Climatizzatore Ottico

come raffreddare senza elettricità....dallo spazio!

Lorenzo Pattelli, INRiM

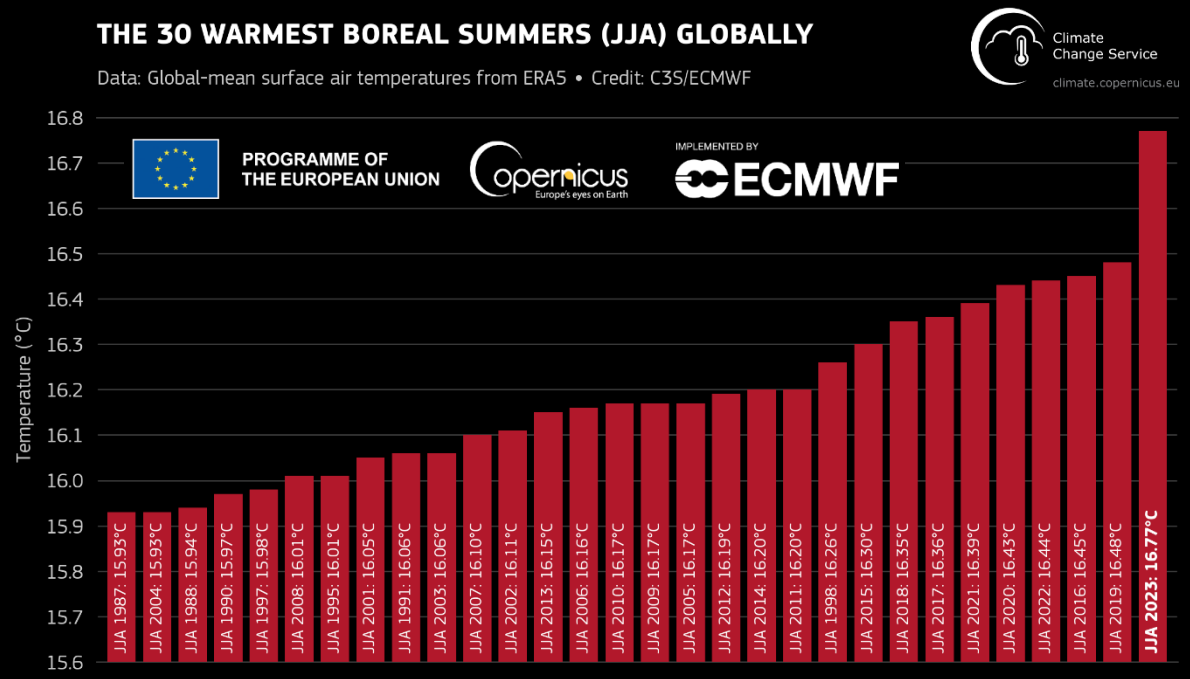
l.pattelli@inrim.it

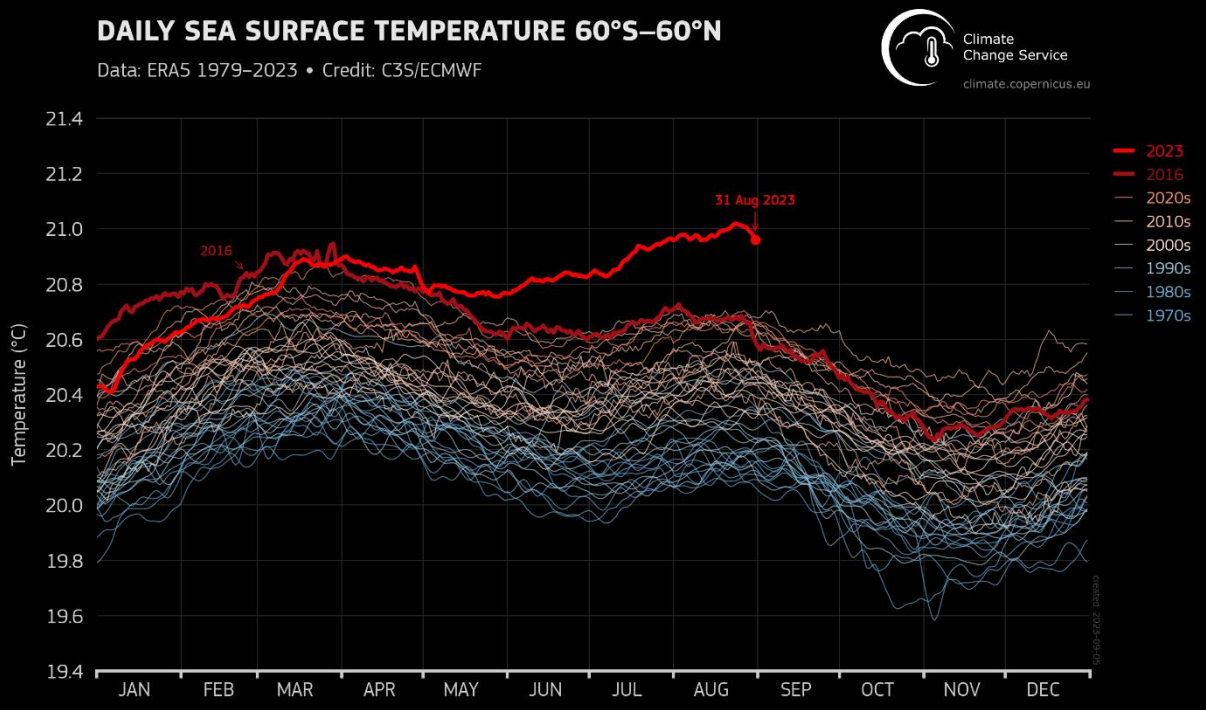
10 Novembre 2023

METROLOGY PARTNERSHIP | EURAMET

INRiM ISTITUTO NAZIONALE DI RICERCA METROLOGICA

LENS European Laboratory for Non-linear Spectroscopy





nature sustainability

PERSPECTIVE

https://doi.org/10.1038/s41893-020-00627-w

Check for updates

Cooling for sustainable development

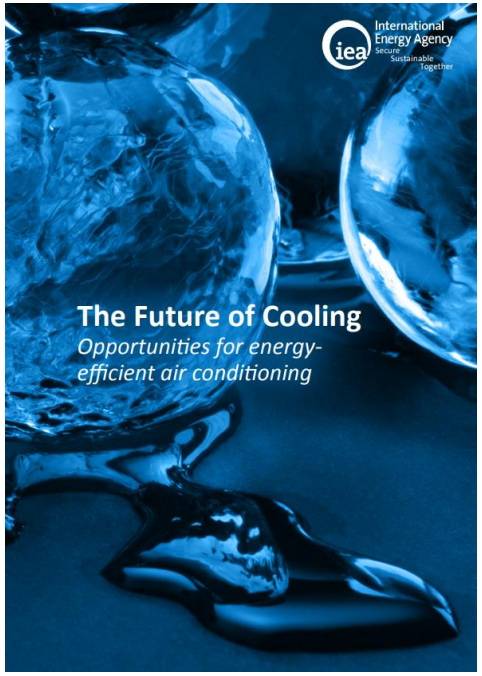
Radhika Khosla[1,2]✉, Nicole D. Miranda[1,3], Philipp A. Trotter[1,2,4], Antonella Mazzone[1,2], Renaldi Renaldi[1,3], Caitlin McElroy[1,2], Francois Cohen[1,2,5], Anant Jani[1], Rafael Perera-Salazar[1,6] and Malcolm McCulloch[1,3]

The unprecedented rise in cooling demand globally is a critical blind spot in sustainability debates. We examine cooling as a system comprised of active and passive measures, with key social and technical components, and explain its link to all 17 Sustainable Development Goals. We propose an analytical and solution-oriented framework to identify and shape interventions towards sustainable cooling. The framework comprehends demand drivers; cradle-to-cradle stages; and system change levers. By intersecting cooling stages and levers, we discuss four specific, exemplary interventions to deliver sustainable cooling. We propose an agenda for research and practice to transition towards sustainable cooling for all.

R. Khosla et al. *Nat. Sustain.* **4**.3 (2021)

source: World Economic Forum

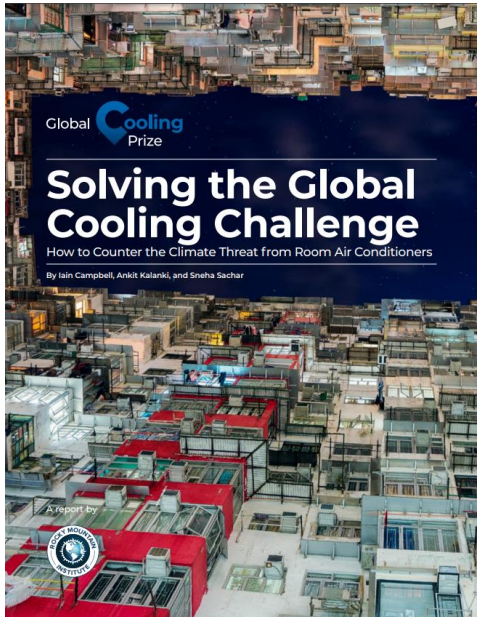
the World faces a looming "cold crunch"

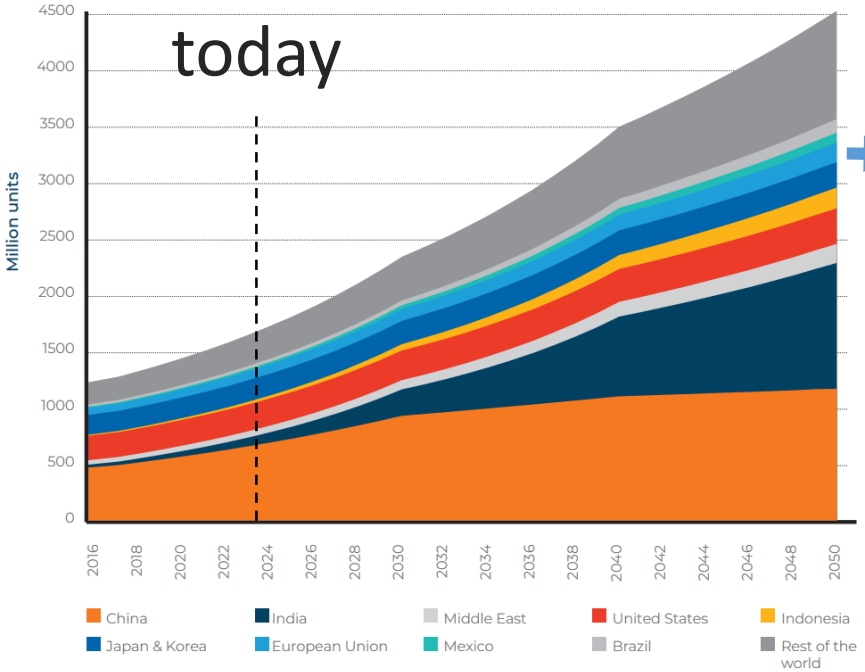


8%

10/s

3.3TW



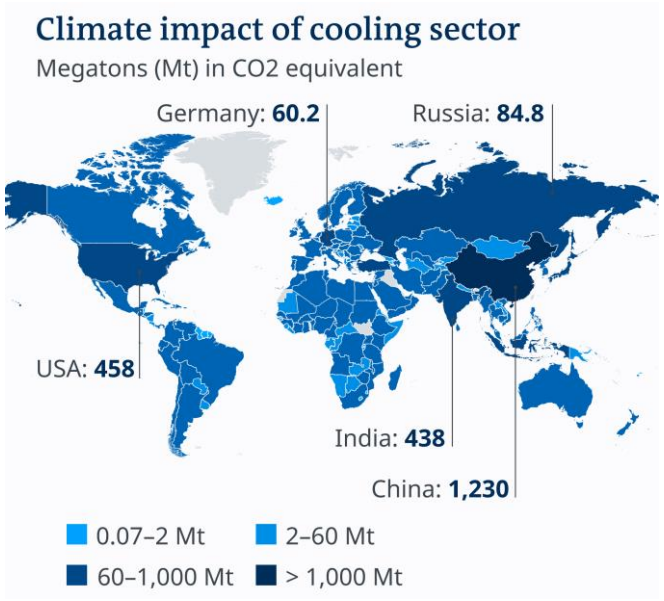


→ EU: 3x nuovi condizionatori entro il 2050

80 GW di nuova capacità di potenza richiesta solo per il settore residenziale

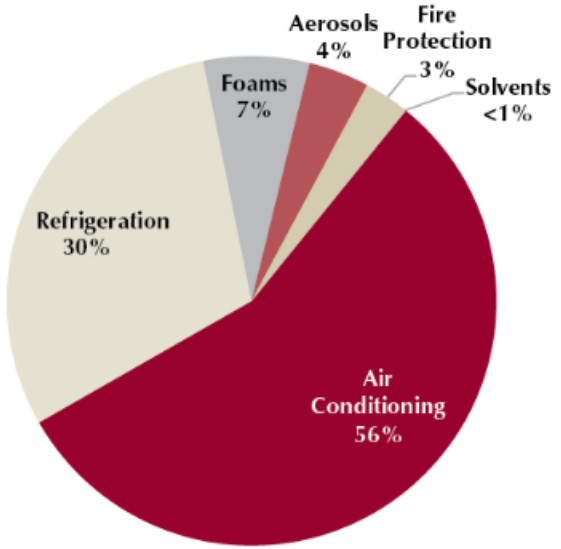
CO_2 emissions of cooling sector

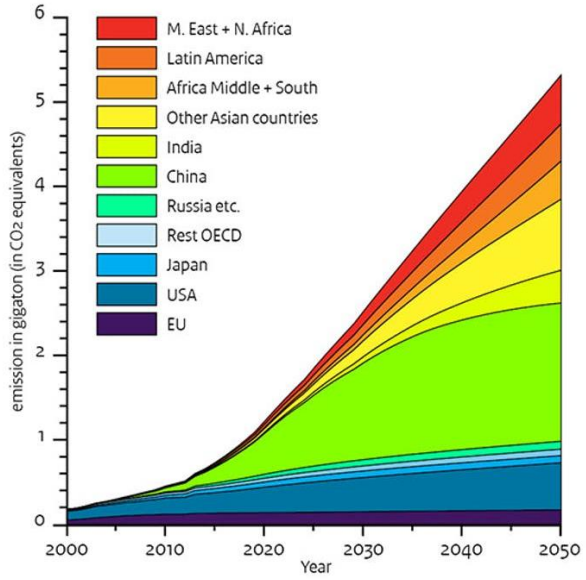
source: the Green Cooling Initiative



hydro-fluorocarbon leakages and incorrect disposal

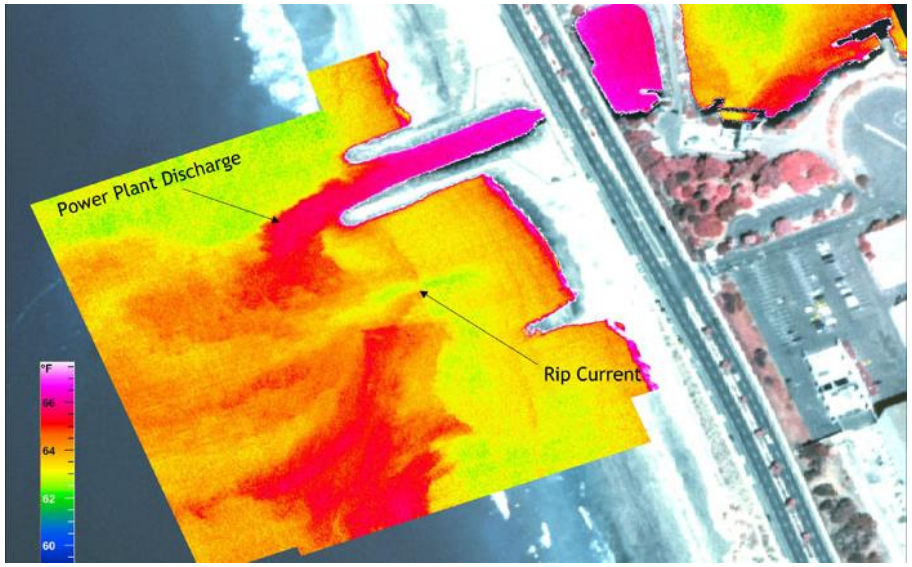
source: Center for Climate and Energy Solutions





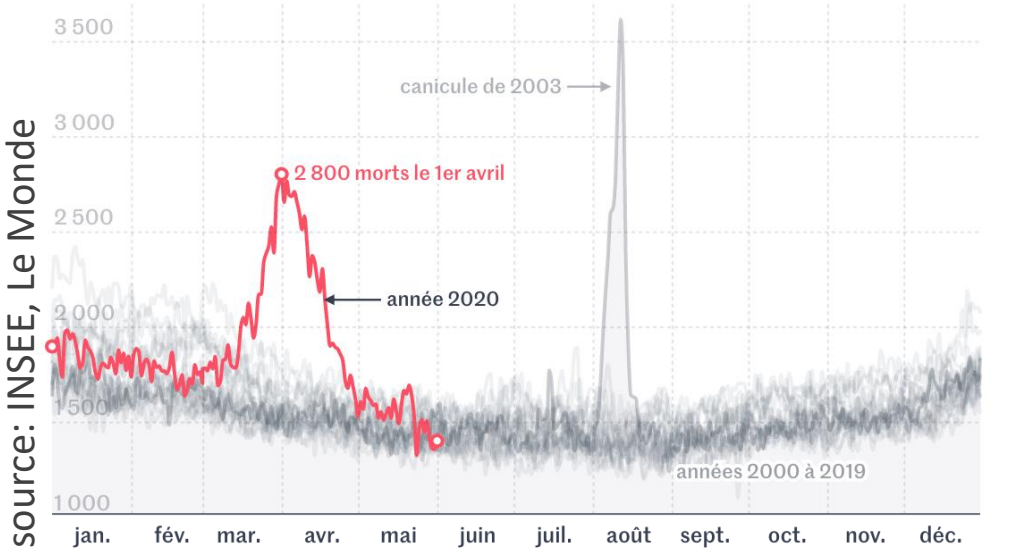
thermal discharges in the environment

source: Ocean Imaging Corp.

