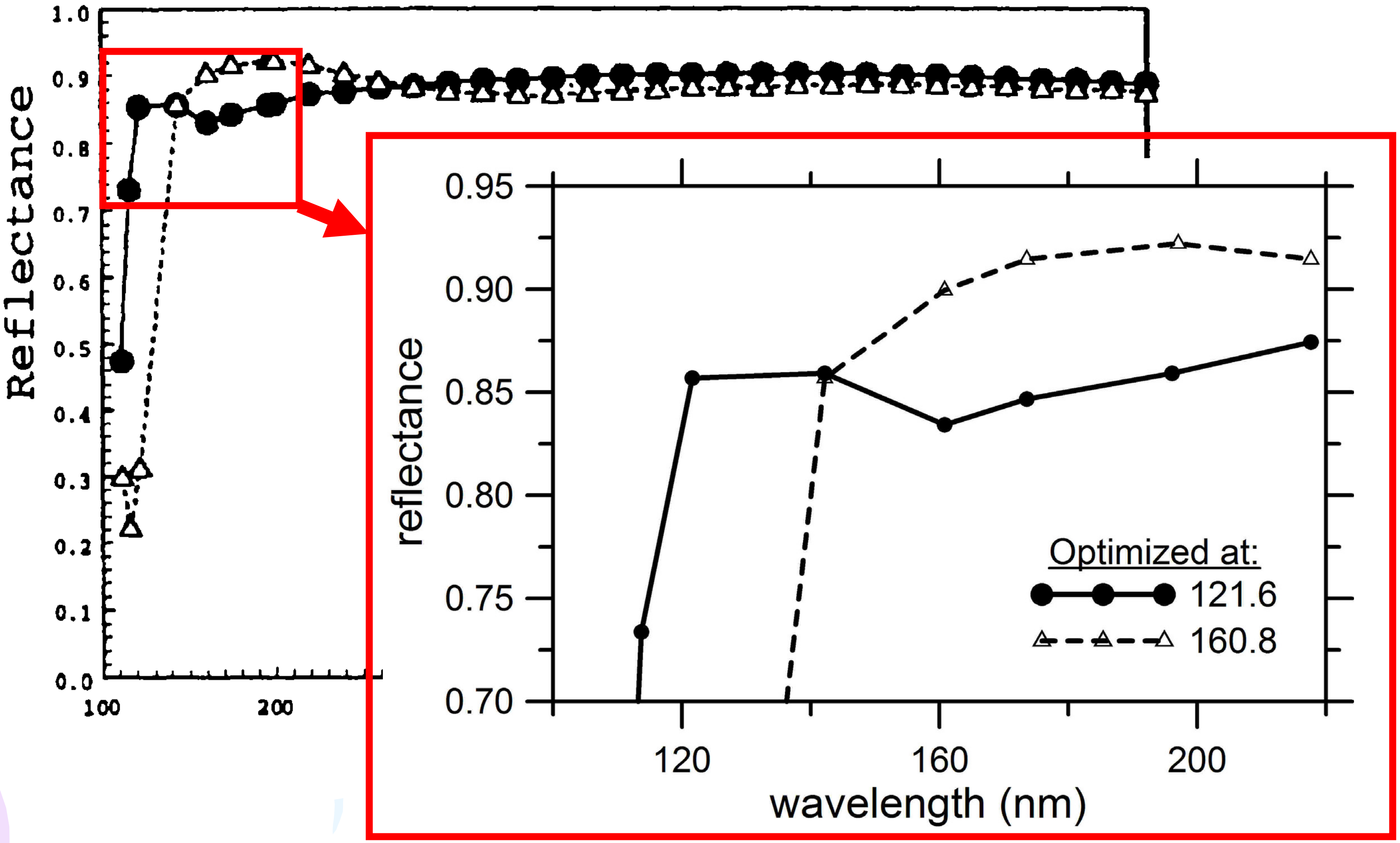
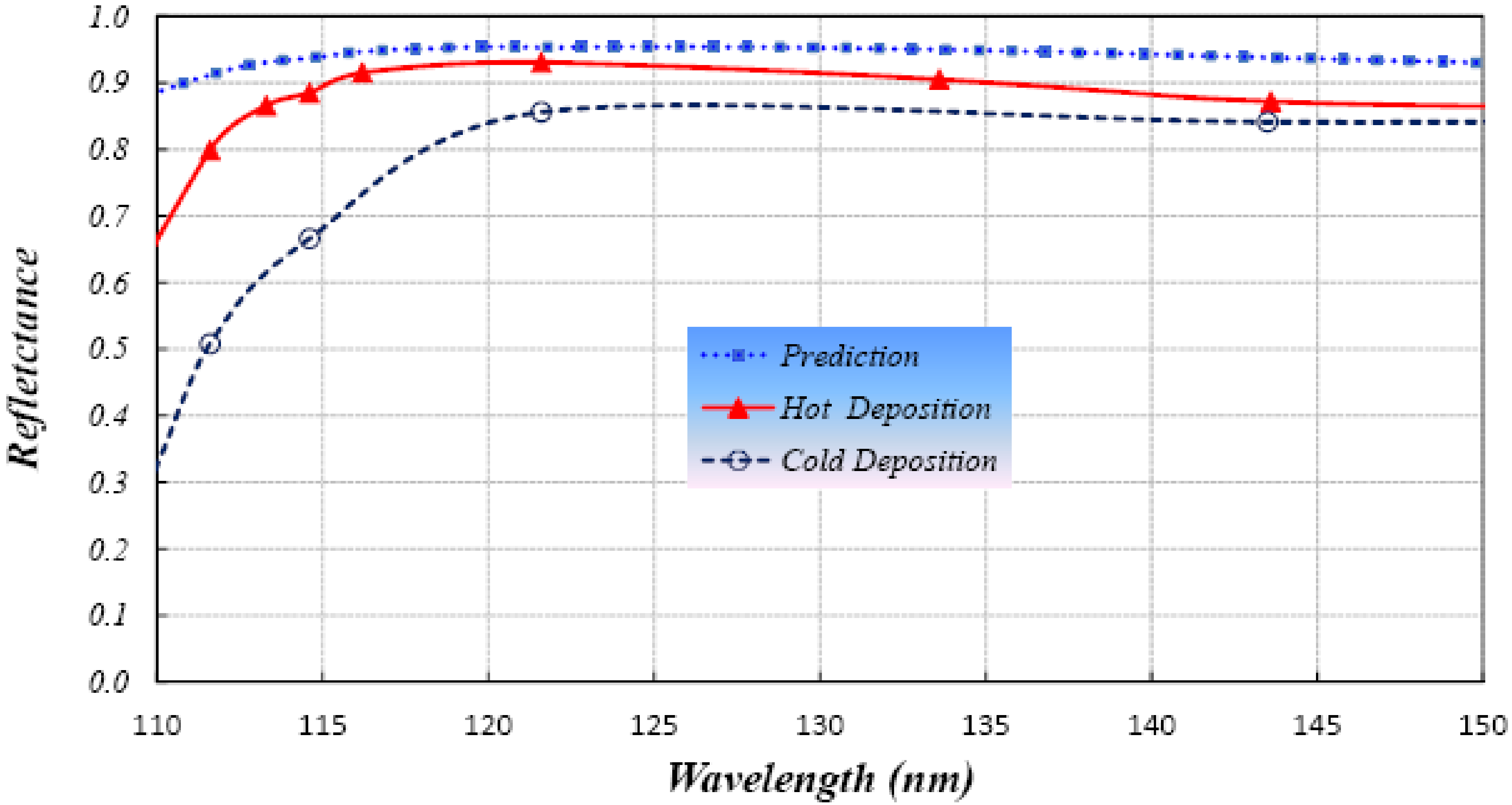