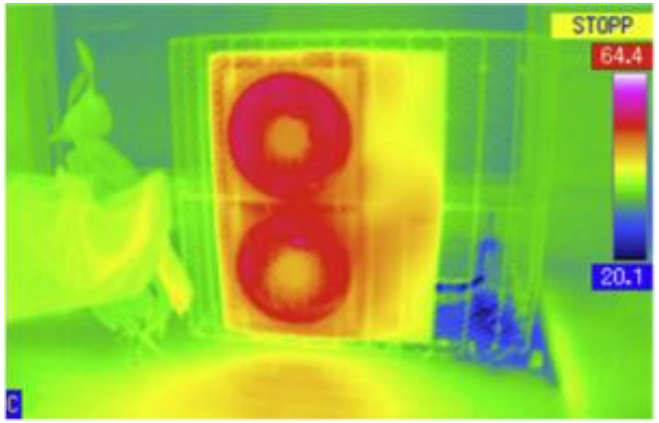


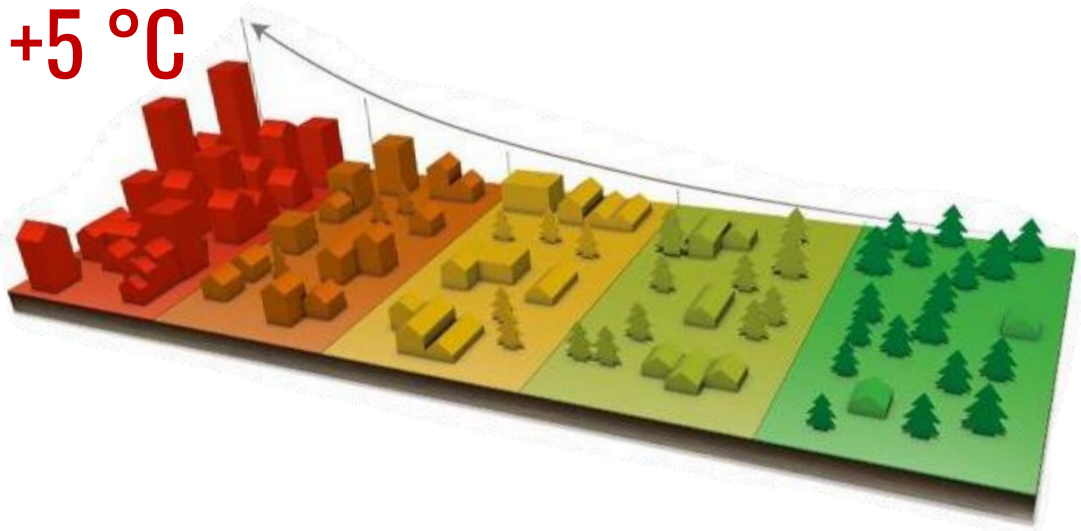
health risks during heat waves

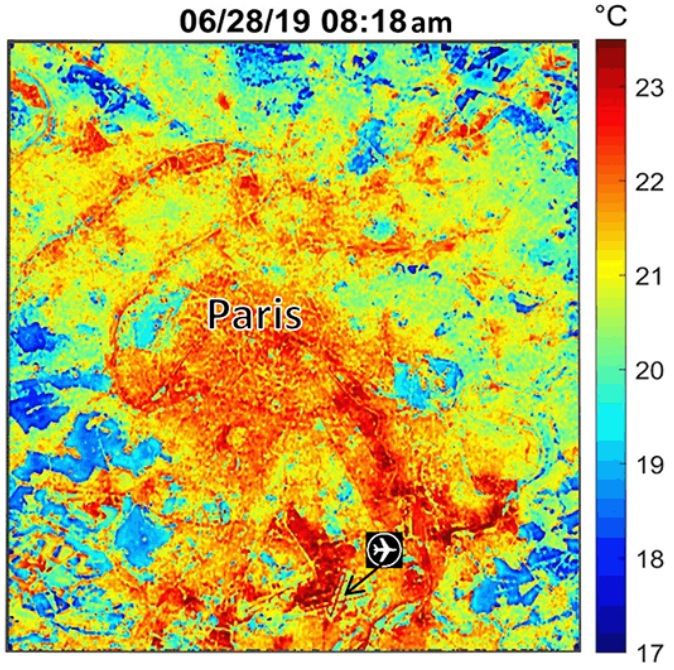
source: INSEE, Le Monde

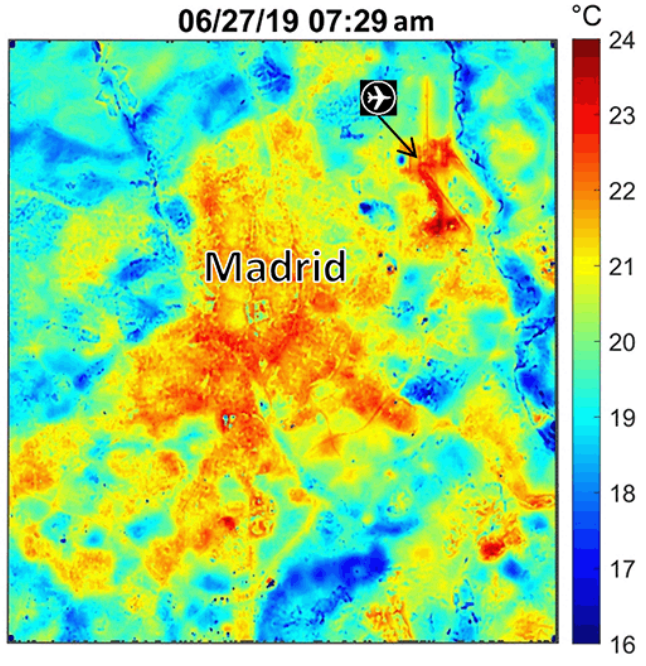


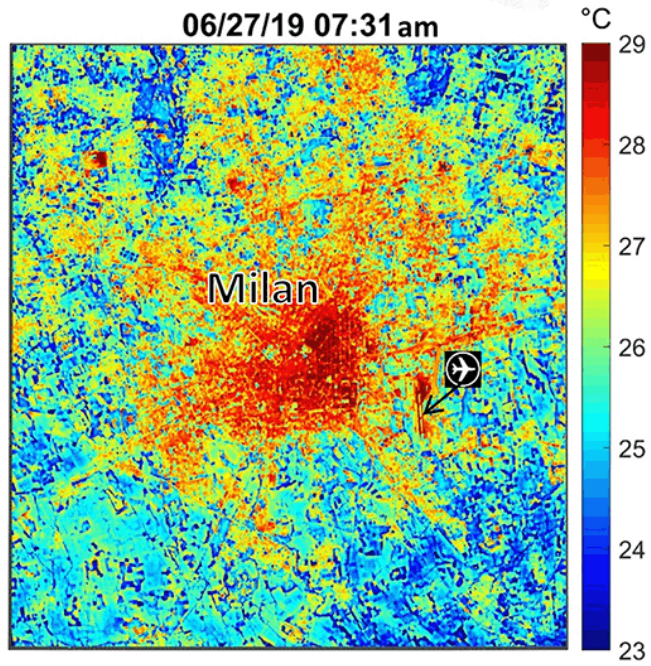
the vicious circle between cooling and heating











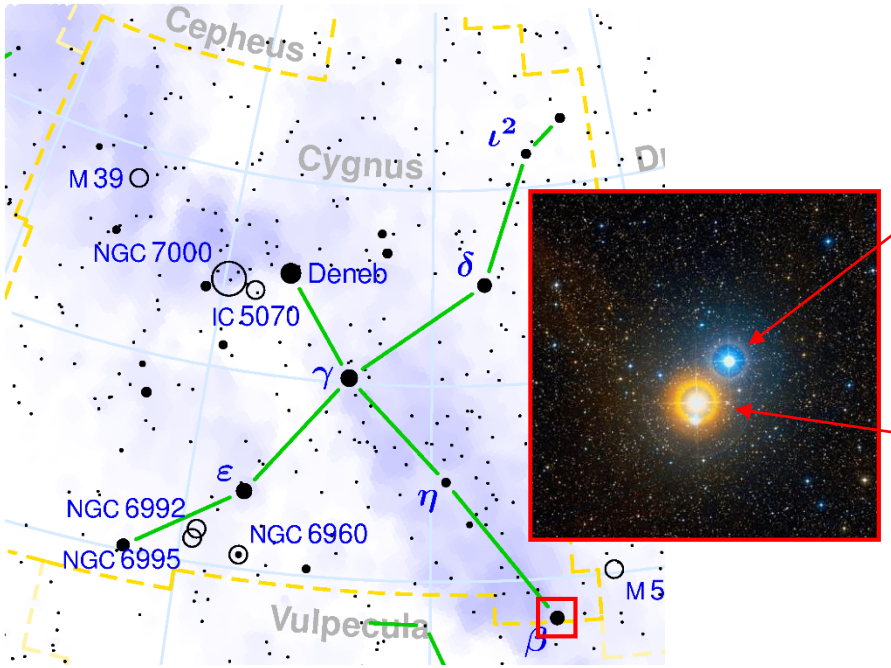
source: NASA ECOSTRESS project

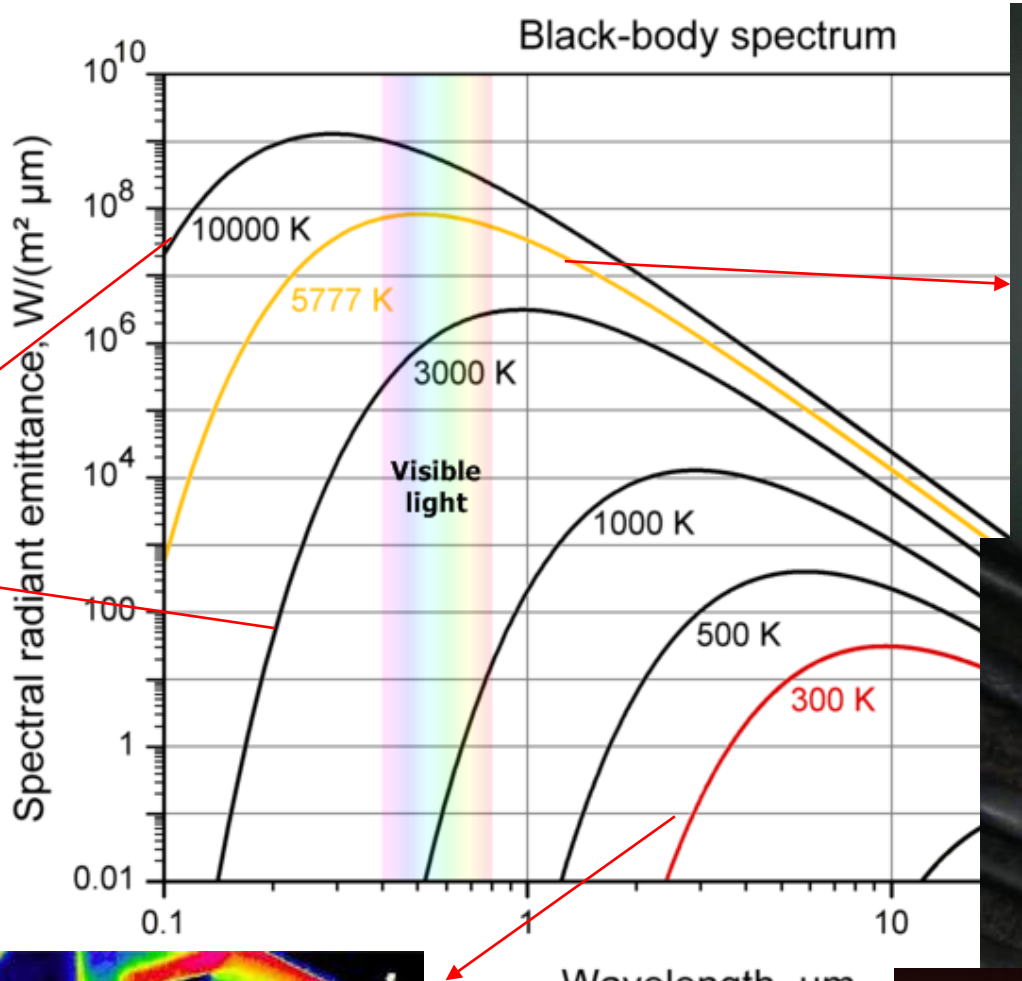
heat exchange modes

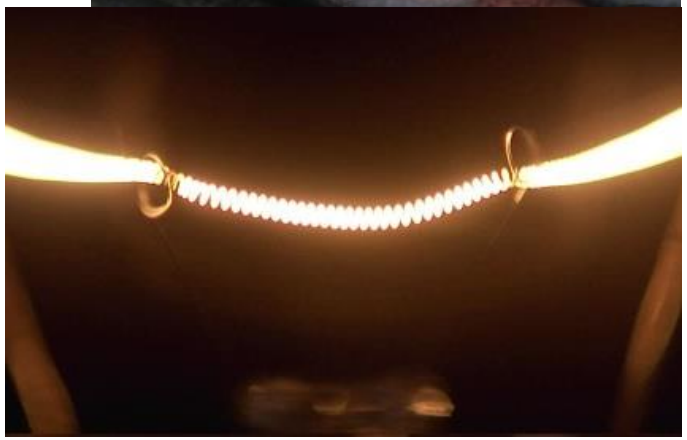
- conduction
- convection
- radiation


YOU ARE HERE

blackbody radiation







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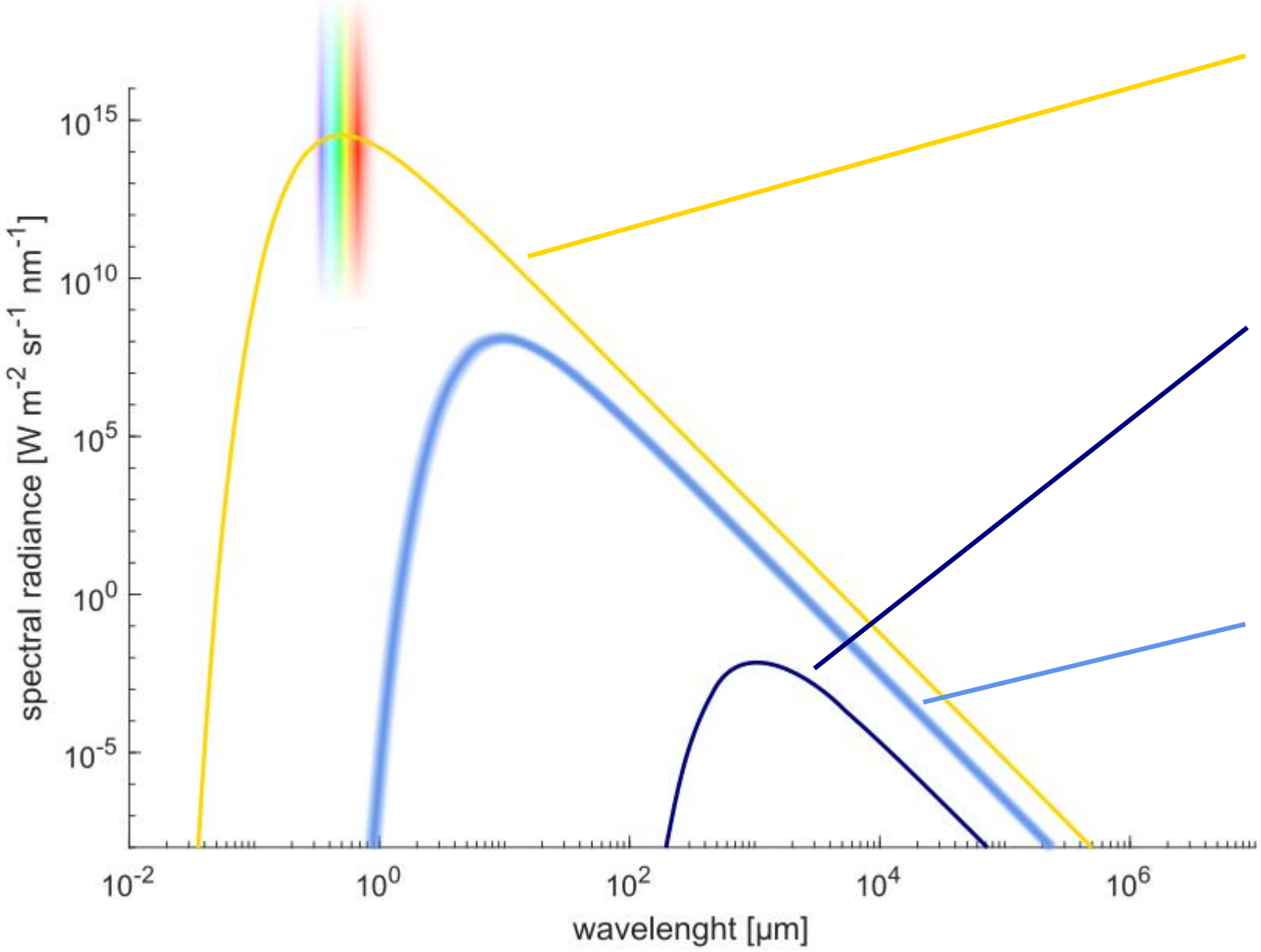

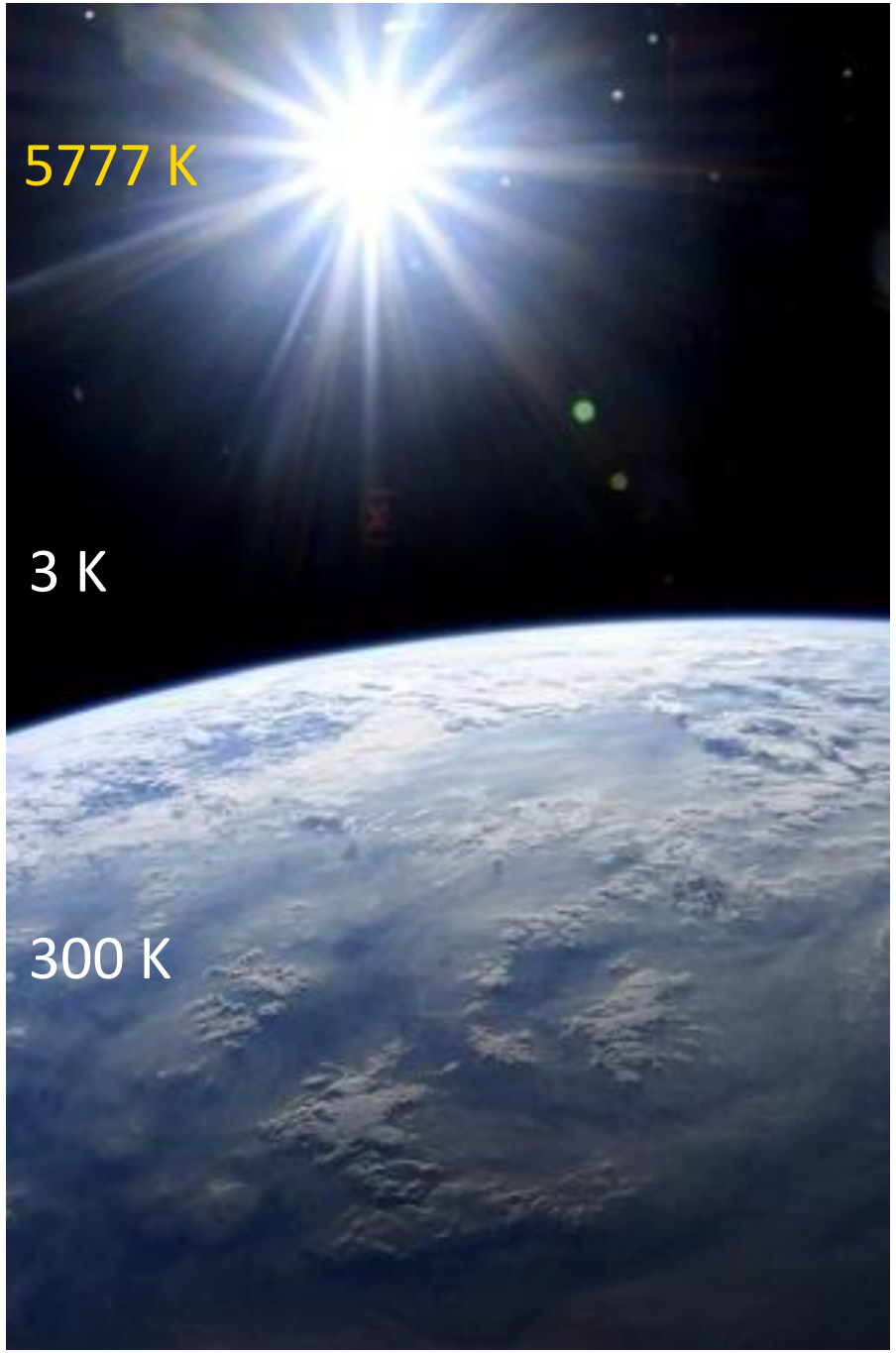

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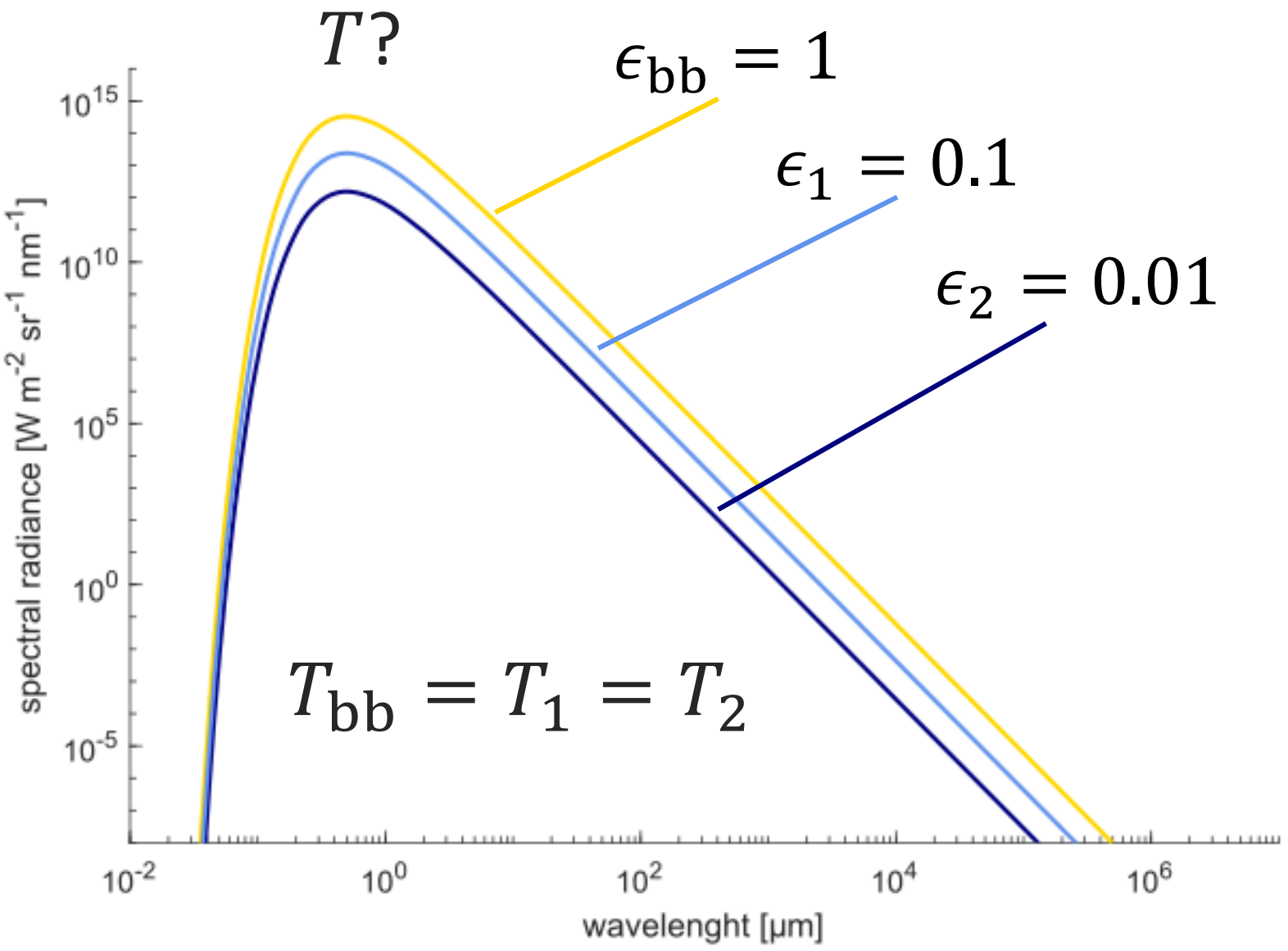
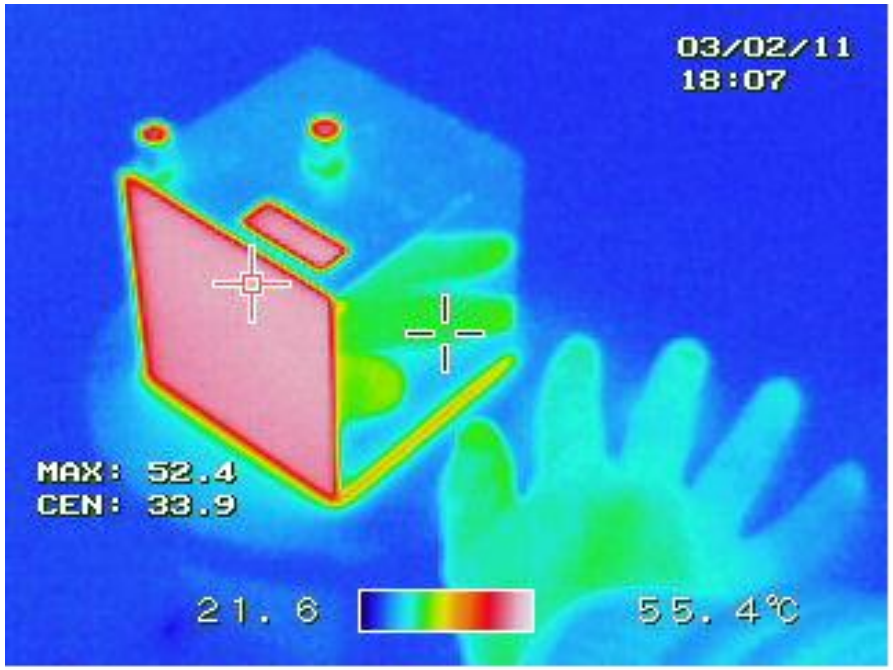


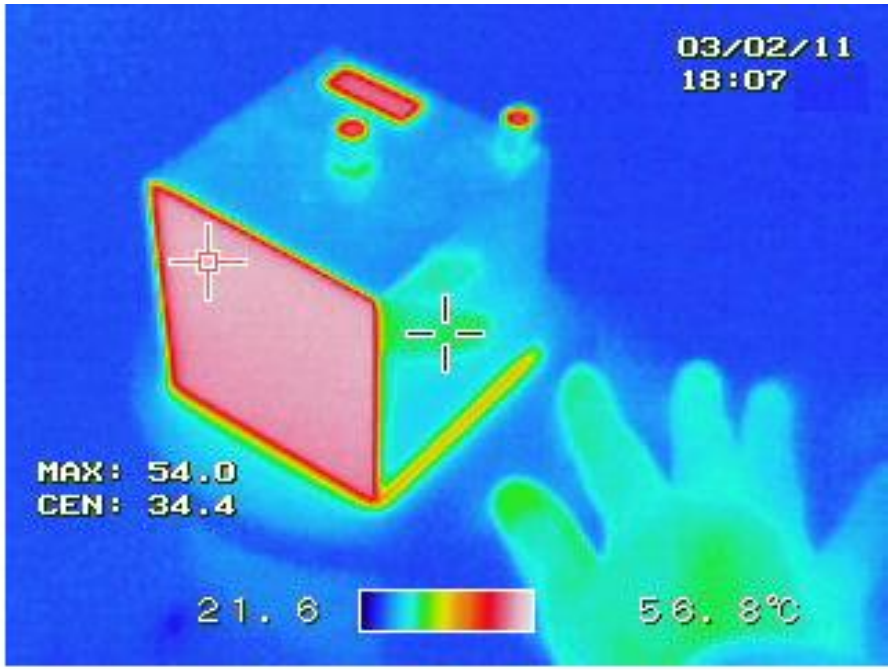
thermal emissivity

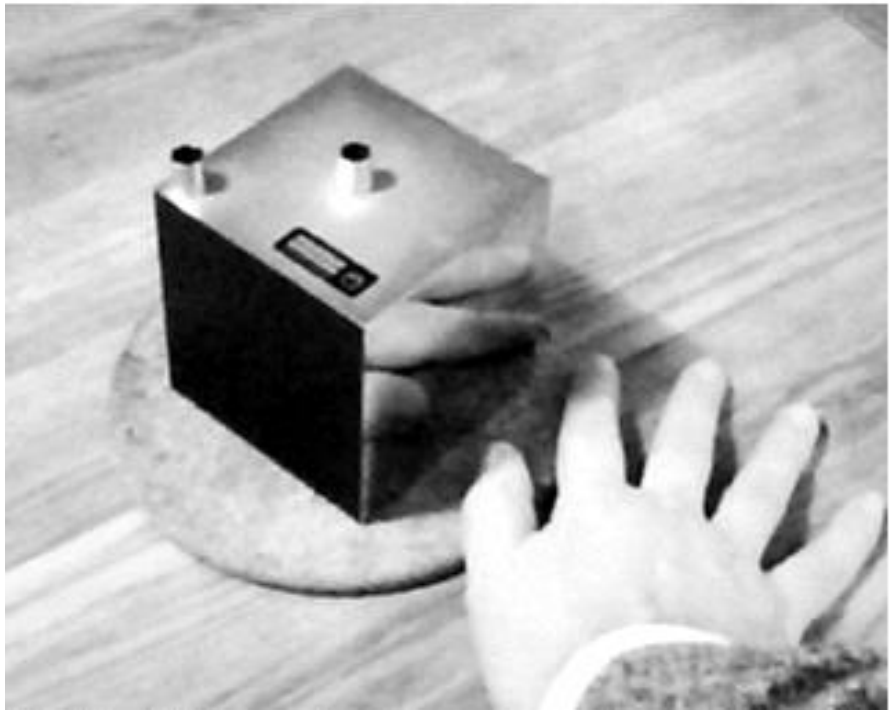
good absorbers
are good emitters

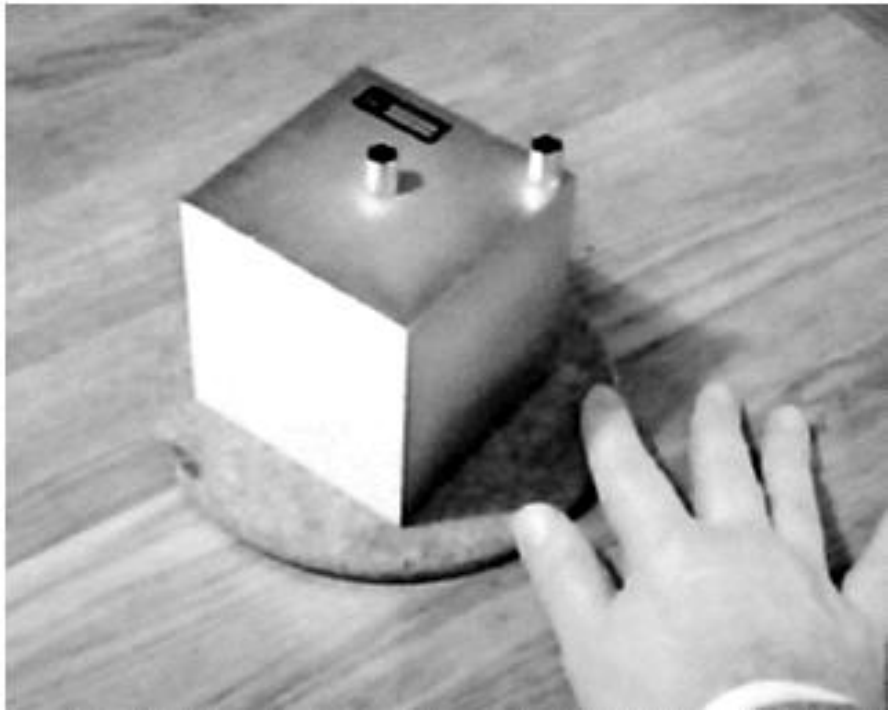
$$\epsilon(\lambda) = \alpha(\lambda)$$

Material	Emissivity, ε
ice	0.97
pure water	0.96
snow	0.8–0.9
glass (flat)	0.95
grass	0.98
soil	0.93
aluminum foil	0.03
asphalt	0.88–0.94









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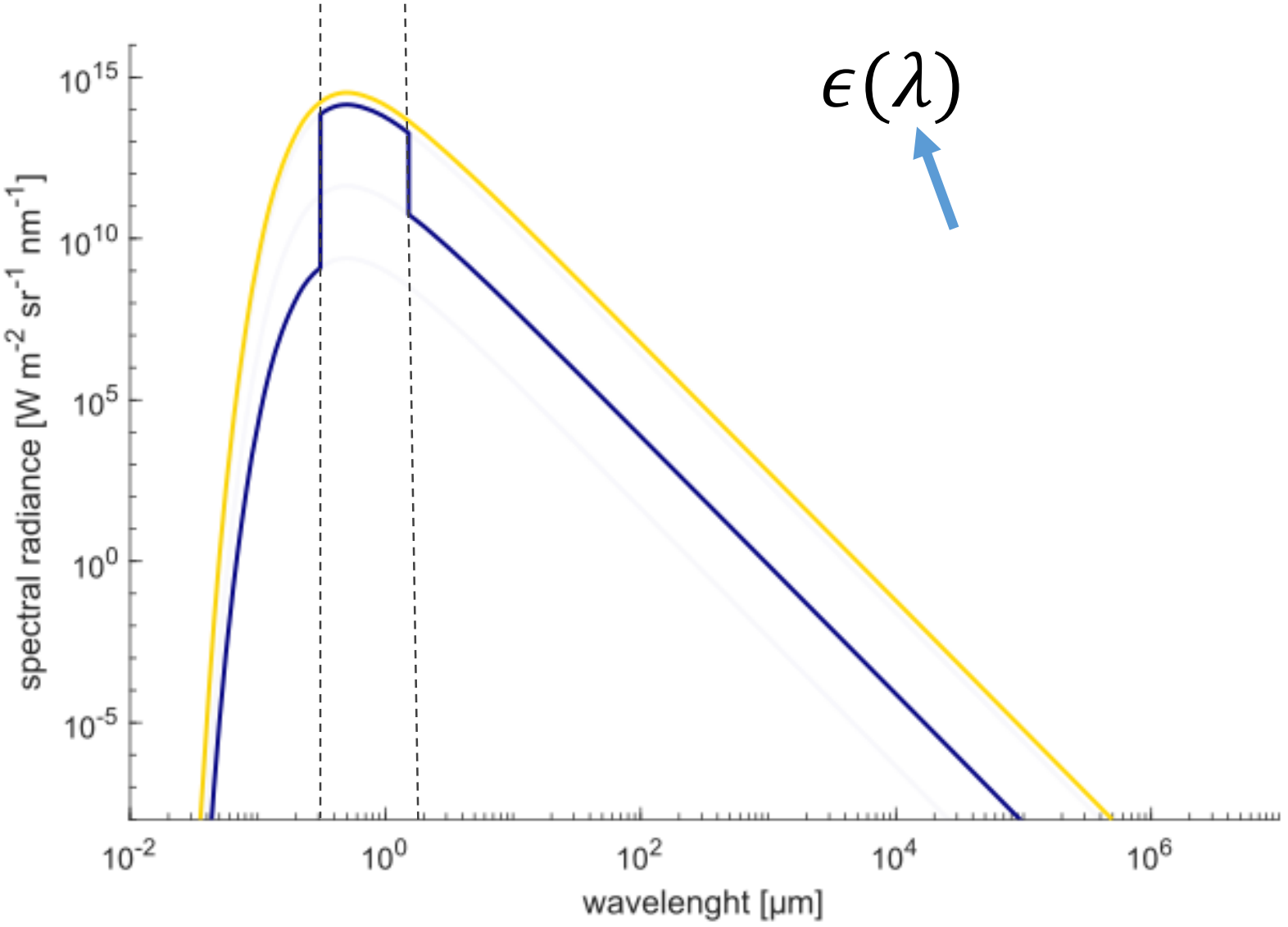

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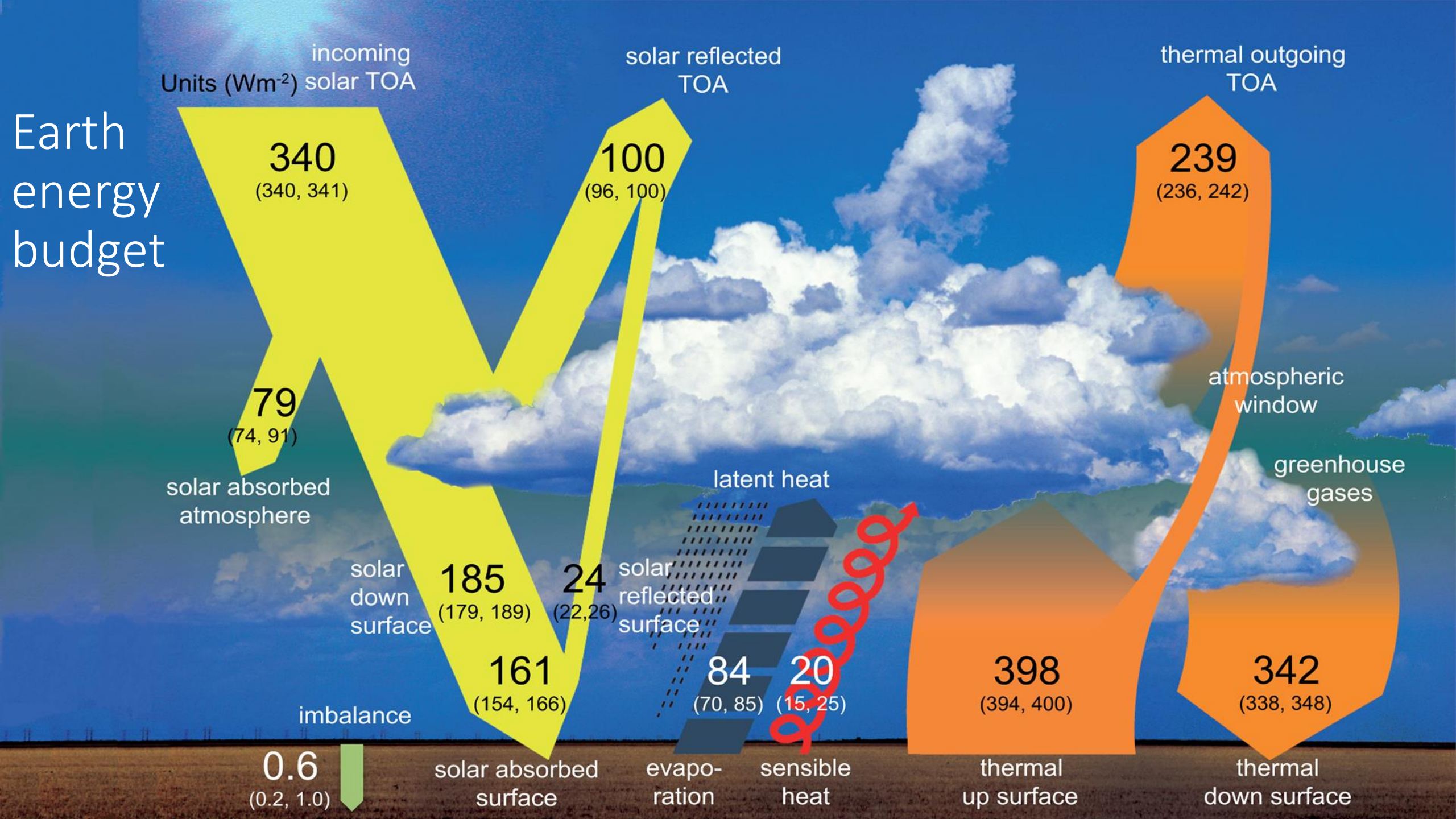
Earth energy budget



Earth energy budget

incoming solar TOA
Units (Wm^{-2})
340
(340, 341)

solar reflected TOA
100
(96, 100)

thermal outgoing TOA
239
(236, 242)

... 997 ¢

latent heat

solar down surface
185
(179, 189)

24
(22,26)
solar reflected surface

161
(154, 166)

84
(70, 85)

20
(15, 25)

398
(394, 400)

342
(338, 348)

imbalance
0.6
(0.2, 1.0)