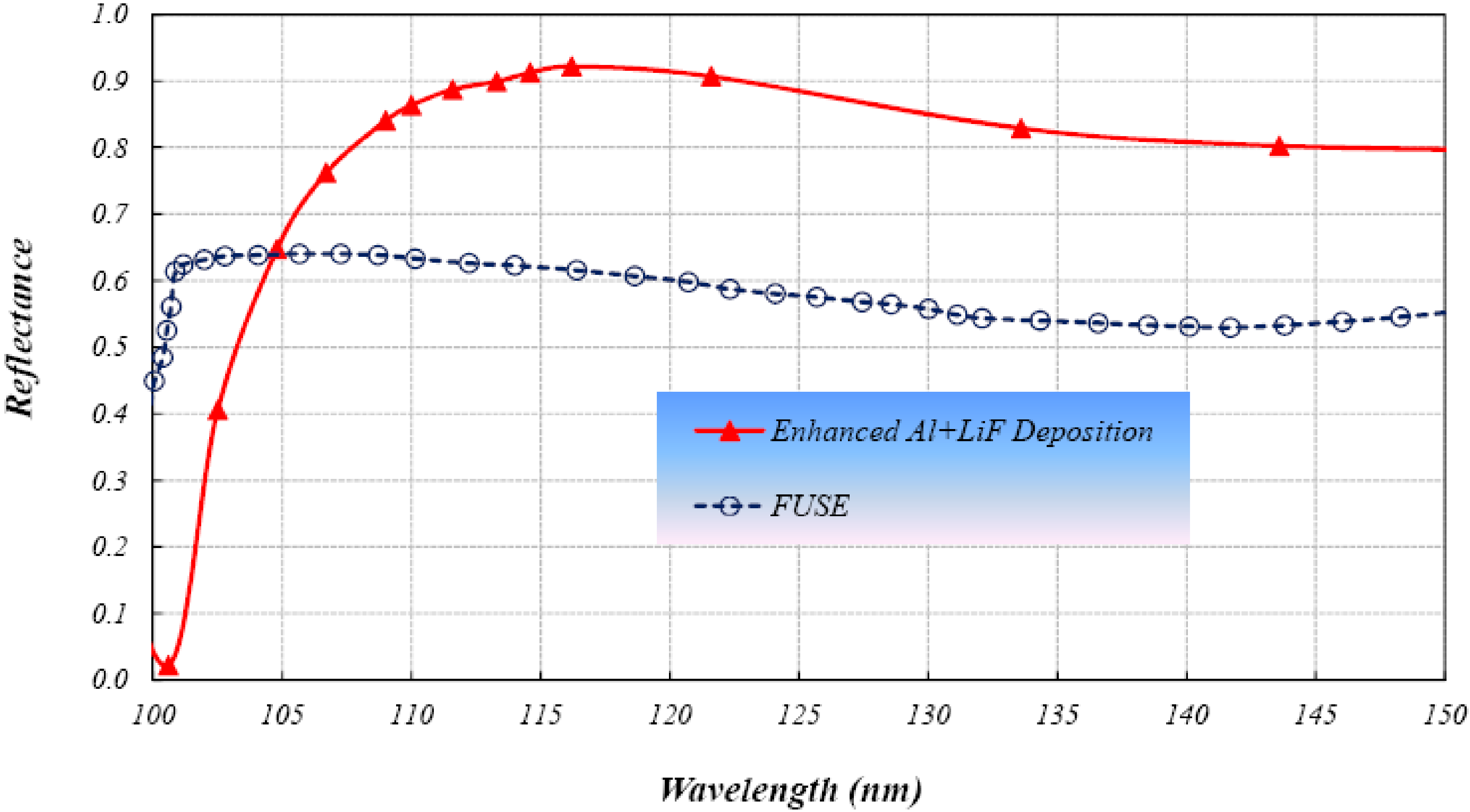
Keski-Kuha et al., ASP Conf. Ser. 1**64**, 406 (1999)

Refl increase of Al+MgF_2: MgF_2 deposited on hot (220°C) Al (+a little MgF_2)



Quijada et al., Proc. SPIE **9144**, 91444G (2014)

And the same for Al+LiF:
LiF deposited on hot (250°C) Al (+a little LiF)



Quijada et al., Proc. SPIE **9144**, 91444G (2014)

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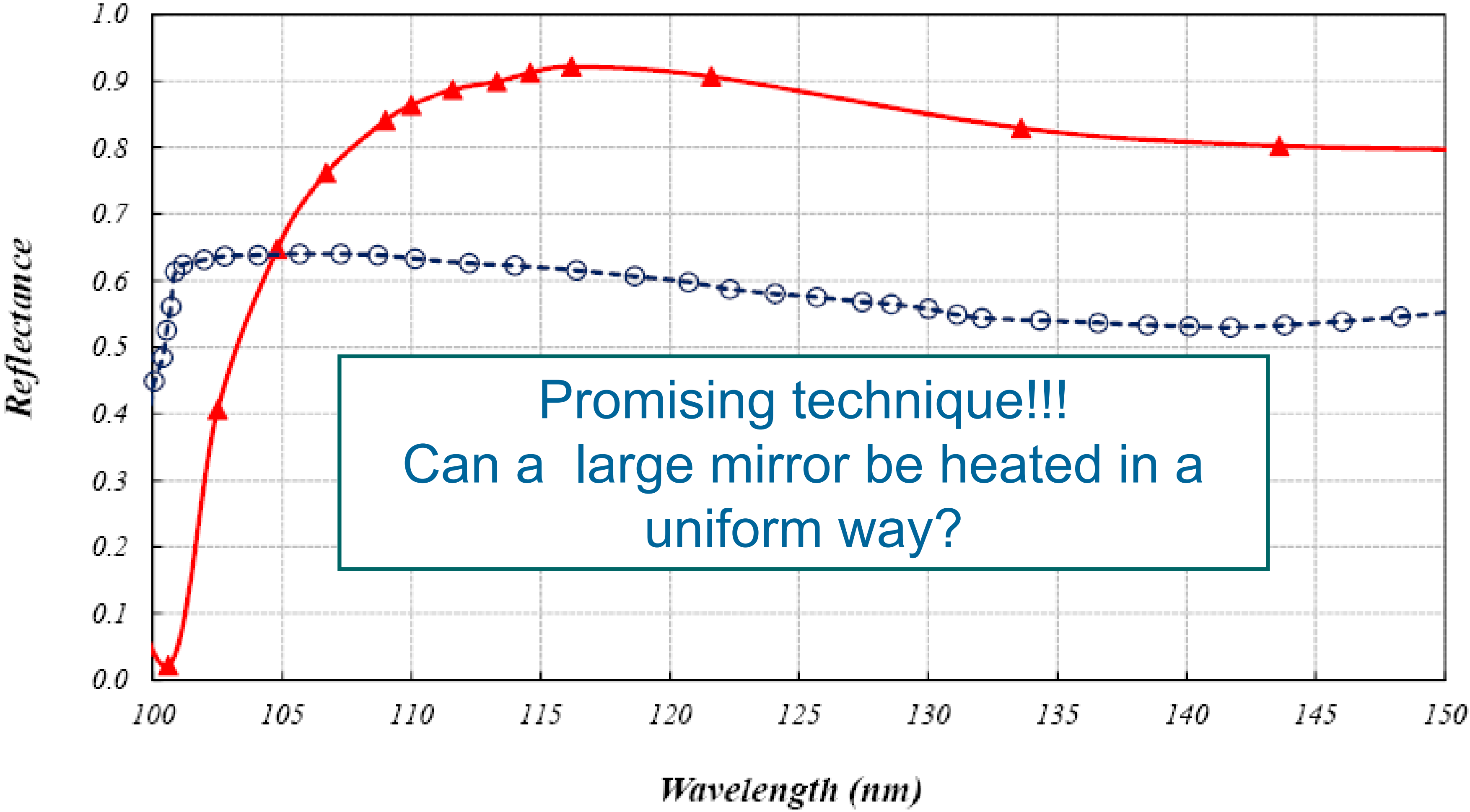
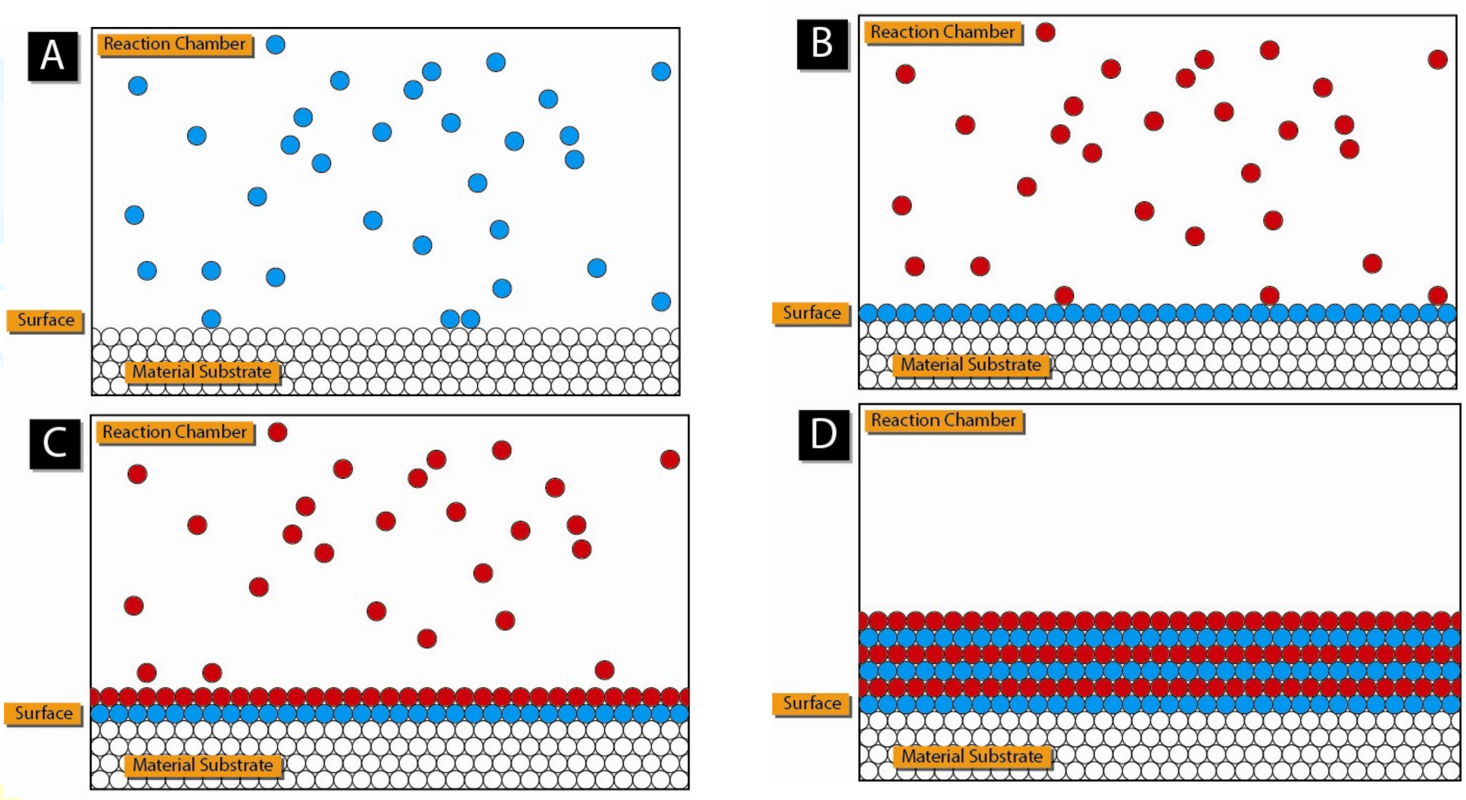


Promising technique!!!
Can a large mirror be heated in a uniform way?

Quijada et al., Proc. SPIE **9144**, 91444G (2014)

Can we use the magics of **A**tomic **L**ayer **D**eposition?

- ALD: exposing substrate to alternate gases (precursors)
- One monolayer deposited in each cycle
- High uniformity
- **Without pinholes?**
- **Can we protect Al with an ultrathin ALD-MgF2?**



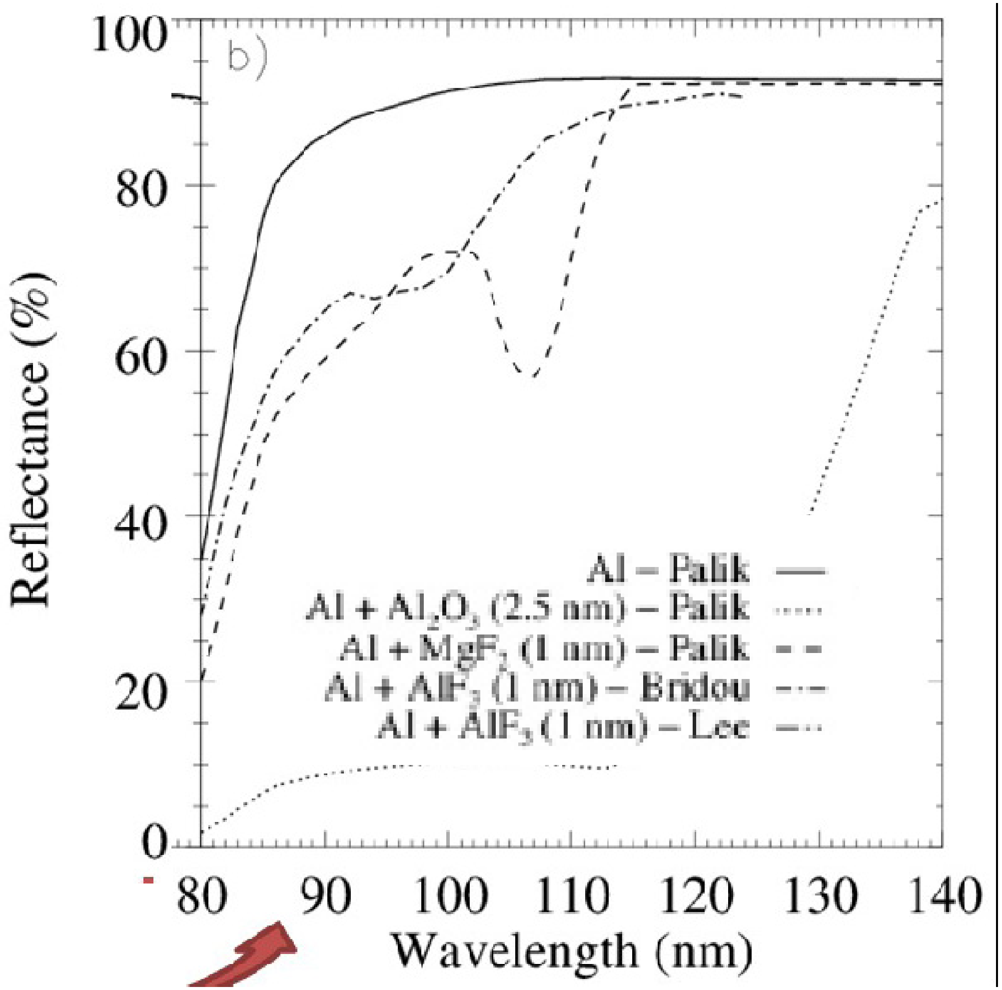
Source: wikipedia

Extended high Refl down to 90 nm: ultrathin protection (MgF_2 or AlF_3) for Al

Sembach, Astro2010 Technology Development report:

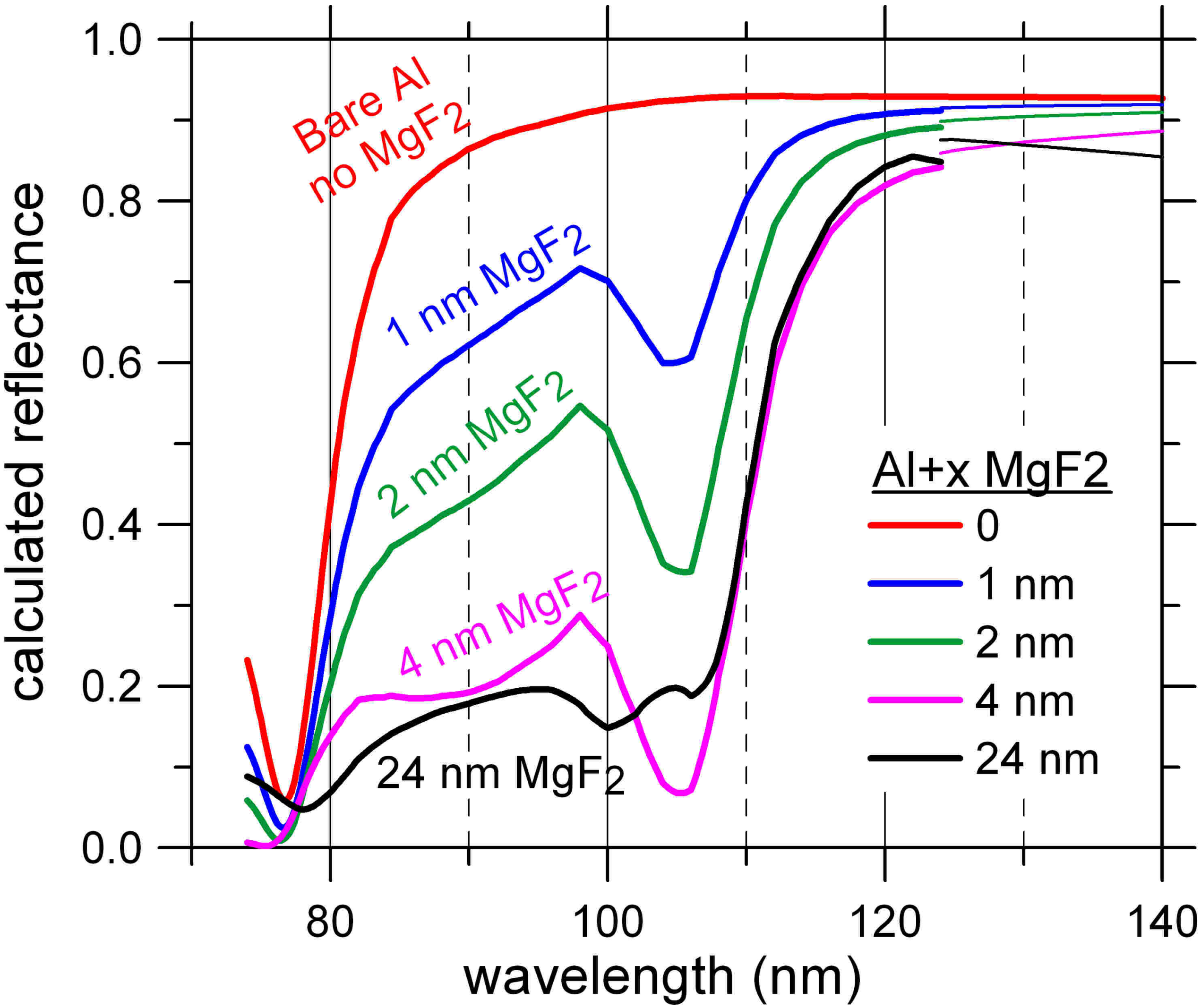
Al protected with 1-nm thick ALD MgF2:

"if 1 nm layer of single-crystal MgF2…can be deposi-ted uniformly on large optics and are stable, they may provide an avenue for high reflectivity in the UV"

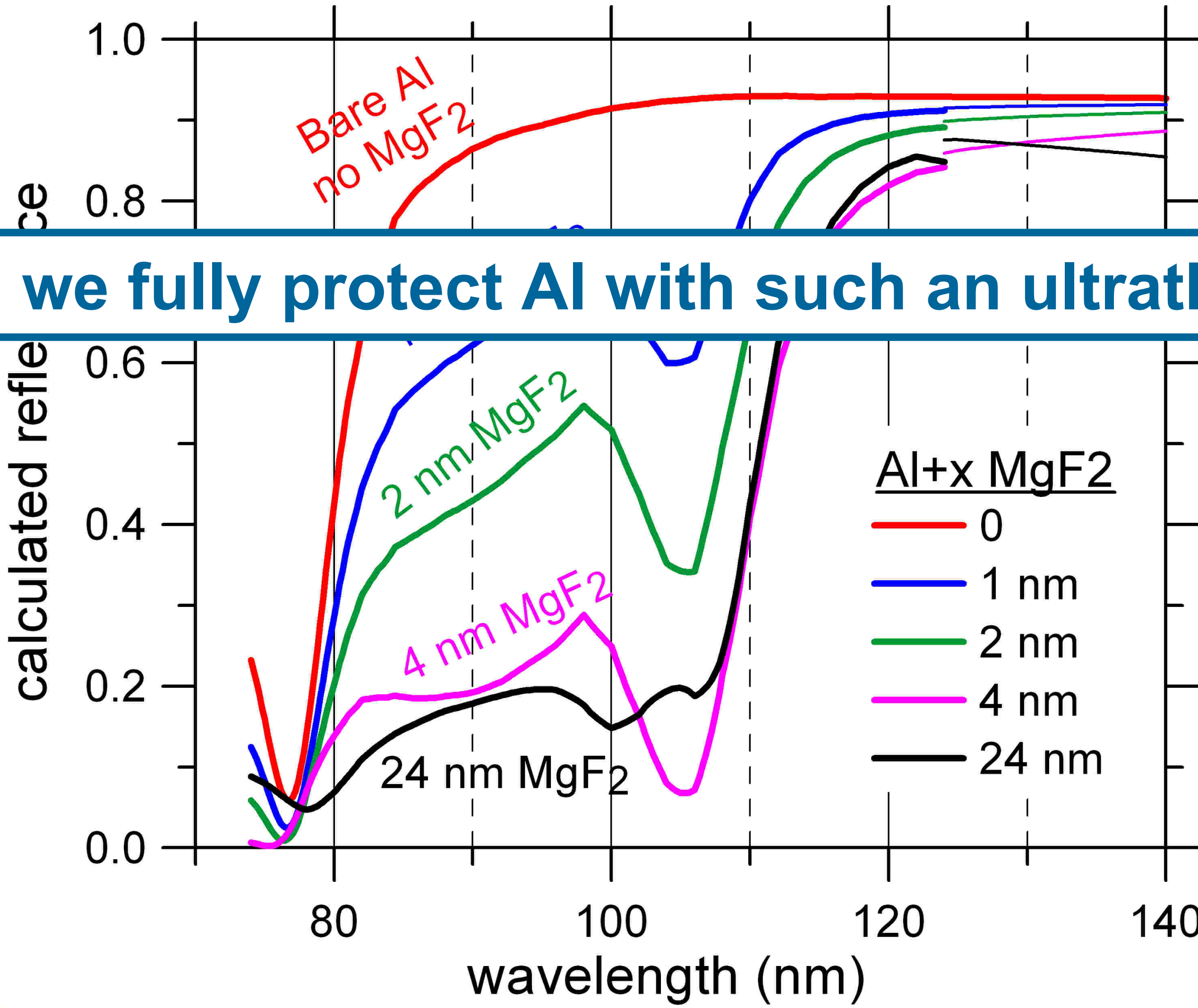


Moore et al., Proc. SPIE **9144**, 91444H (2014)

Extended high Refl down to 90 nm: ultrathin protection of MgF_2 for Al



Extended high Refl down to 90 nm: ultrathin protection of MgF_2 for Al



Can we fully protect Al with such an ultrathin film?