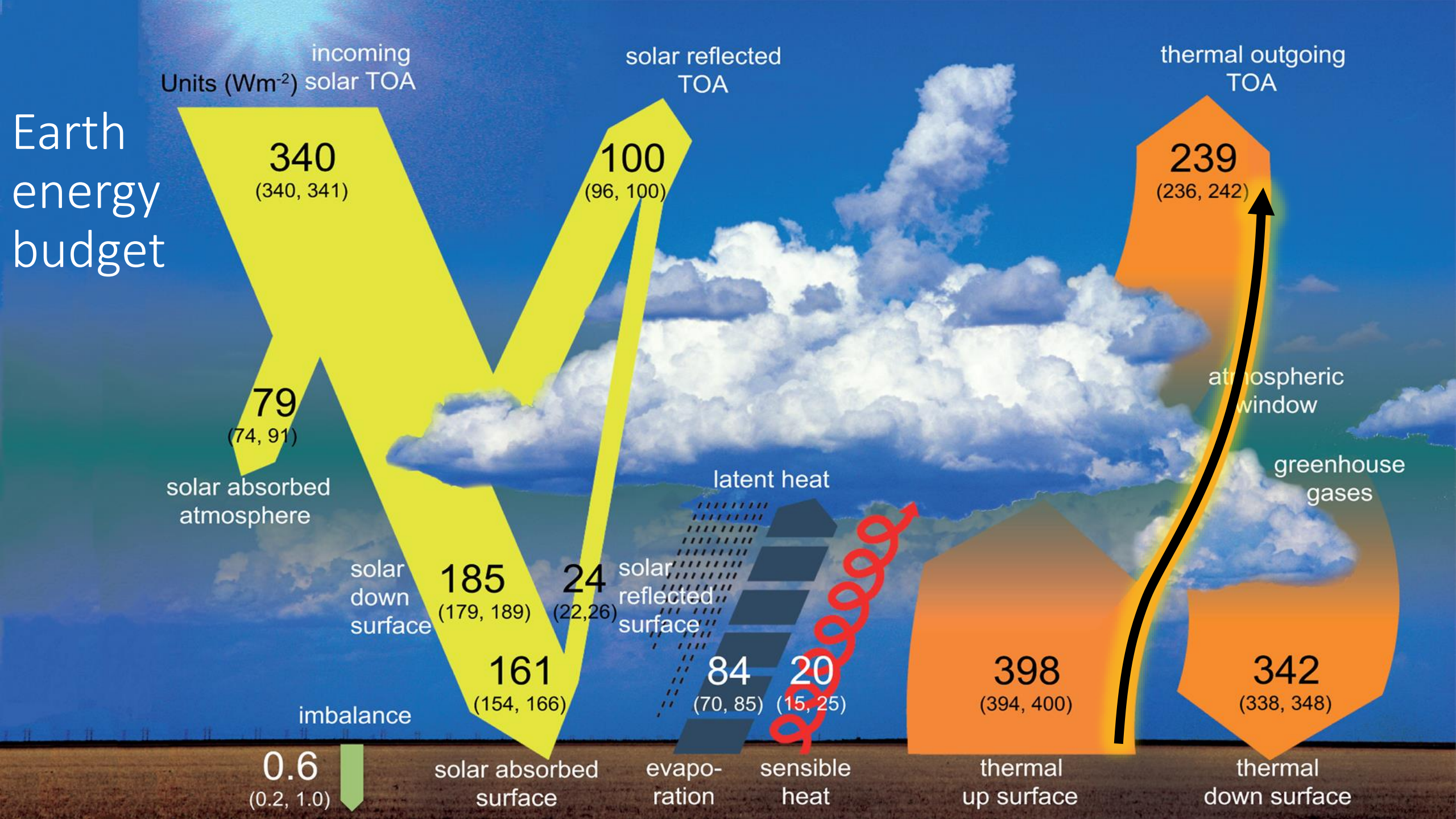
solar absorbed surface

evapo-ration

sensible heat

thermal up surface

thermal down surface


Earth energy budget
Units (Wm-2)
incoming solar TOA
340
(340, 341)
solar reflected TOA
100
(96, 100)
thermal outgoing TOA
239
(236, 242)
79
(74, 91)
solar absorbed atmosphere
atmospheric window
greenhouse gases
latent heat
solar down surface
185
(179, 189)
24
(22,26)
solar reflected surface
161
(154, 166)
84
(70, 85)
20
(15, 25)
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(394, 400)
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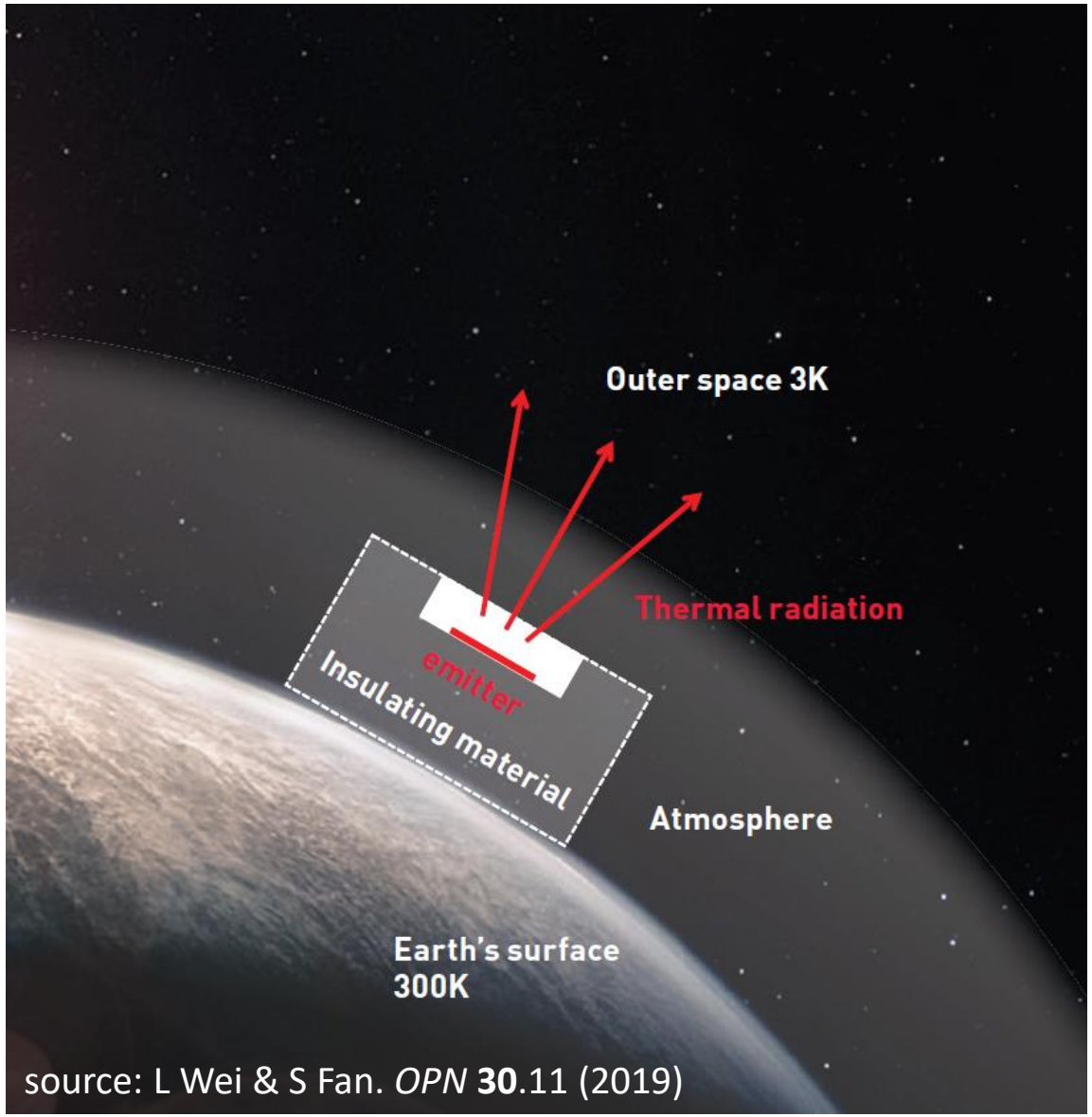
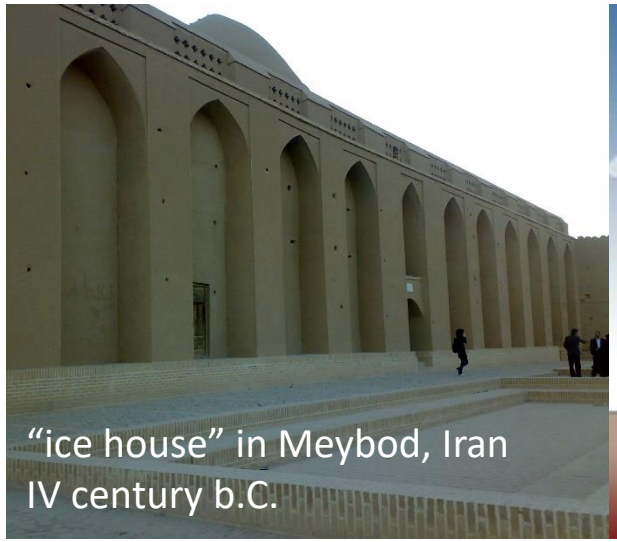
(338, 348)
imbalance
0.6
(0.2, 1.0)
solar absorbed surface
evapo-ration
sensible heat
thermal up surface
thermal down surface

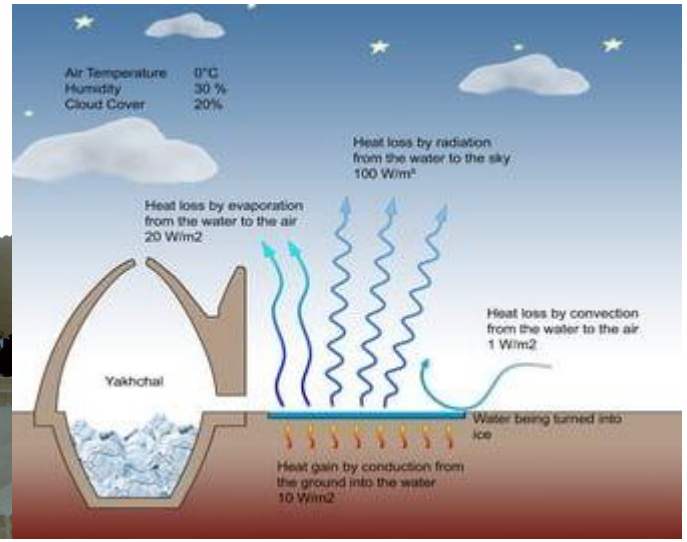
cold space as a renewable thermal sink



source: L Wei & S Fan. *OPN* **30**.11 (2019)



"ice house" in Meybod, Iran
IV century b.C.



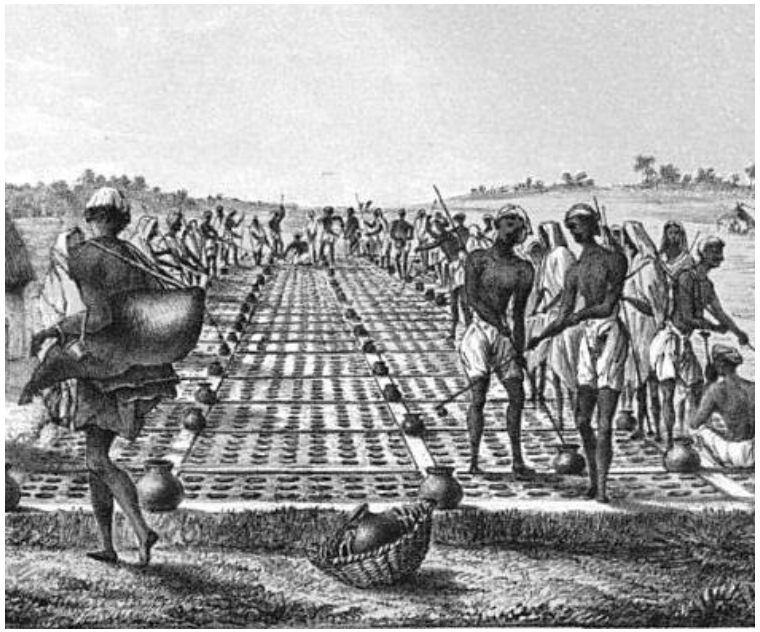
XXII. *The Proceſs of making Ice in the* Eaſt Indies. *By Sir* Robert Barker, *F. R. S. in a Letter to Dr.* Brockleſby.

TO DR. RICHARD BROCKLESBY, F. R. S.

SIR, Spring-Gardens, March 2, 1775.

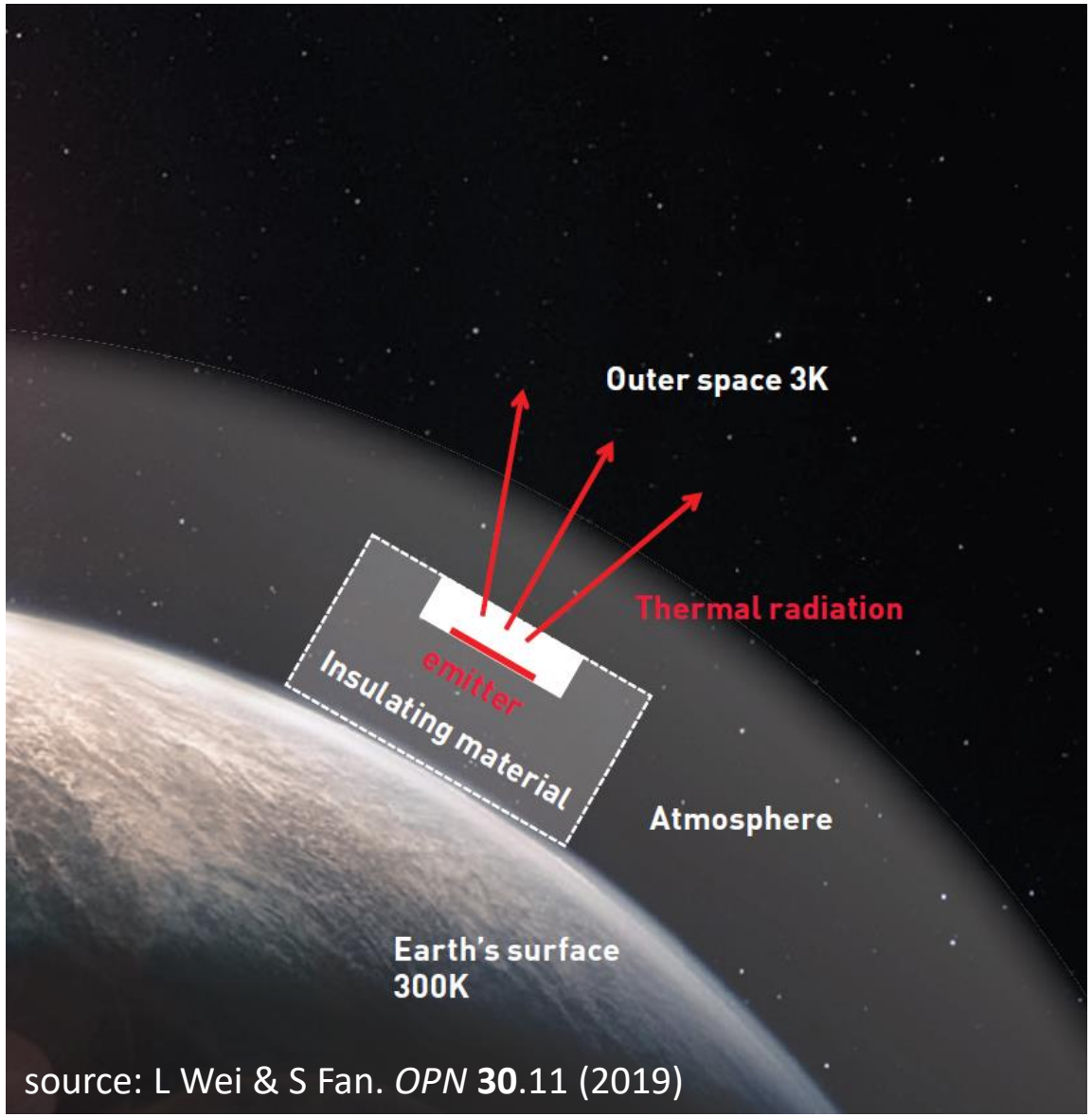
Redde, Mar. 9, 1775. THE proceſs of making ice in the Eaſt Indies having become a ſubject of ſpeculation, I beg permiſſion to preſent you with the method by which it was performed at Allahabad, Mootegil, and Calcutta, in the Eaſt Indies, lying between 25½ and 23½ degrees of North latitude. At the latter place I have never heard of any perſons having diſcovered natural ice in the pools or ciſterns, or in any waters collected in the roads; nor has the thermometer been remarked to deſcend to the freezing point; and at the former very few only have diſcovered ice, and that but ſeldom. But in the proceſs of making ice at theſe places it was uſual to collect a quantity every morning, before Sun-riſe (except in ſome particular kinds of weather, which I ſhall ſpecify in the ſequel), for near three months in the year: *viz.* from December till February.

The ice-maker belonging to me at Allahabad (at which place I principally attended to this enquiry) made a ſuf-



R Barker. Phil. Trans. **65** (1775)

cold space as a renewable thermal sink

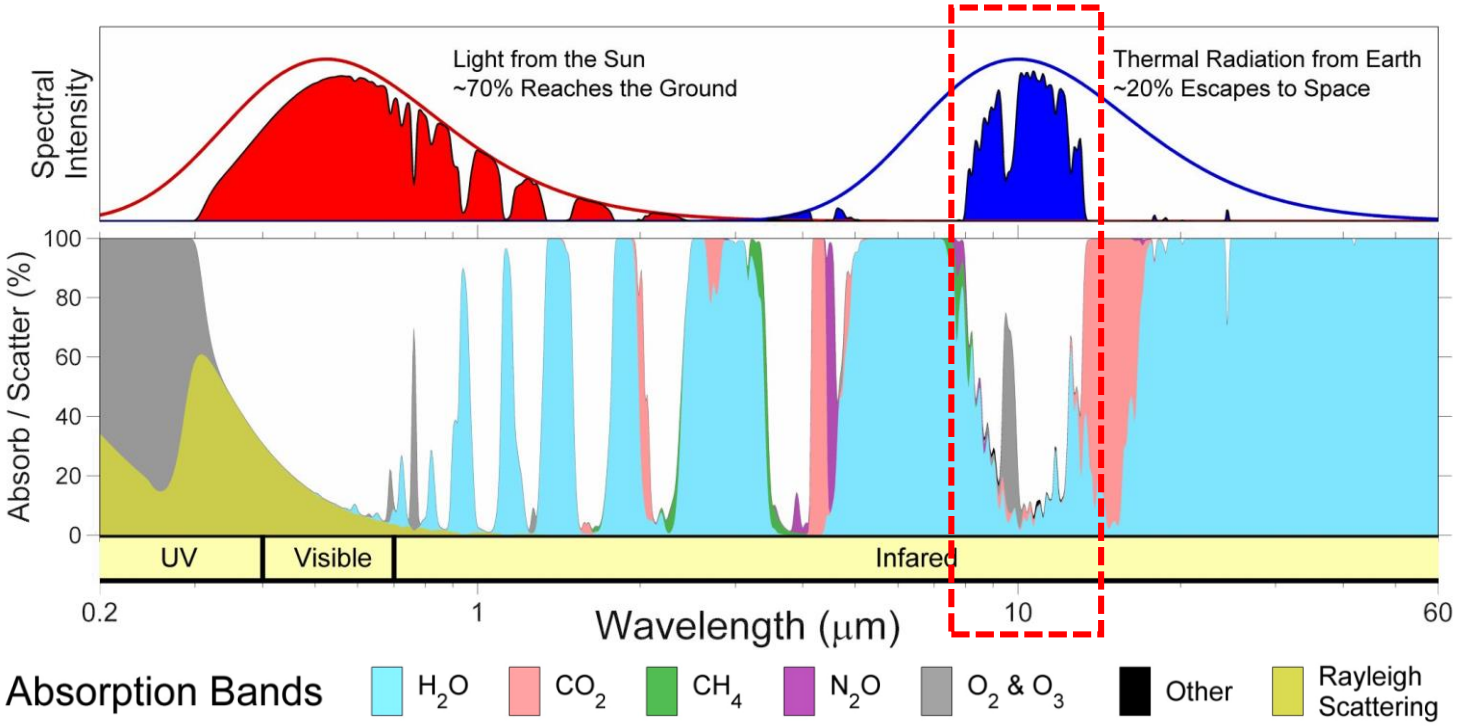


source: L Wei & S Fan. *OPN* **30**.11 (2019)