ALD MgF_2/AlF_3 to protect Al: difficulties

MgF_2: Pilvi et al., J. Mater. Chem. **17**, 5077 (2007):

.- Purity strongly depends on temperature: 80% at 250 C; 99.7% at 400 C

.- Roughness increases with temperature

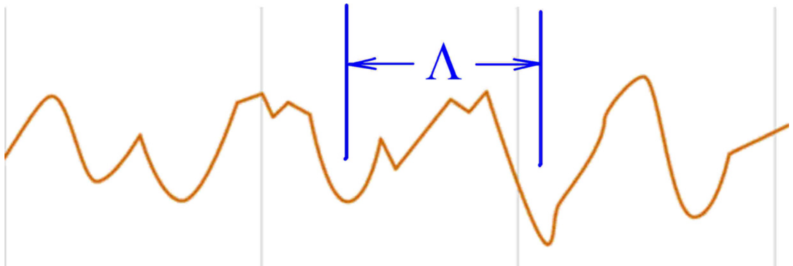
.- ..." the impurity levels are not low enough for really high transmission in vacuum UV"

Can we keep a bare Al film free from oxidation over the first ALD cycles?

Promising technique...,
but needs to demonstrate feasibility

Roughness of Al films: importance of grain width

Roughness effects depend on lateral size Λ of roughness

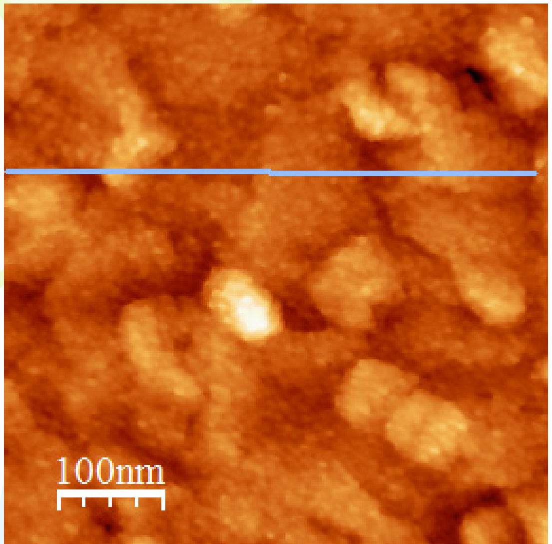


1. $\Lambda < \lambda$: absorption; surface plasmons
Coatings produce mostly this roughness

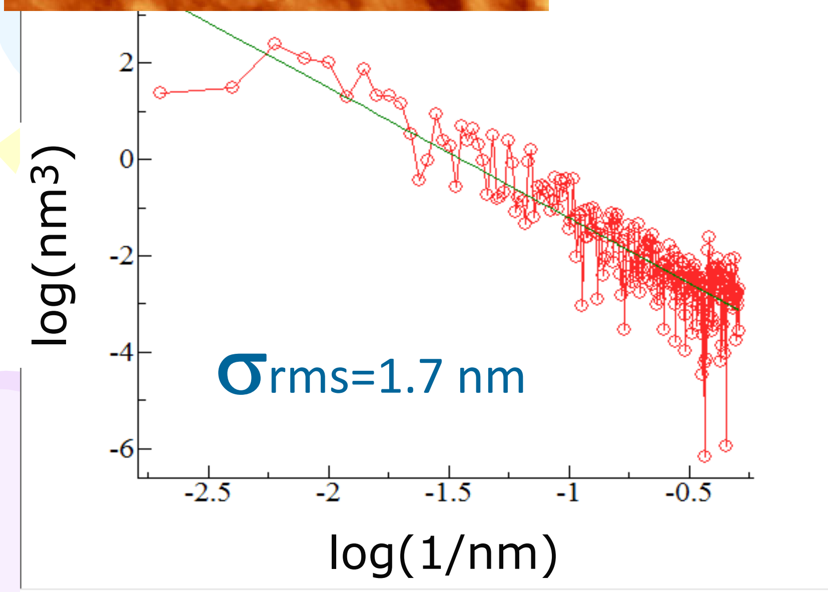
2. $\Lambda > \lambda$: **scattering**
Most contribution comes from substrate (polishing)

Contribution No. 2 is more destructive, such as for internal coronagraphy

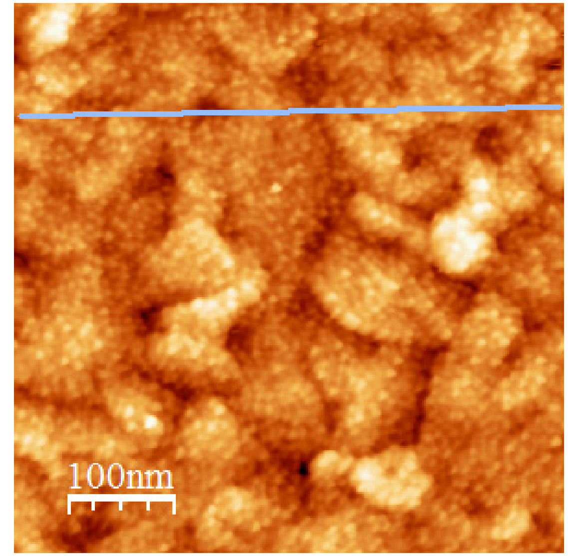
Roughness of Al/MgF_2 films

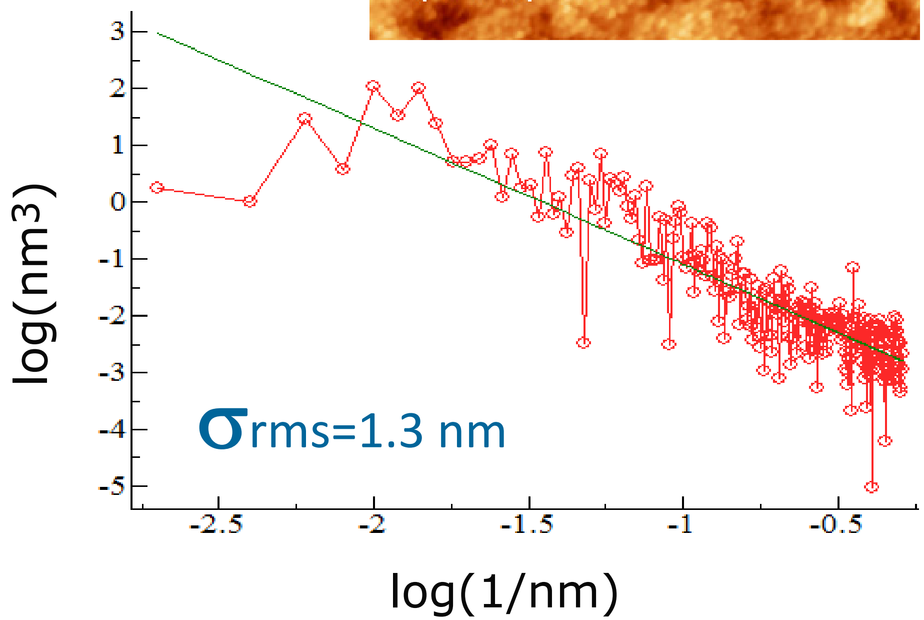


Top
MgF2 at
RT



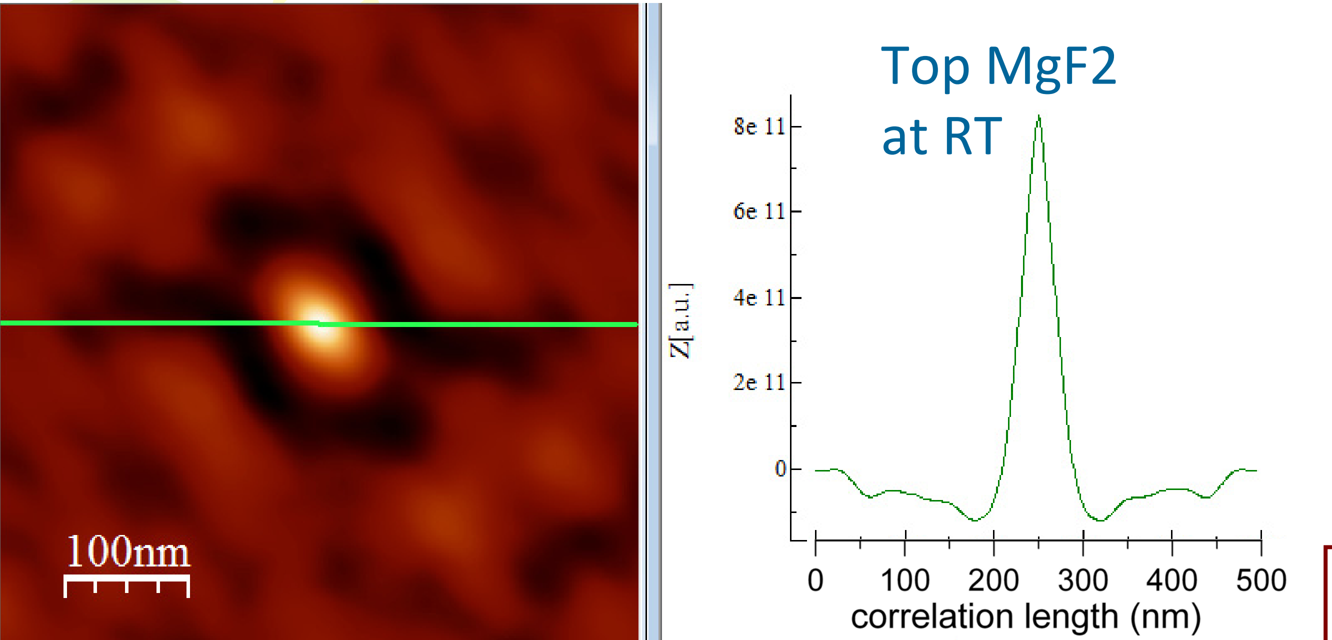
Top
MgF2 at
150 °C

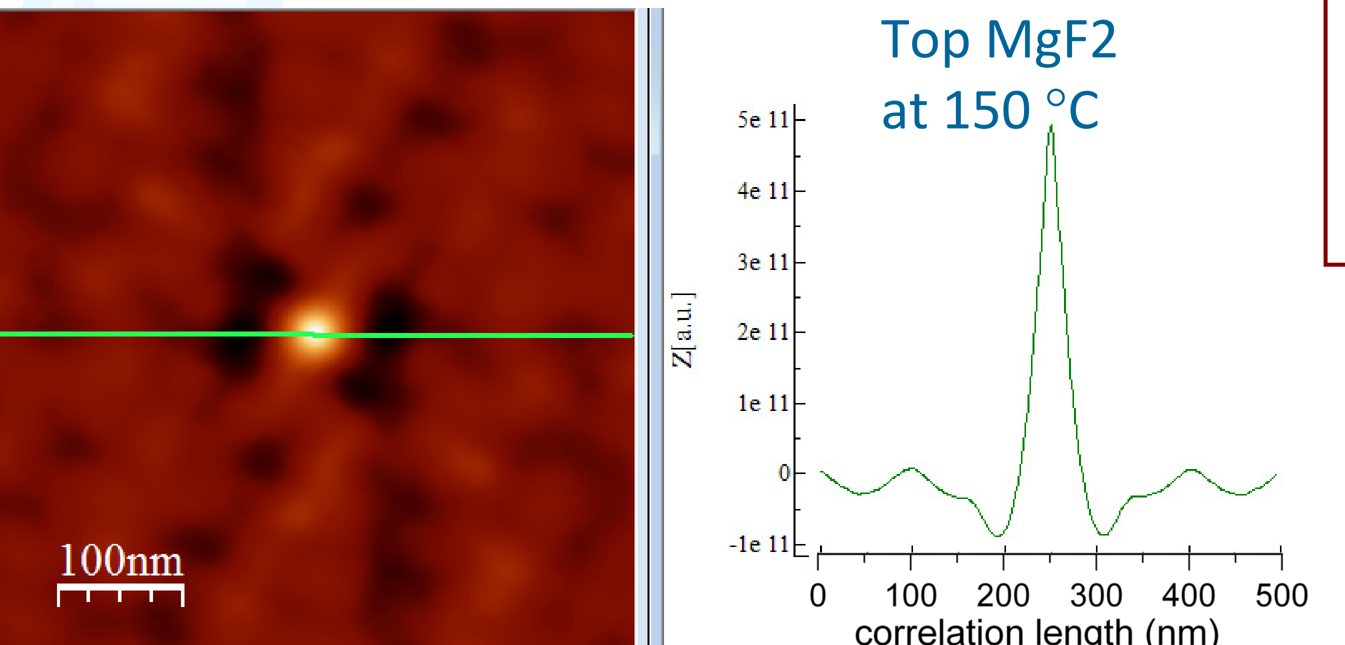




Source: GOLD-Instituto de Optica

Roughness of Al/MgF_2 films





Grain width: ~or< λ

Source: GOLD-Instituto de Optica

Can we minimize roughness of Al films?

- ✓ Maybe by amorphization of Al! ☺

Soufli et al., Appl. Phys. Lett. **101**, 043111 (2012)

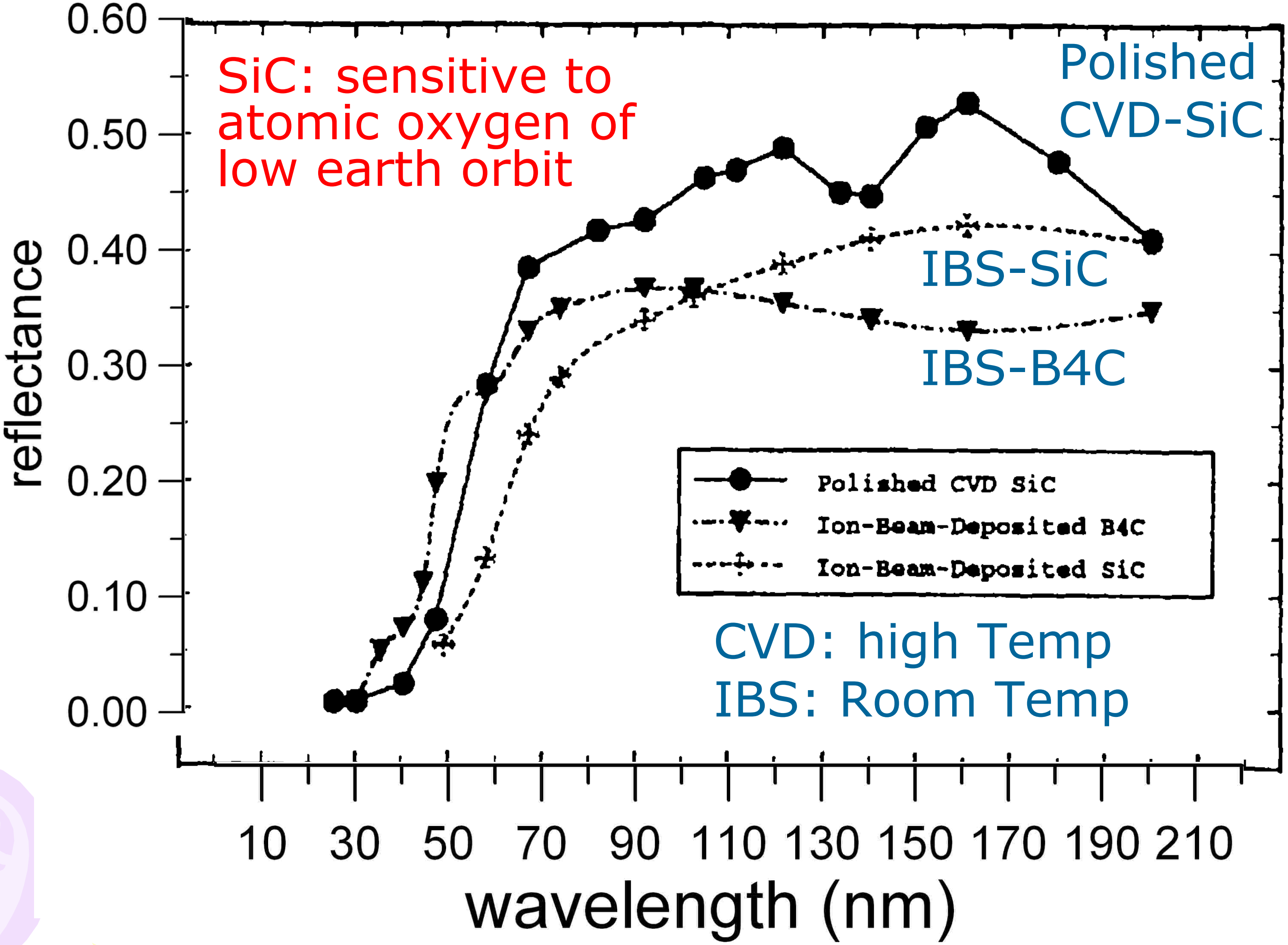
Sputter-deposited Al on Mg: spontaneously intermix to form a **partially amorphous** layer