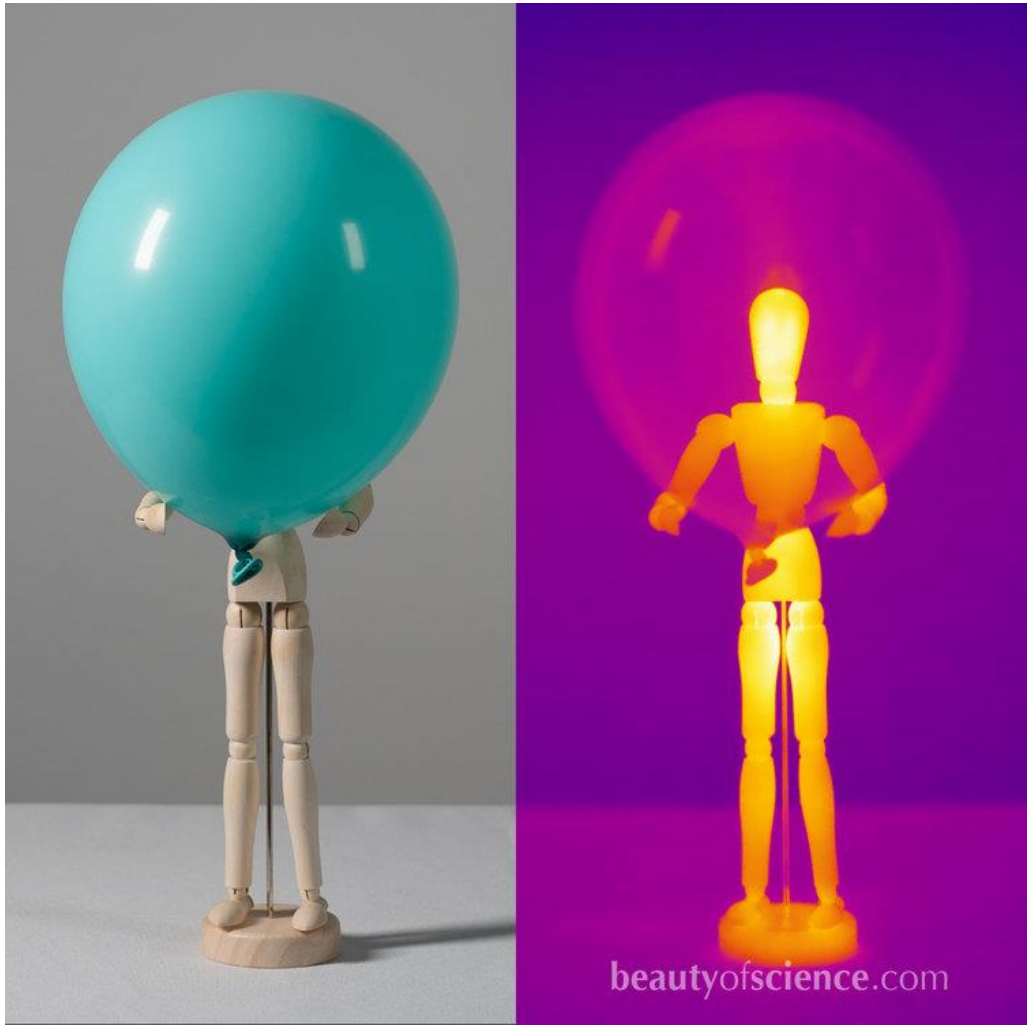
fine prima parte

domande?

the sky transparency window



source: www.beautyofscience.com/seeing-heat

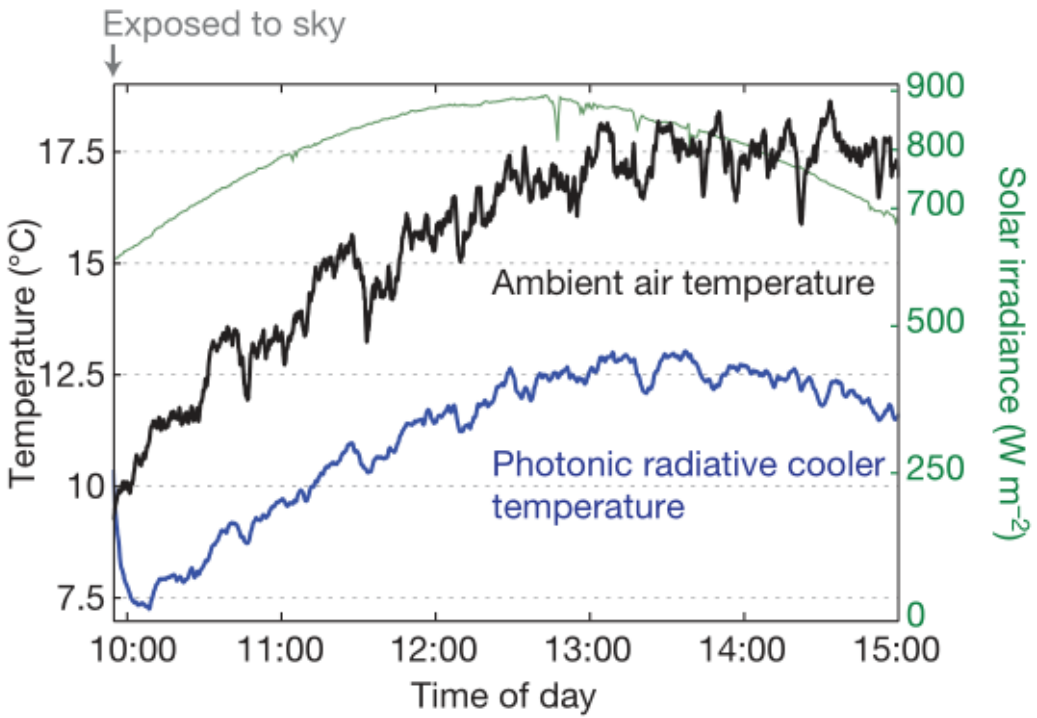


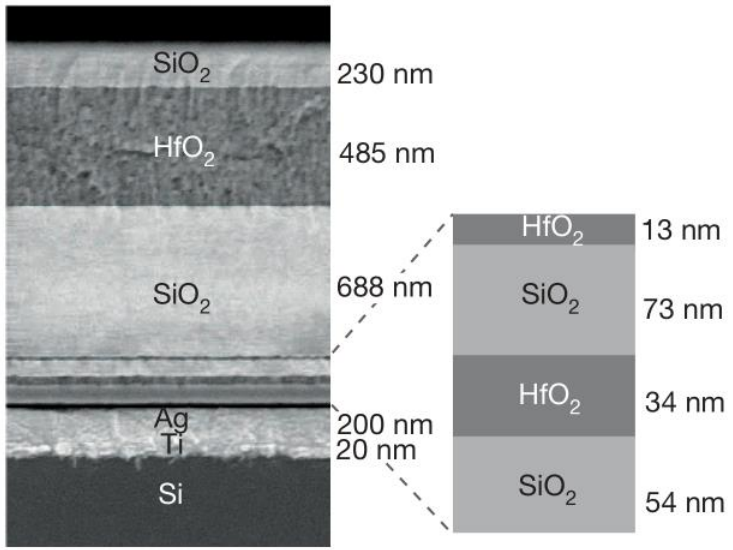
nature

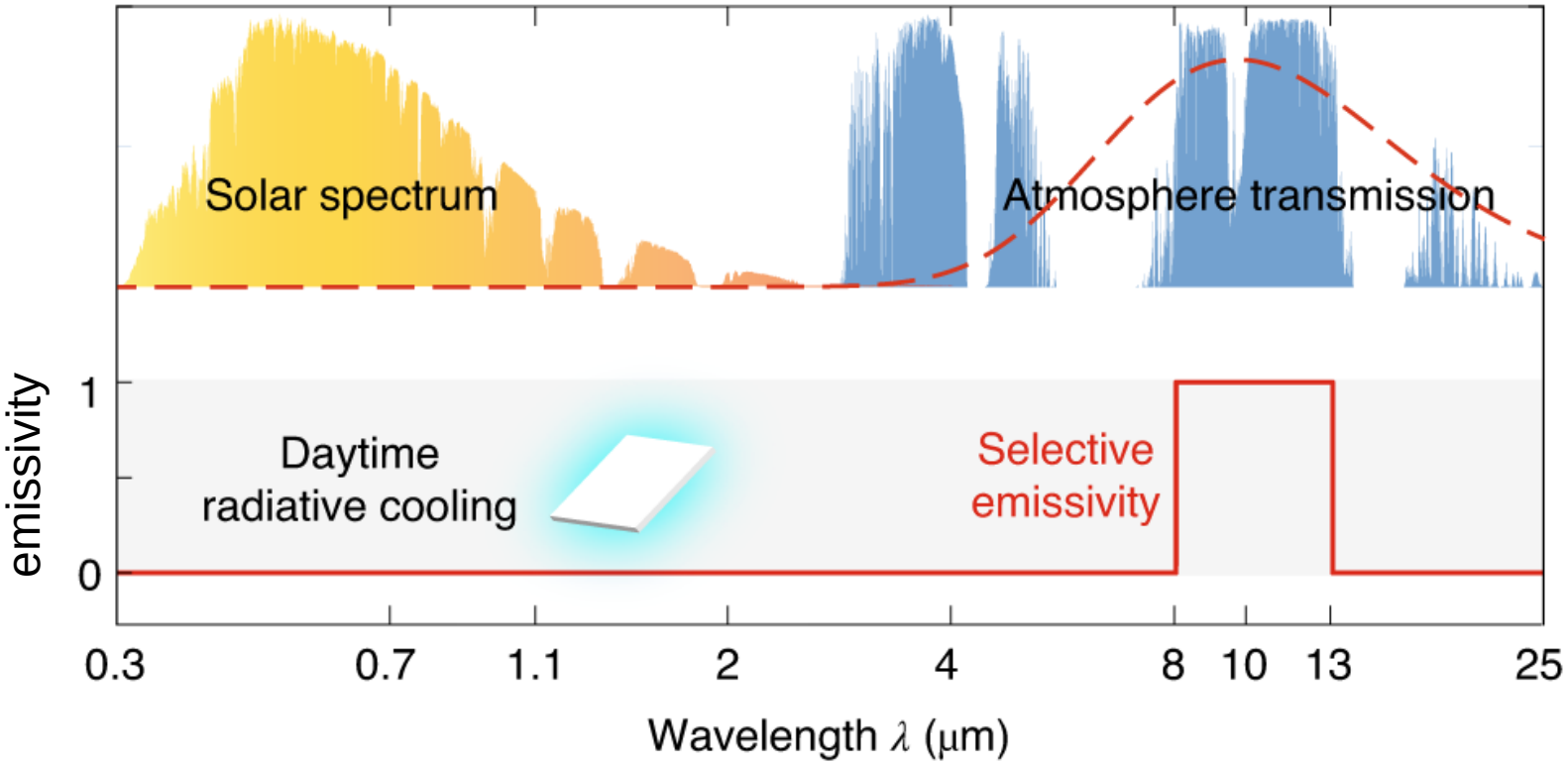
22 September 2014.

Passive radiative cooling below ambient air temperature under direct sunlight

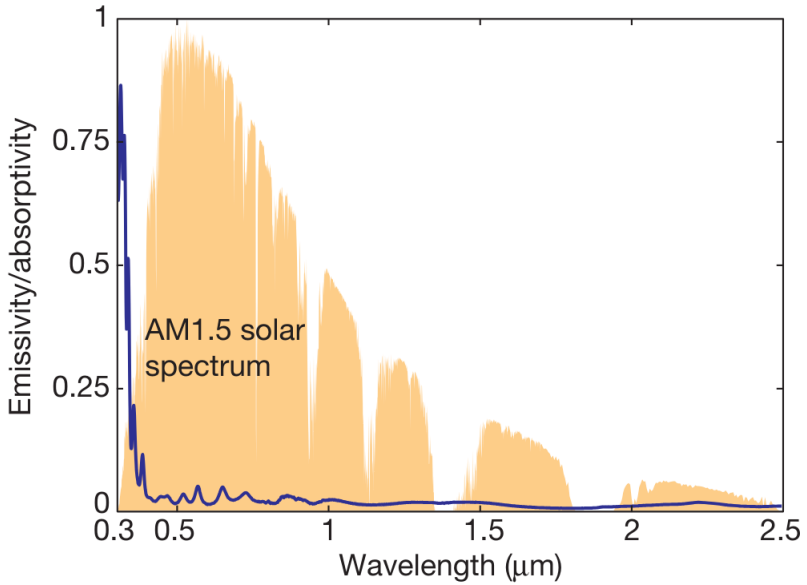
Aaswath P. Raman[1], Marc Abou Anoma[2], Linxiao Zhu[3], Eden Rephaeli[1] & Shanhui Fan[1]

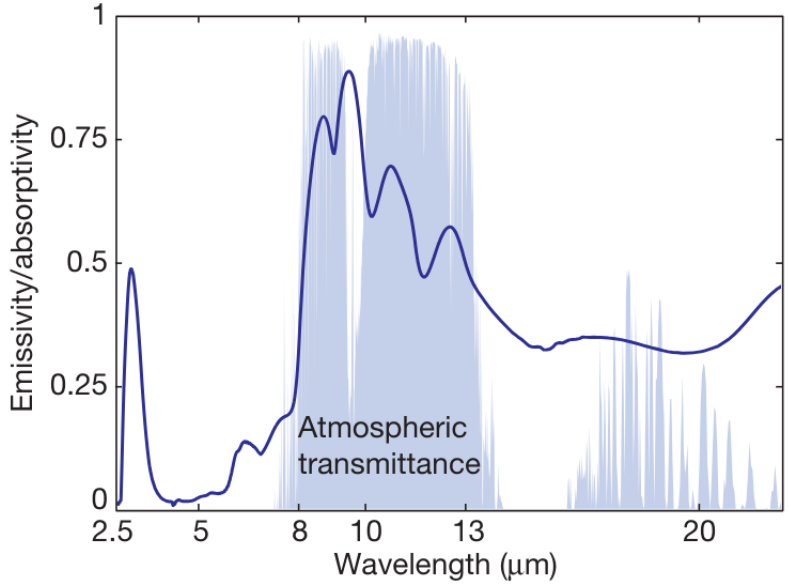




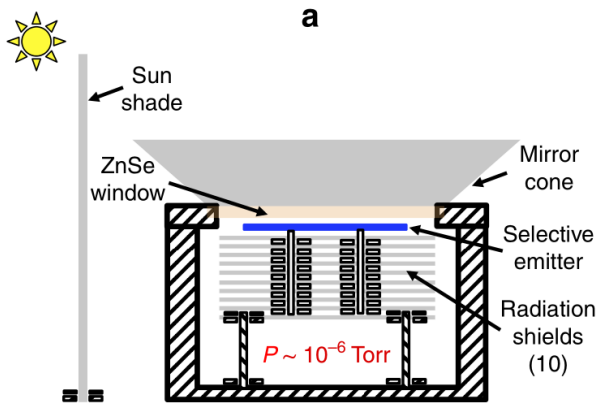

Solar spectrum
Atmosphere transmission
emissivity
1
0
Daytime
radiative cooling
Selective
emissivity
0.3
0.7
1.1
2
4
8
10
13
25
Wavelength λ (μm)

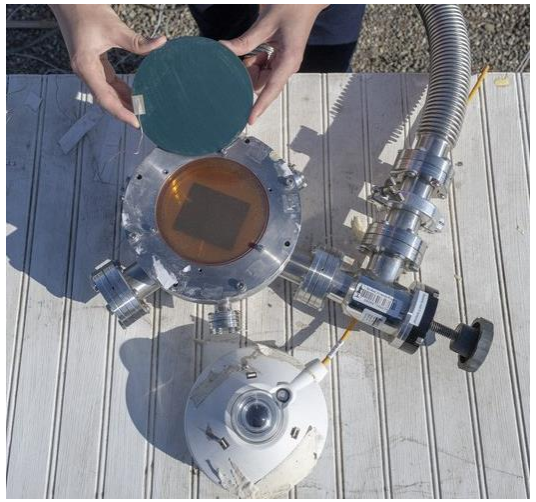

Stanford
University

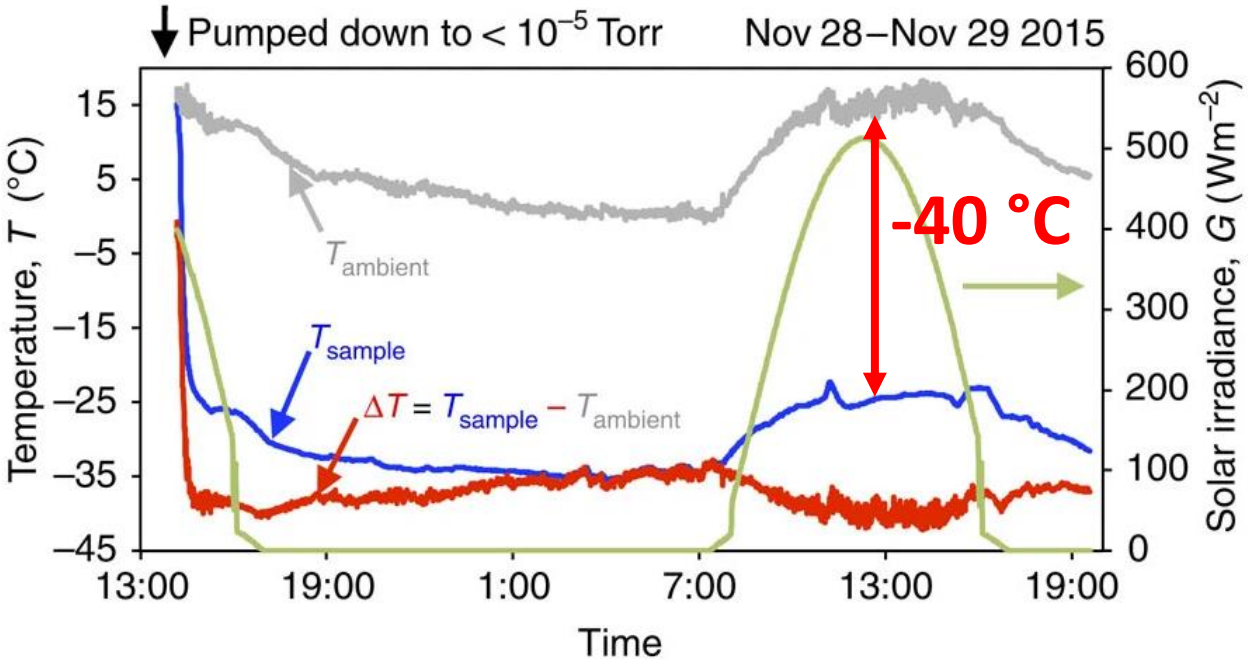

Emissivity/absorptivity
1
0.75
0.5
0.25
0
AM1.5 solar
spectrum
0.3
0.5
1
1.5
2
2.5
Wavelength (μm)


Emissivity/absorptivity
1
0.75
0.5
0.25
0
Atmospheric
transmittance
2.5
5
8
10
13
20
Wavelength (μm)

… sky is the limit?

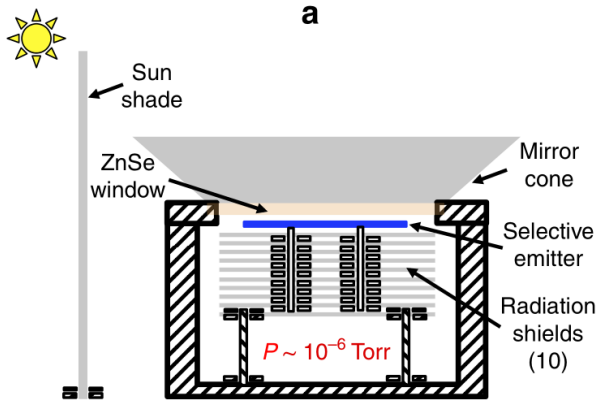


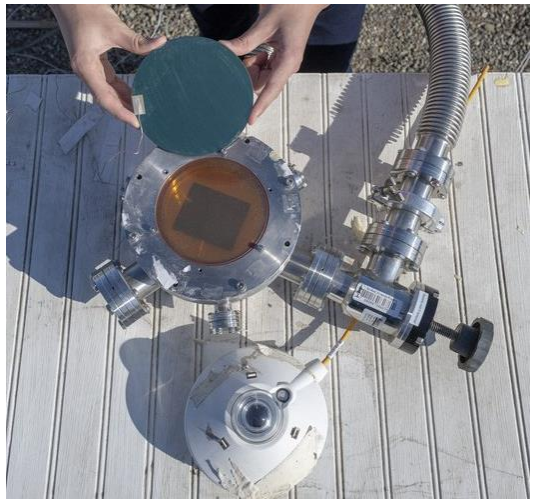


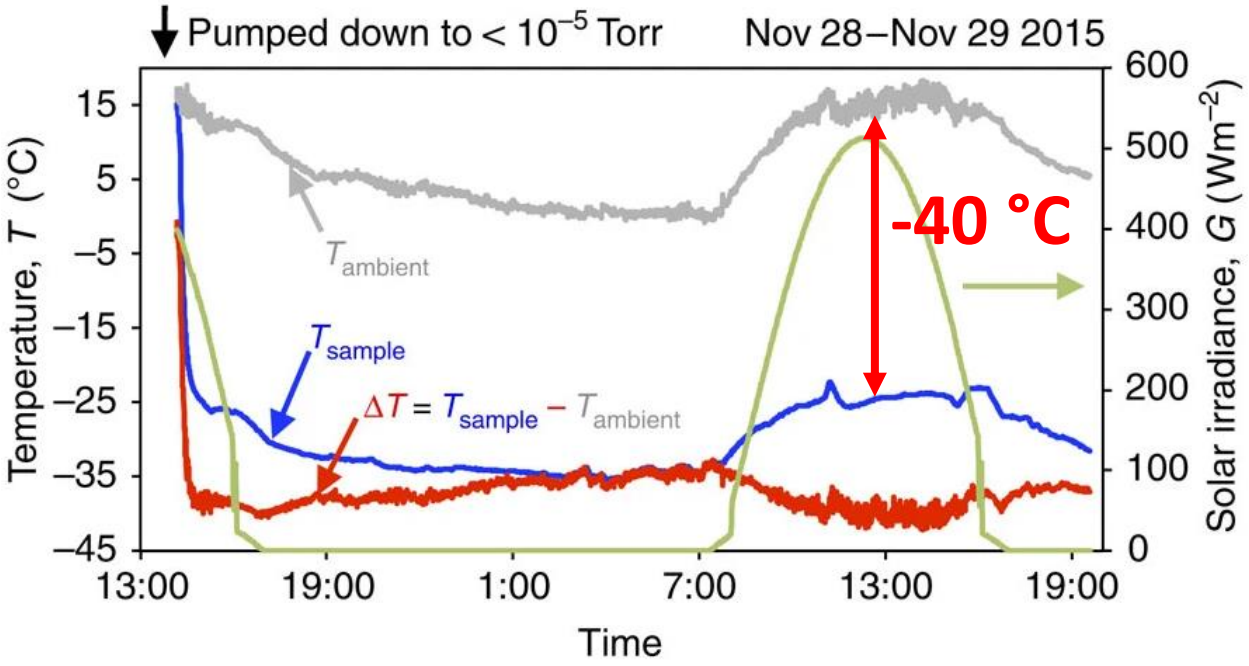


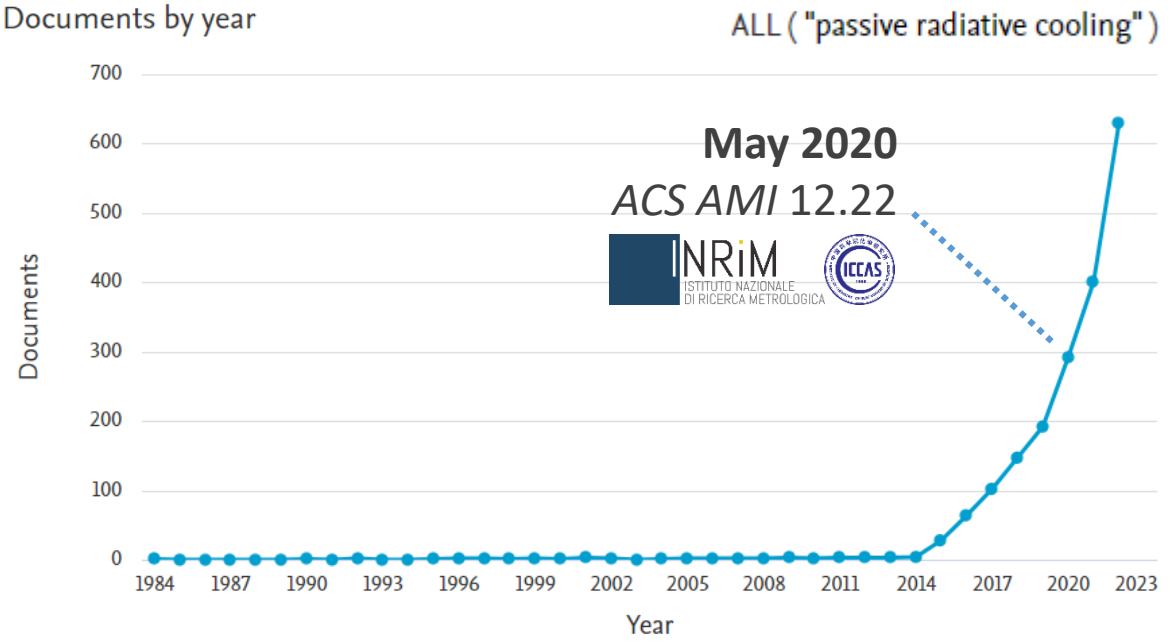
Z Chen et al., *Nat Commun* **7**.1 (2016)

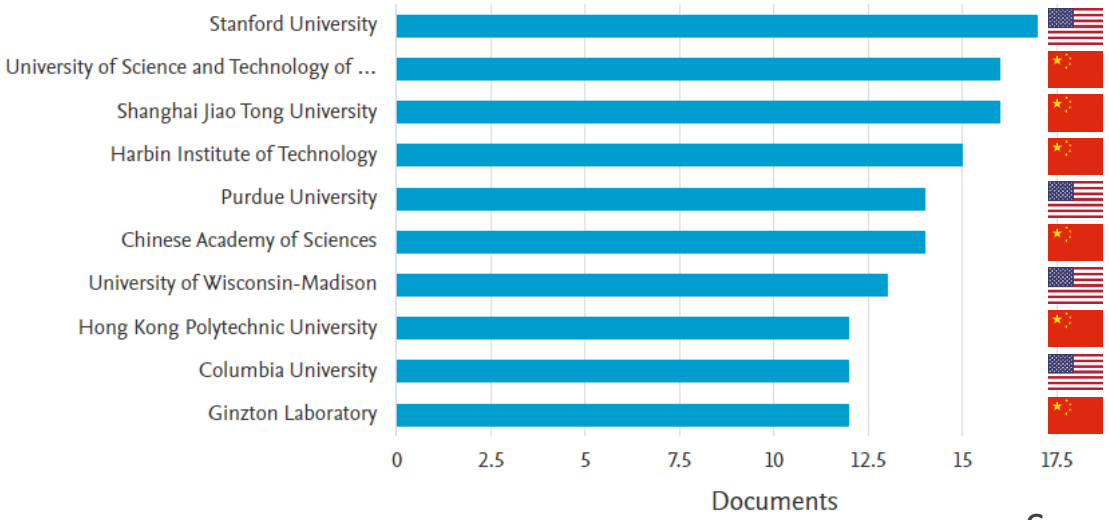
… sky is the limit?











Z Chen et al., *Nat Commun* **7**.1 (2016)

source: *Scopus*

meanwhile… 40 years before (!)

THE RADIATIVE COOLING OF SELECTIVE SURFACES

S. CATALANOTTI, V. CUOMO, G. PIRO, D. RUGGI,
V. SILVESTRINI and G. TROISE
Istituto di Fisica Sperimentale dell'Università di Napoli, Via Antonio Tari 3, 80138 Napoli, Italy

(*Received* 22 *March* 1974; *in revised form* 26 *August* 1974)

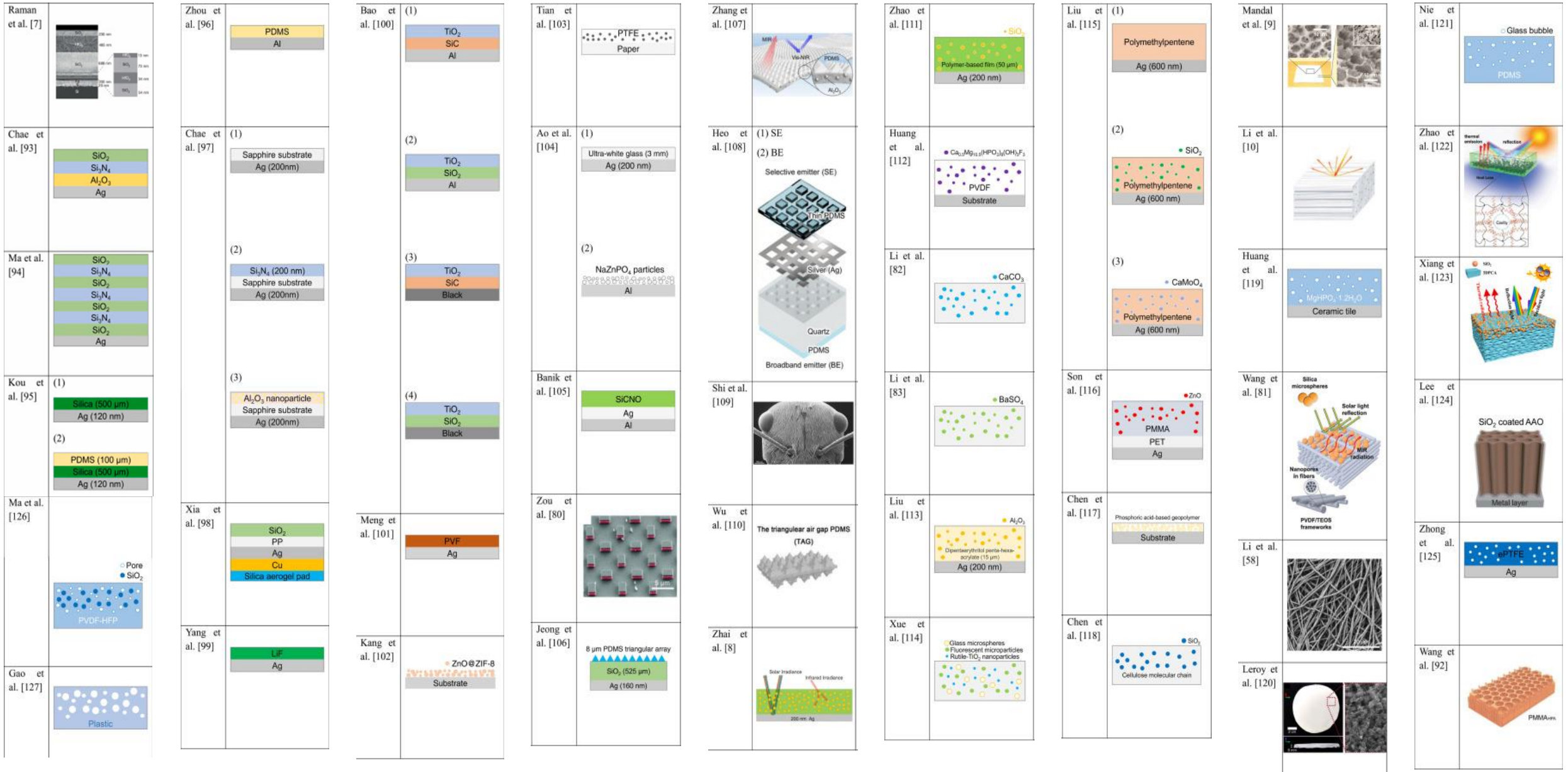
Abstract—We have realized a selective surface with optical properties matched to the atmospheric window 8–13 μm. With respect to a black radiator, this surface is considerably more effective for cooling by exposition to the clear sky: in particular, a cooling effect is obtained also during the day. Theoretical results and experimental data are presented.

Acknowledgments—The measurements of the optical properties of the components of our set-up were performed in the laboratories headed by Prof. Califano (University of Florence) and by Prof. Paiaro (University of Naples). We particularly want to thank Prof. Sarofim (M.I.T., Boston, U.S.A.) for useful discussions and for a critical reading of the manuscript.

Prof. Salvatore Califano
1931 – 2022

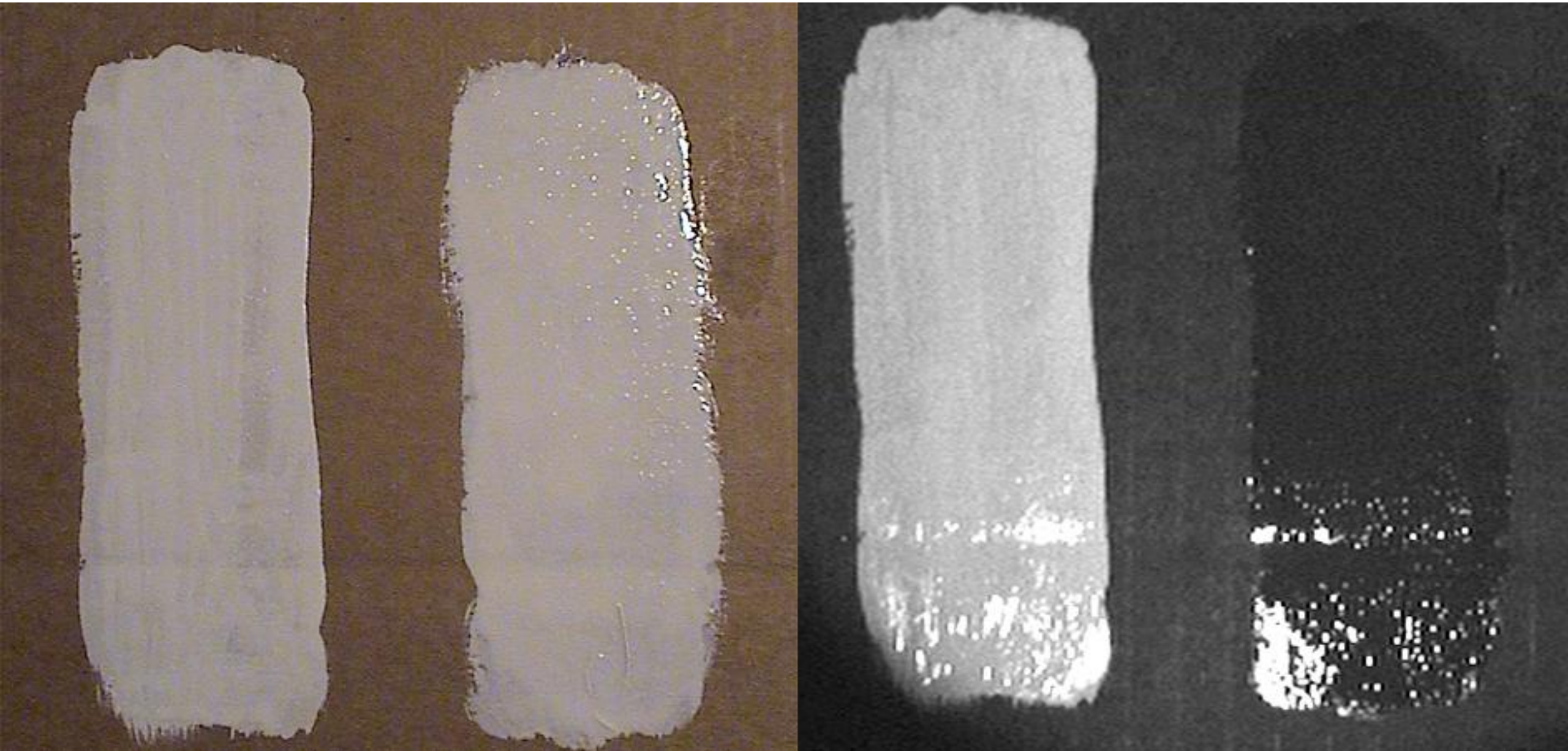
Professore Emerito di Chimica Fisica all'Università degli Studi di Firenze, fondatore del LENS

an «expolosion» of different materials …



X Yu et al., *Nano Energy* **88**, 106259 (2021)

what about «white» paints?



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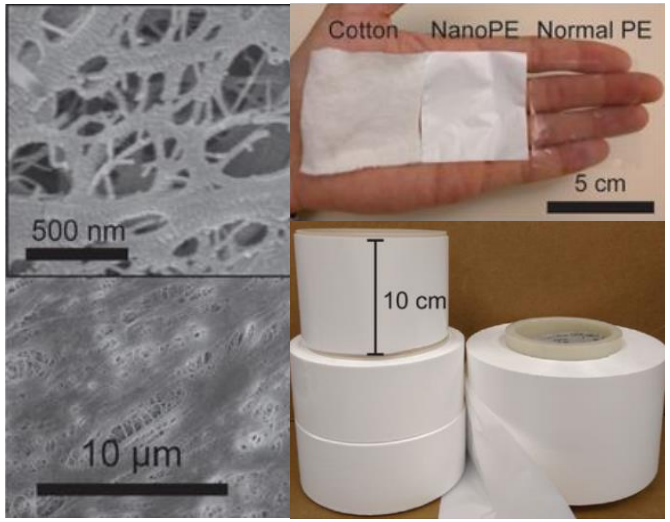
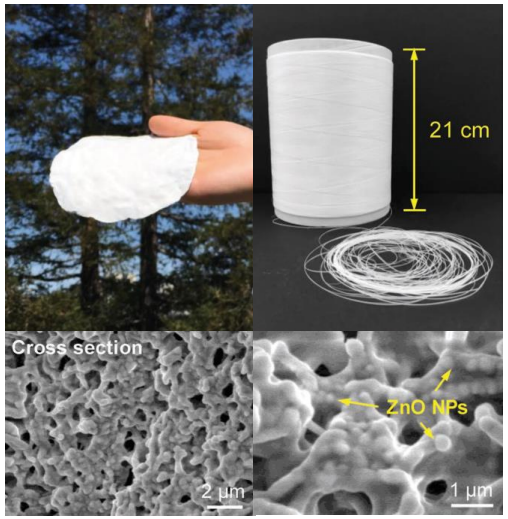
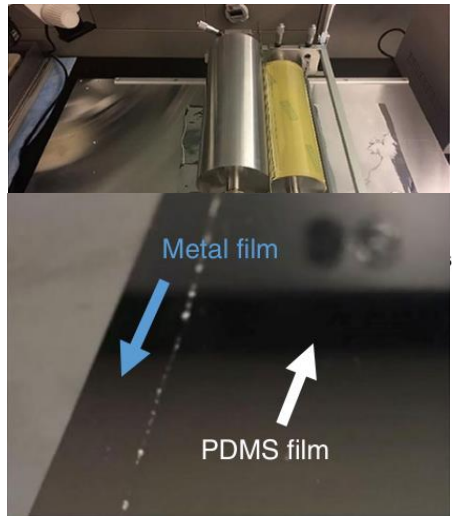


Hsu et al. *Science* **353**.6303 (2016)

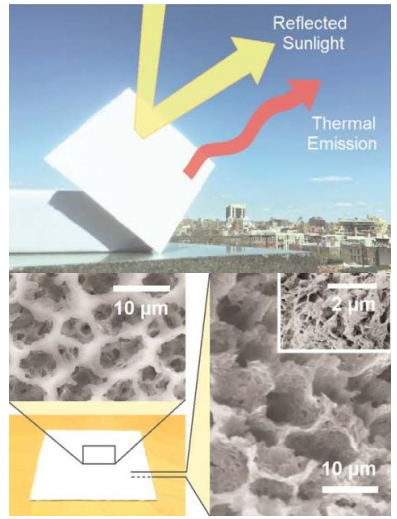
Li et al. *Science* **364**.6442 (2019)



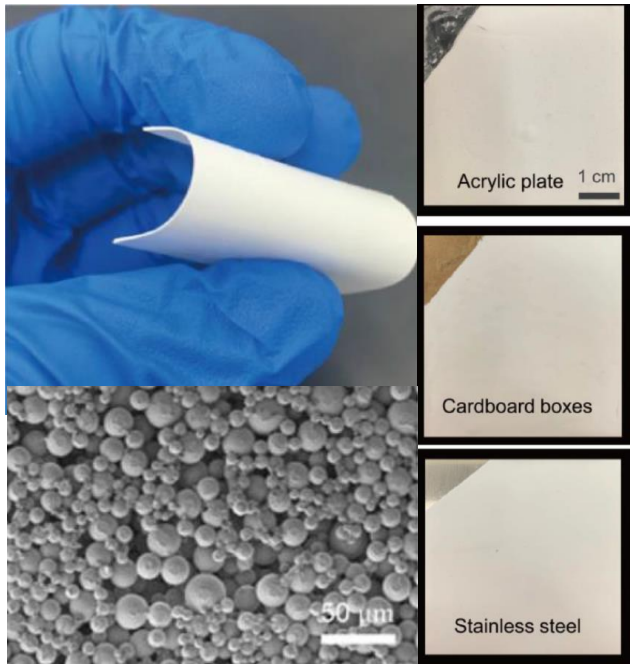
Cai et al. *Adv Mater* **30**.35 (2018)