"The intermixed layer consists of sparse Al and Mg crystallites embedded in a matrix of amorphous Al-Mg material".

"The average **crystallite size is reduced by 70% for Al** and by 45% for Mg".

"amorphous films have **better passivating properties** than crystalline ones due to reduced grain boundaries, vacancies, and defects"

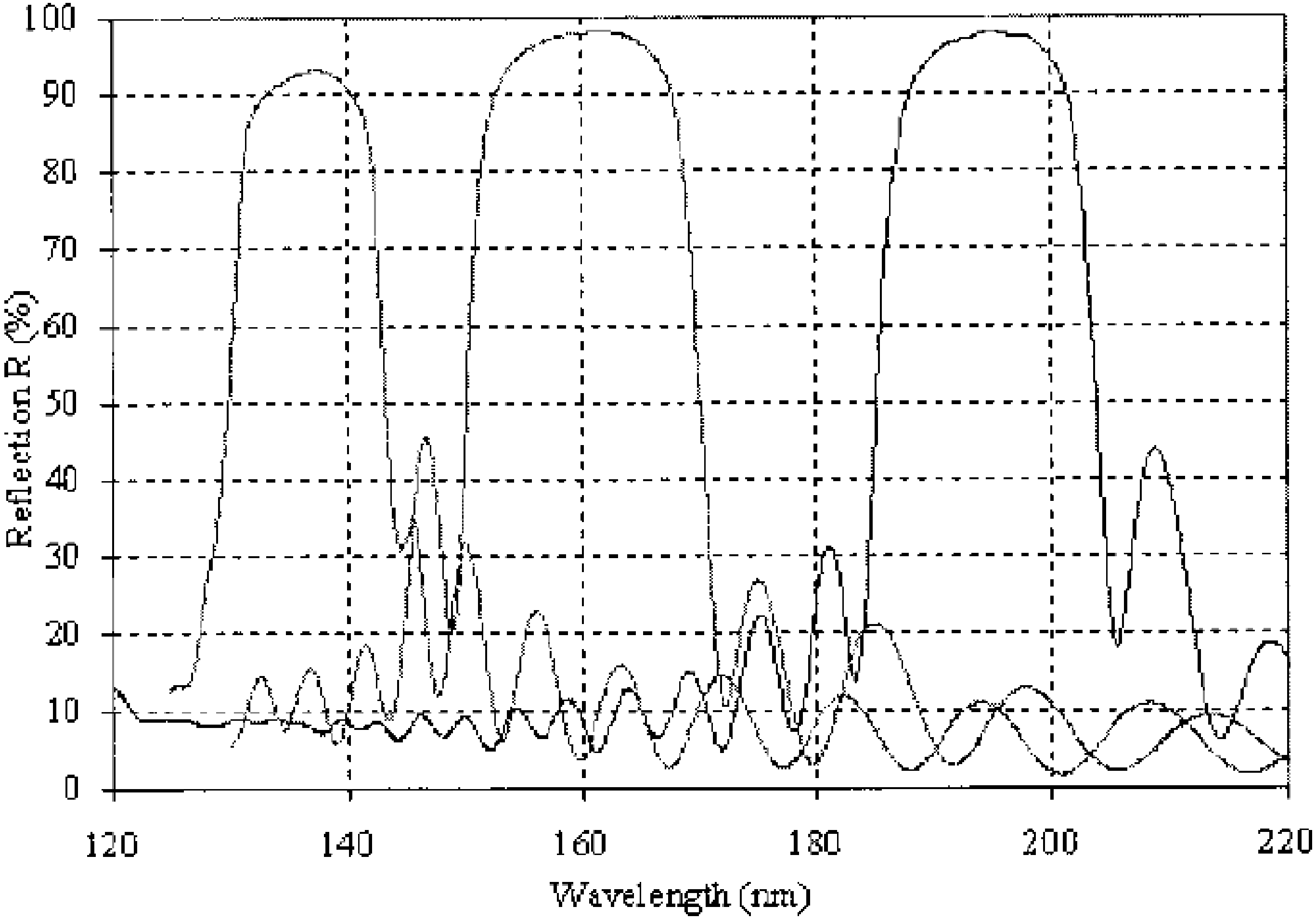
Broadband mirrors: down to λ<100 nm



Keski-Kuha et al., ASP Conf. Ser. 1**64**, 406 (1999)