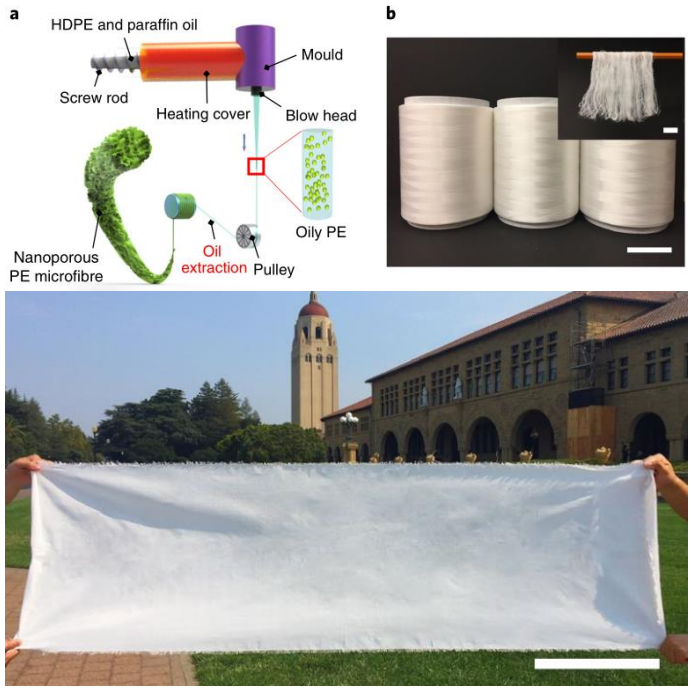
Zhou et al. *Nat Sust* **2**.8 (2019)



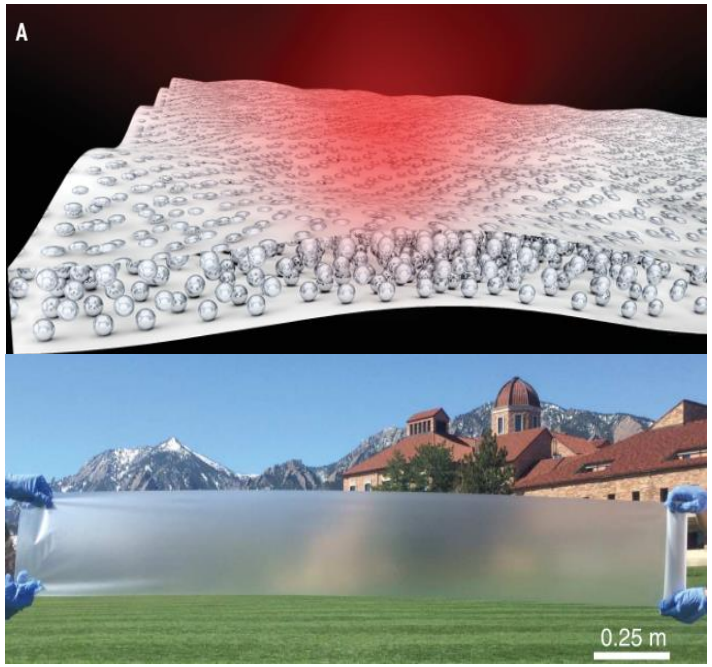
Mandal et al. *Science* **362**.6412 (2018)



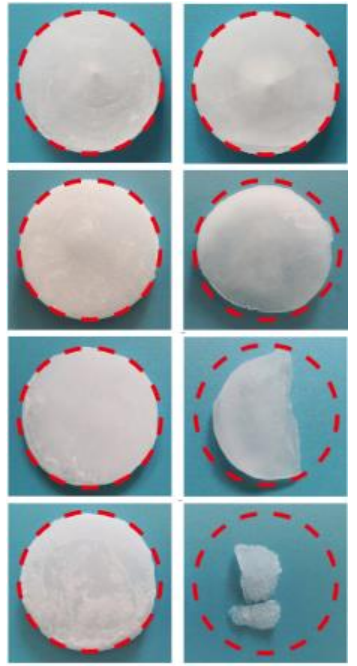
Zhao et al., *Appl Mater Today* **26** (2022)



Peng et al. *Nat Sust* **1**.2 (2018)

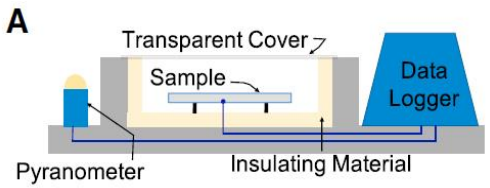


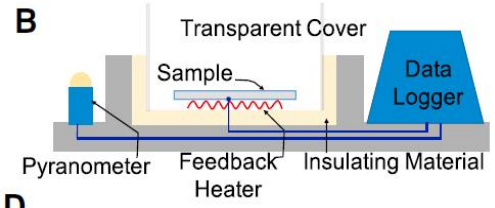
Zhai et al. *Science* **355**.6329 (2017)

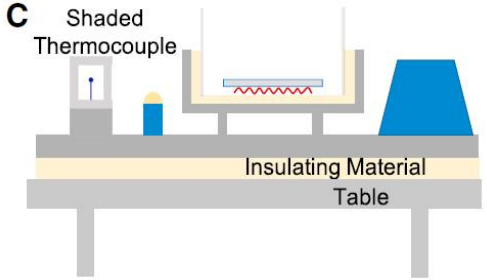


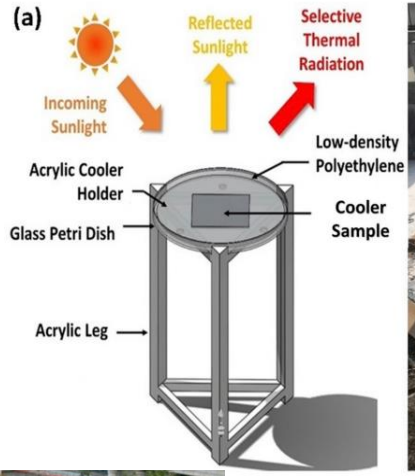
Li et al. *Sci Adv* ***8****.6* (2022)

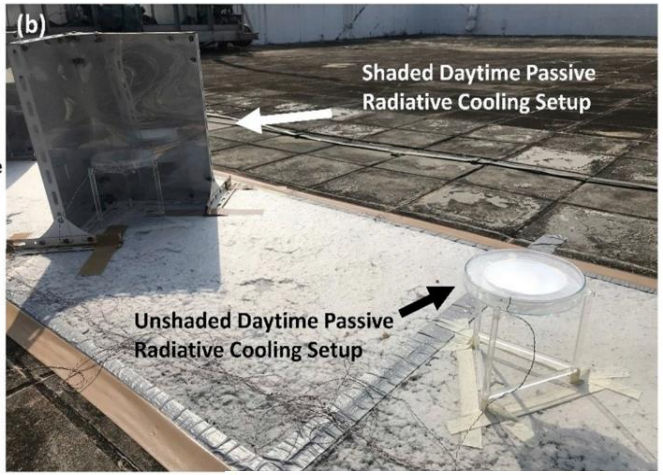
… and measurement methods

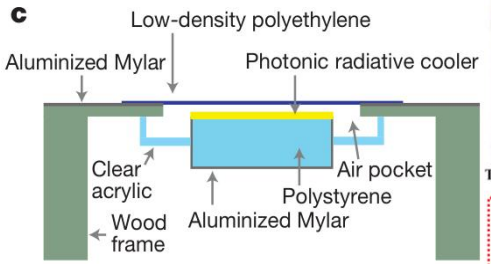


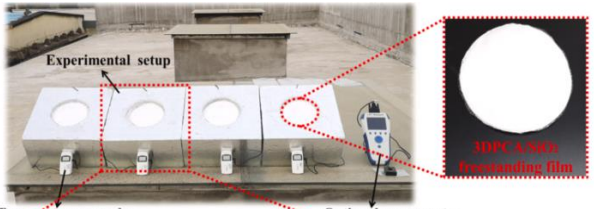


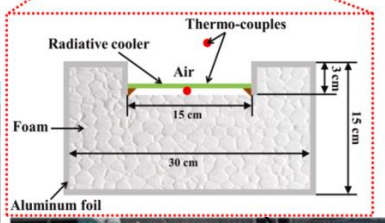


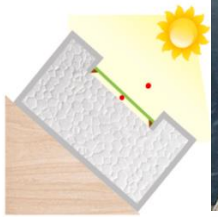


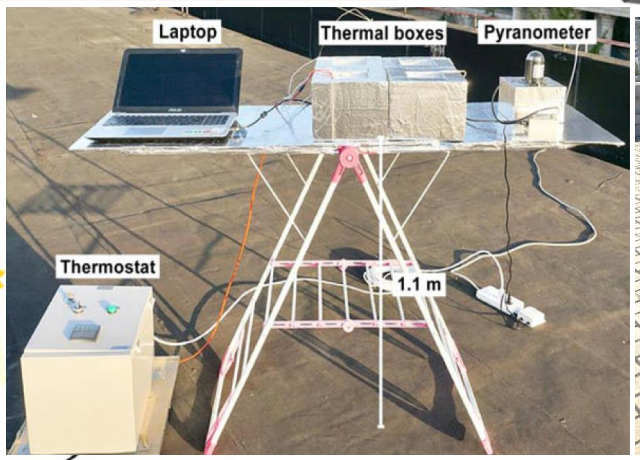


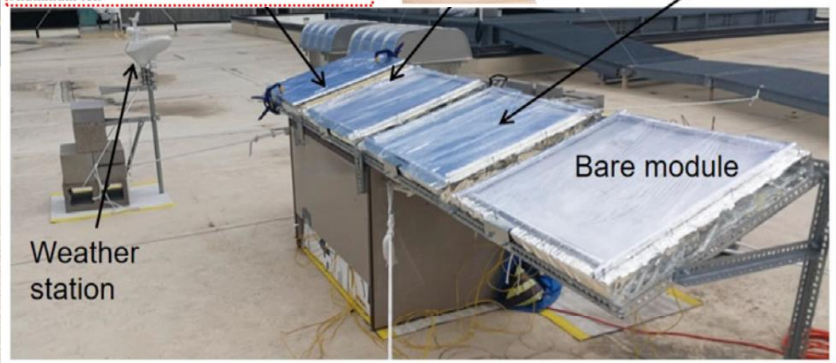


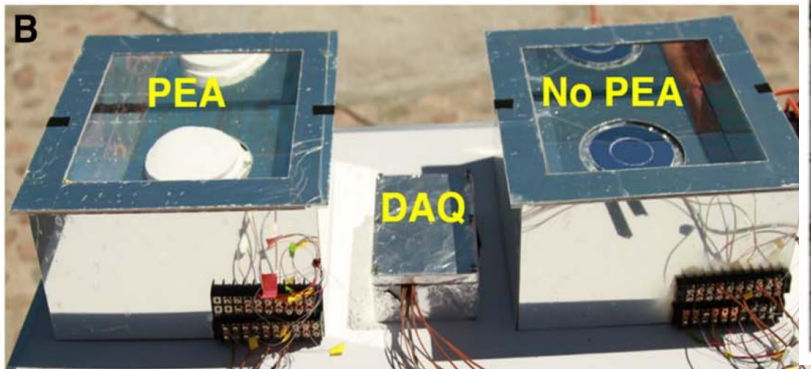


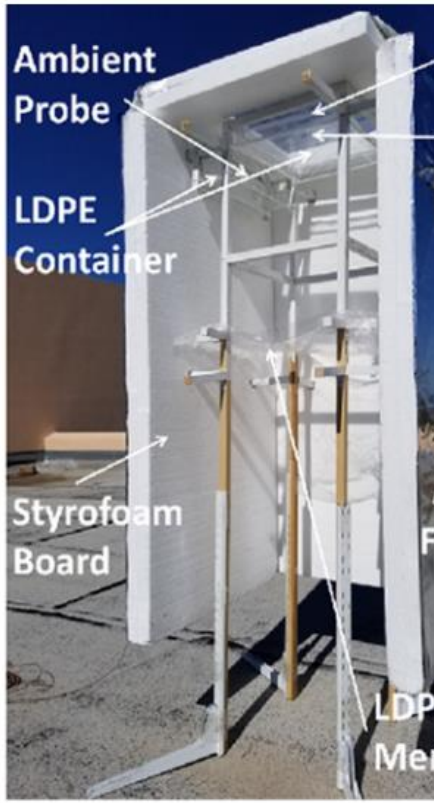












… measuring what?

cooling performance of 5 °C under a solar irradiance of 834 W/m^2

highly selective emissivity of 88.7%

temperature drops of 30 °C compared to black paint

radiative cooling power of 104 W/m^2 under a solar intensity of 671 W/m^2

making the coating 3.3 °C cooler than commercial white paints under a high solar flux of 1100 W/m^2

our $BaSO_4$-acrylic paint shows a figure of merit of 0.77

drop of 4.8 °C was achieved with convection shield

sub-ambient cooling of 2.8 °C for surface cooling and 1.0 °C for space cooling

emitter surface decreased by 21.4 °C comparing to the bare ones at noon

average cooling power of 117 W/m^2

increasing emissivity from 0.9 to 0.97 had little impact

5.5 °C even under solar intensity of 930 W/m^2 and relative humidity of 64%

the net cooling power can reach 59.04 W/m^2 under the conditions of the American standard atmospheric model

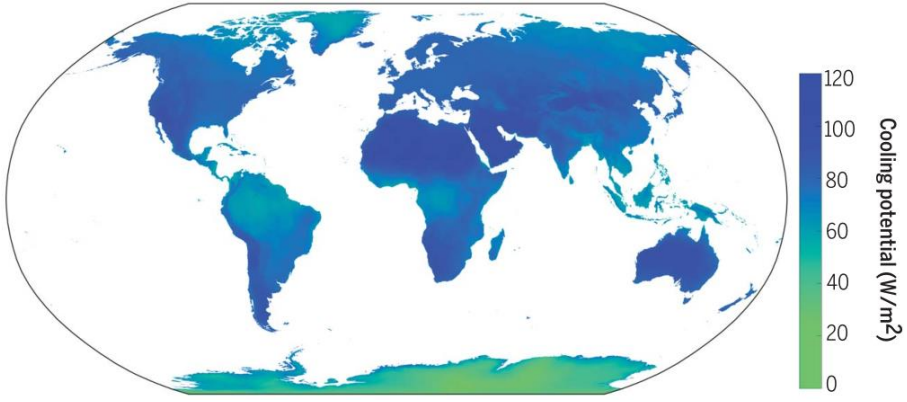
a net cooling power of 19.7 W/m^2 in a non-vacuum setup during the peak daytime with shading

cooling power of 95.1 W/m^2 under direct AM1.5 solar irradiation and dry environment

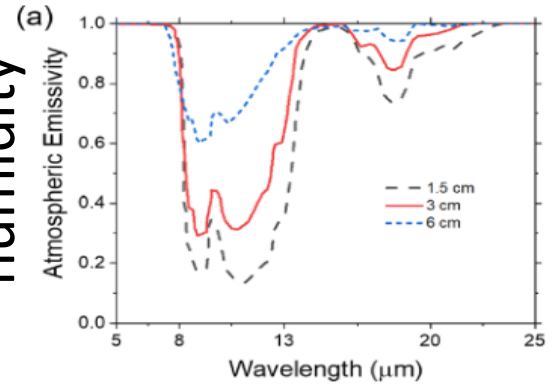
drop by 10.3 °C below the ambient under direct solar irradiation and 1 m/s wind speed

several factors to be considered …

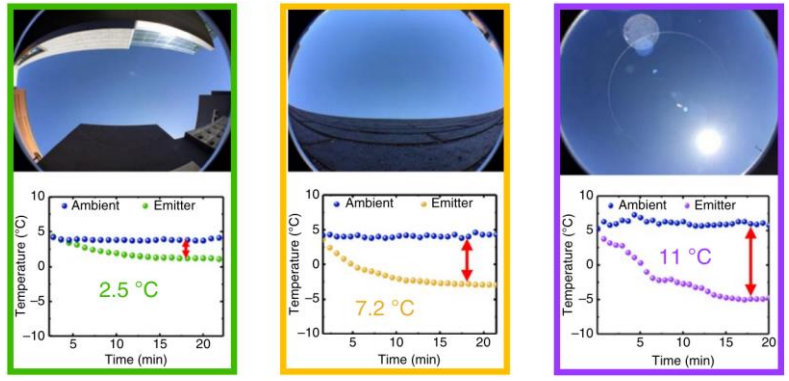
climate



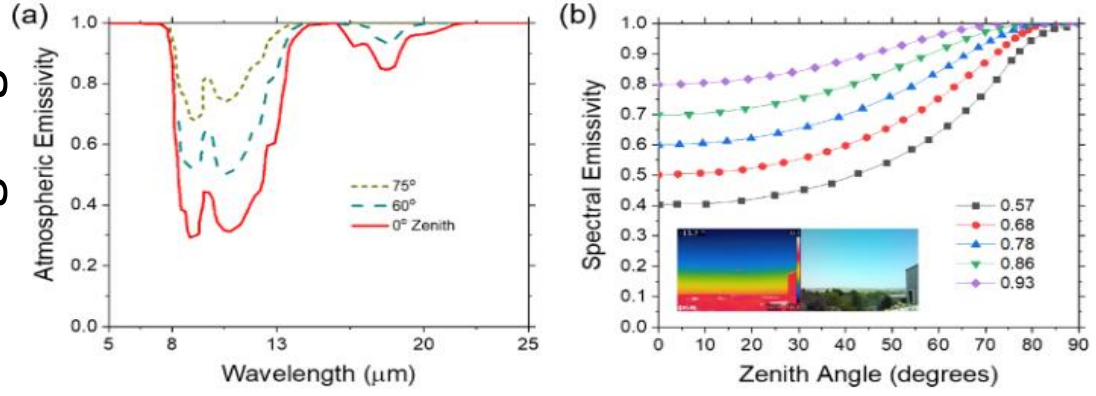
humidity



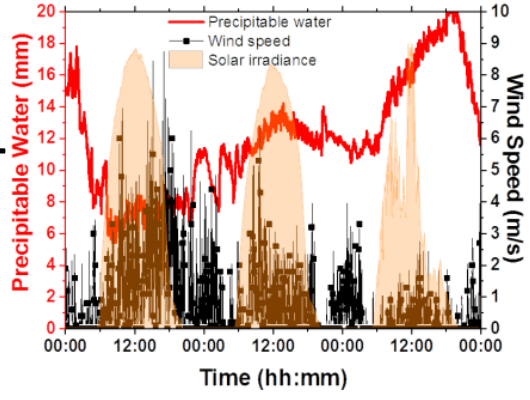
obstacles



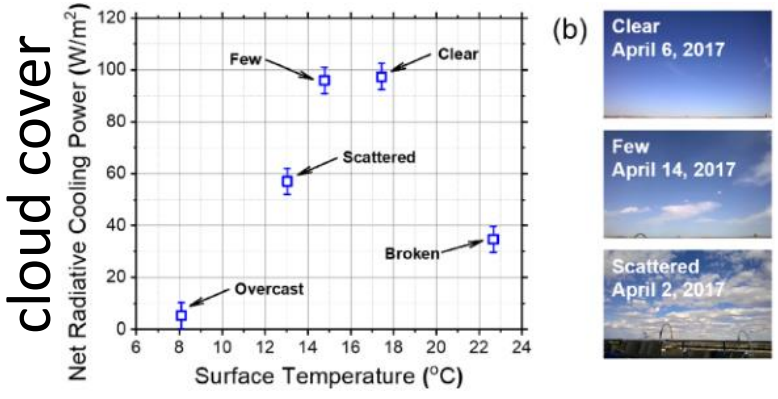
tilting angle



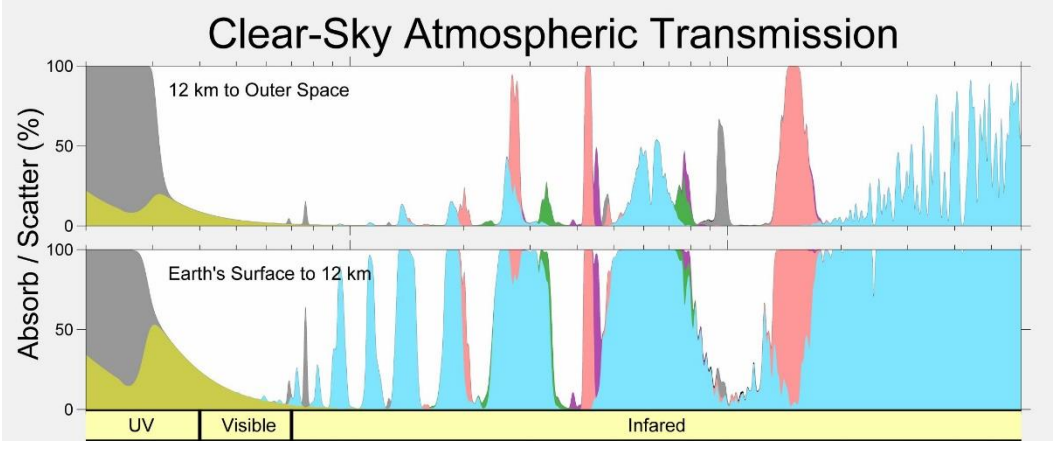
wind speed



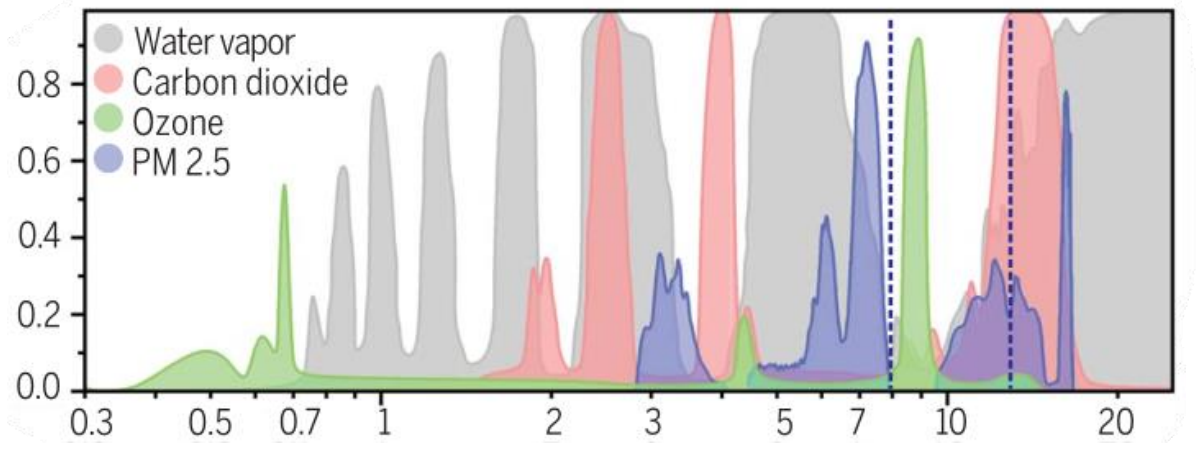
cloud cover



altitude



atmospheric pollution



the PaRaMetric partnership

9 NMIs

INRiM Istituto Nazionale di Ricerca Metrologica
Aalto University School of Science and Technology
CMI Czech Metrology Institute
CSIC Consejo Superior de Investigaciones Científicas
DFM Danish National Metrology Institute
LNE
PTB
RISE
TÜBİTAK

2 Universities

Hellenic Republic National and Kapodistrian University of Athens Est. 1837
Politecnico di Torino 1859

3 research institutes

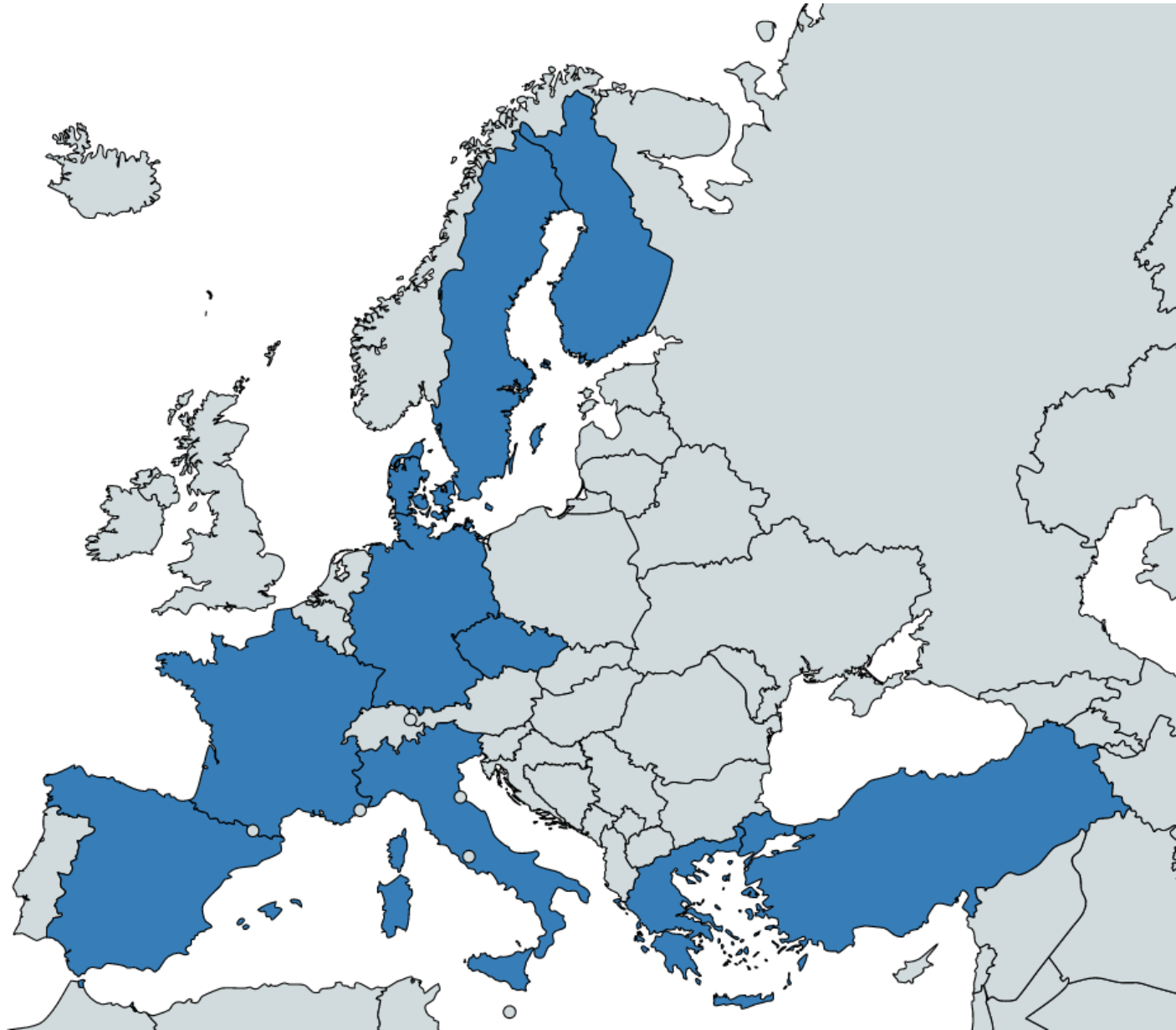
CNR-INO Istituto Nazionale di Ottica Consiglio Nazionale delle Ricerche
FIW München
CAE zero carbon

2 companies

ALMECO GROUP
COOLING PHOTONICS

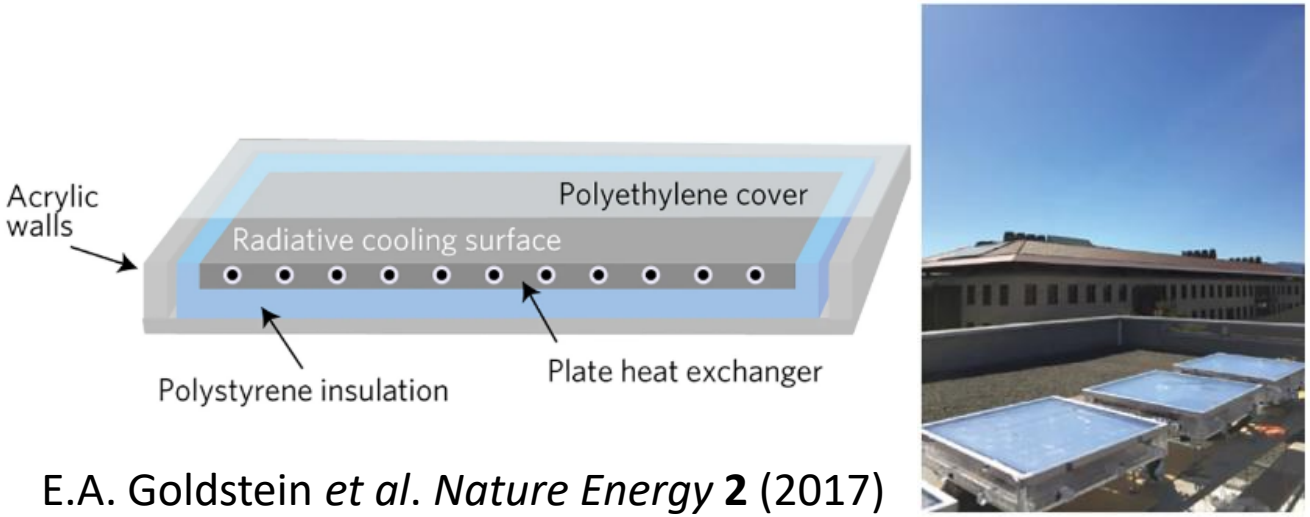
1 association

CTI Energia Ambiente

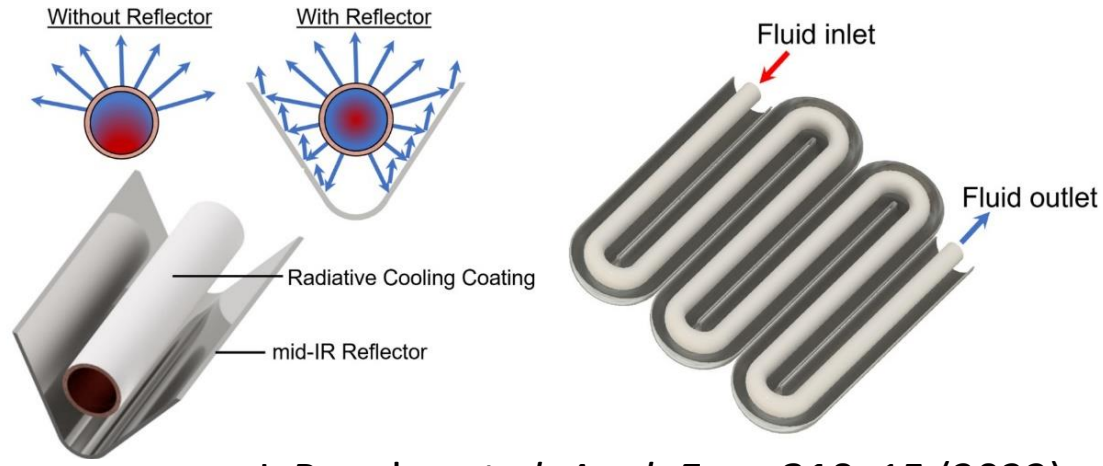


METROLOGY PARTNERSHIP
EURAMET

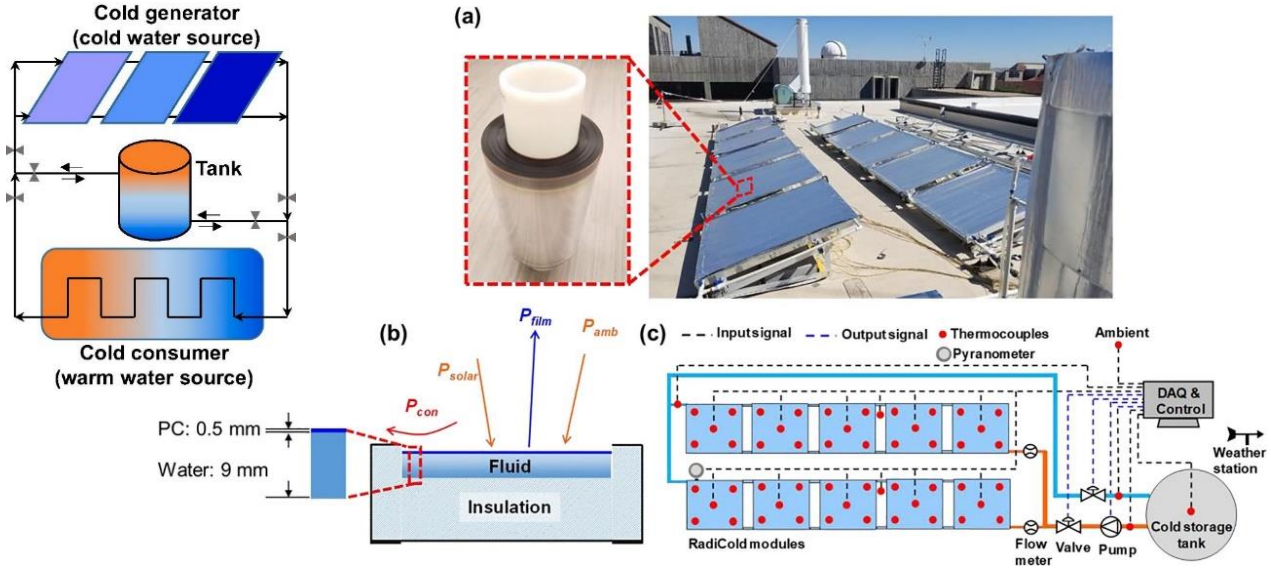
one of many possible applications: cooling of water



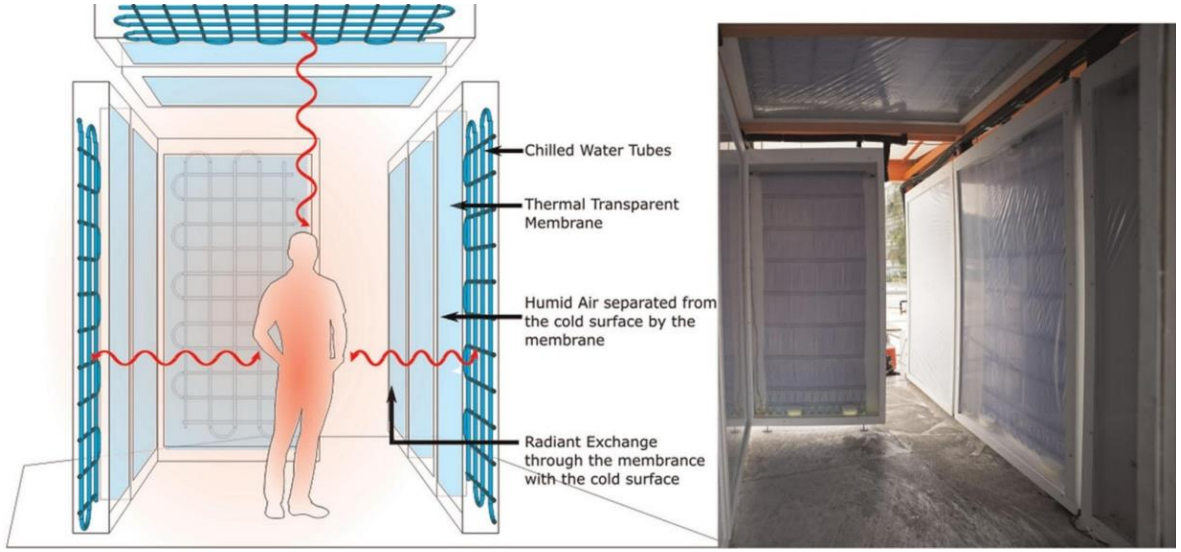
E.A. Goldstein *et al*. *Nature Energy* **2** (2017)



J. Peoples *et al*. *Appl. Ener.* **310**, 15 (2022)

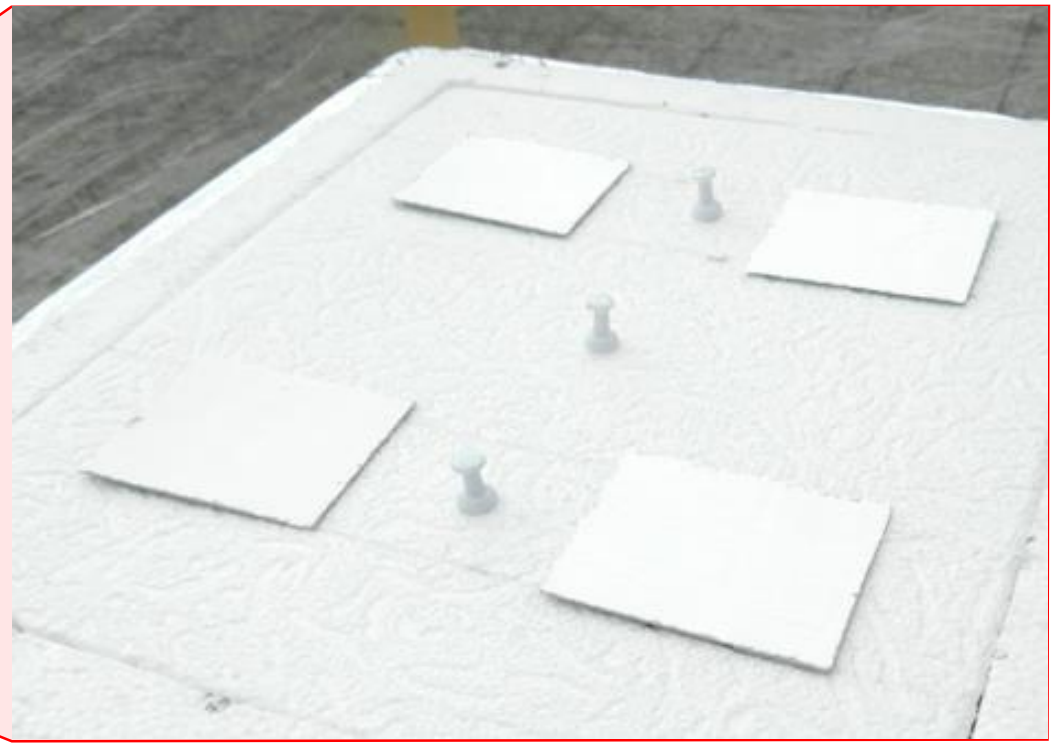


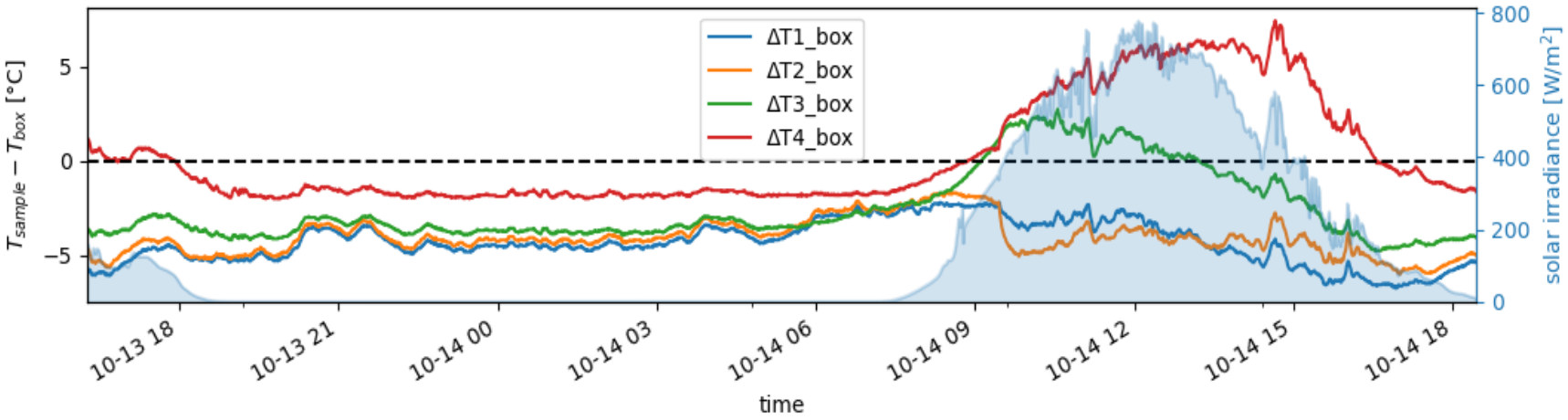
A. Aili *et al*. *En. Conv. Manag.* **186**, 15 (2019)



R. Mokhtari *et al*. Appl. Therm. Eng. **211**, 5 (2022)

experiments in Florence





G.E. Lio

J. Werlé

grazie!

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