Narrowband mirrors centered at λ>120nm

MLs with two fluorides, such as $(MgF2/LaF3)_n$

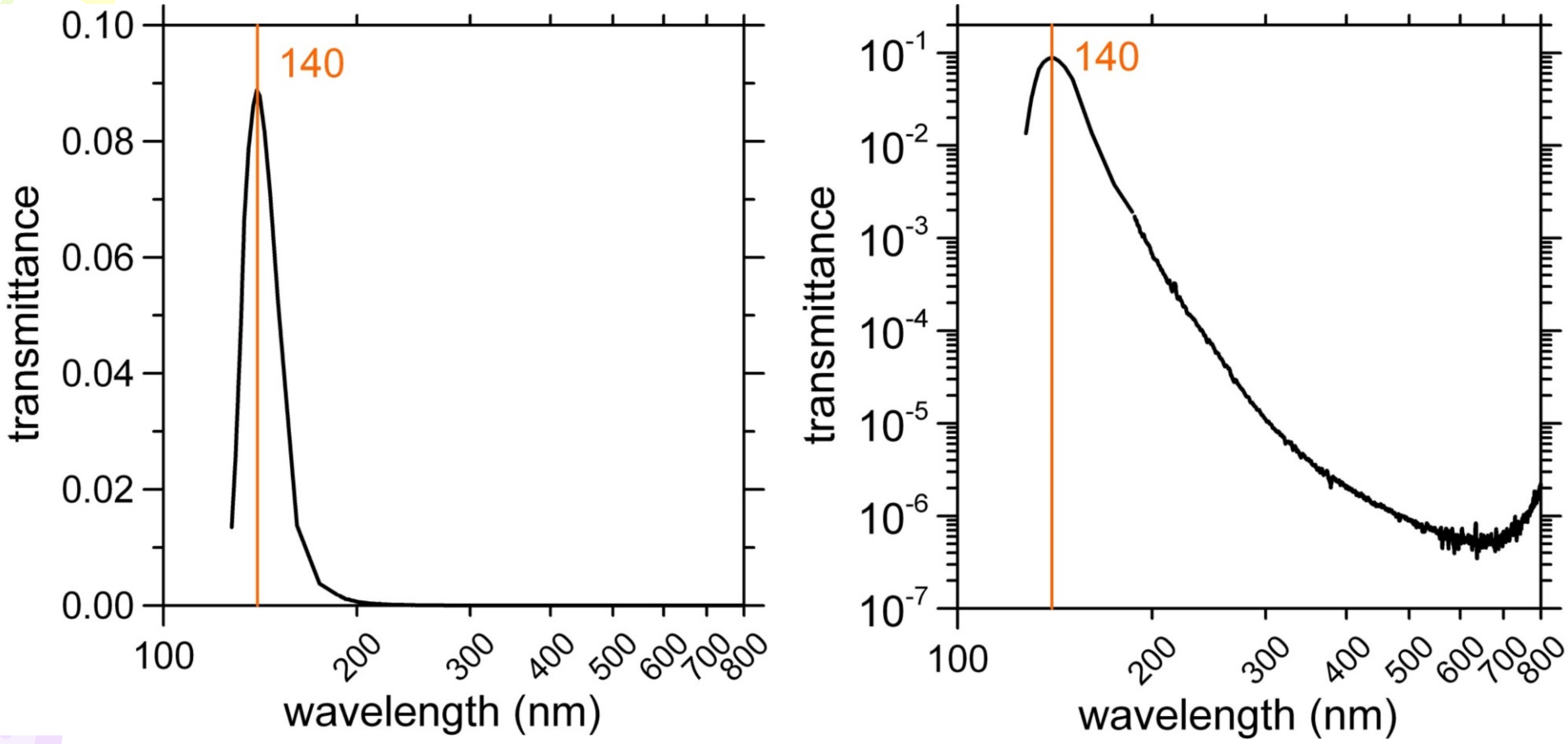


Gatto et al., Appl. Opt. **41**, 3236 (2002)

NB mirrors peaked at 120 nm (GOLD-Instituto de Optica)

Transmittance filters: peaked at $\lambda > 120$ nm

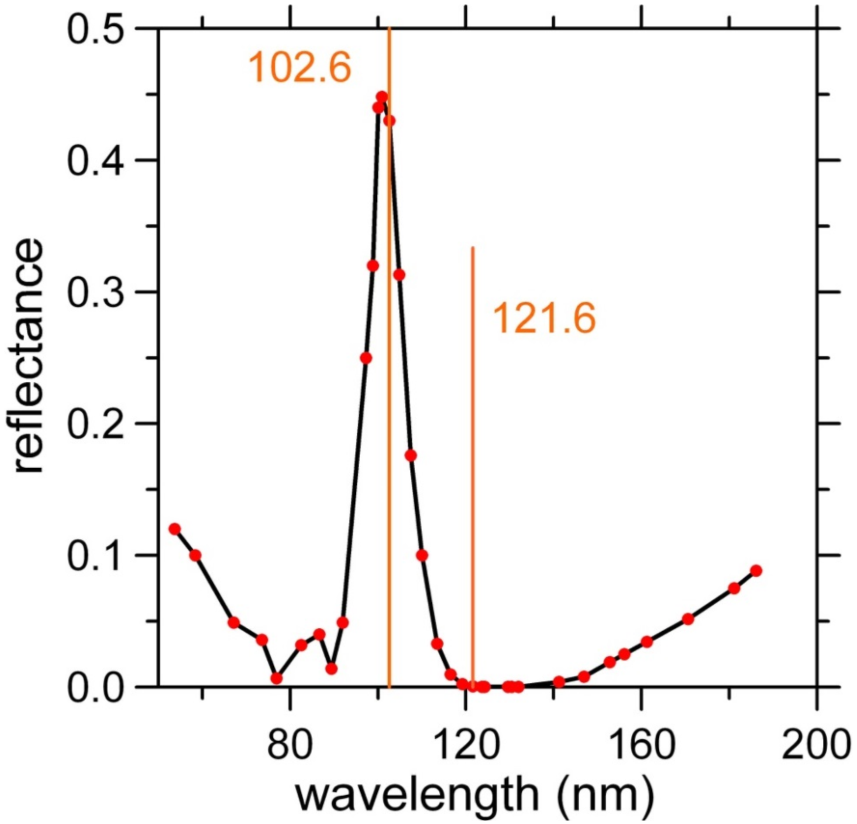
$(Al/MgF_2)_n$ on a transparent substrate



Source: GOLD-Instituto de Optica

Narrowband mirrors centered at λ~100nm Al/LiF/SiC/LiF ML

Imaging solar corona: **Ly**β much weaker than **Ly**α

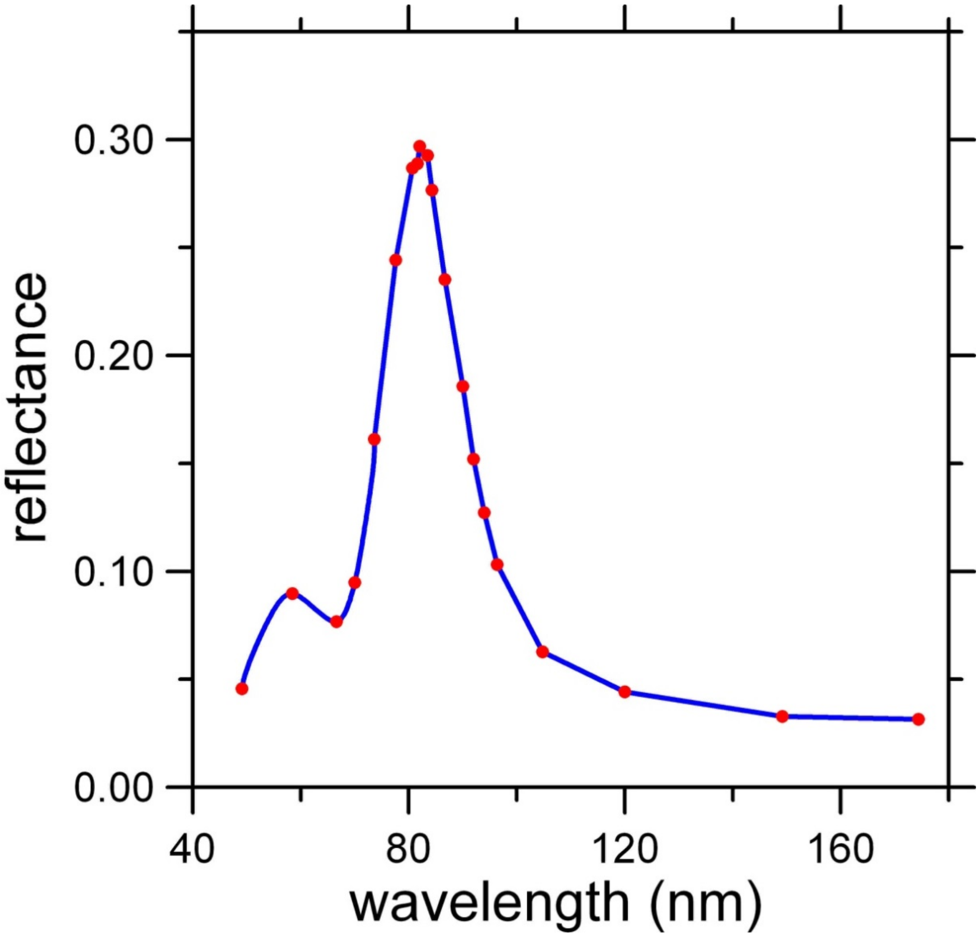


Rodríguez de Marcos et al., Proc. SPIE **8777**, 87771E (2013)

Narrowband coatings at λ<100 nm

Materials strongly absorb in 60 nm<λ<100 nm!!

Eu/SiO/Al/SiO ML



Larruquert et al., Proc. SPIE **8076**, 80760D (2011)

Summary

Al/MgF_2 keeps the paradigm:

- Refl enhancement by heating: could be mature in few years
- Refl extension to λ=90 nm with ultrathin MgF_2: needs to demonstrate feasibility

Acknowledgments

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