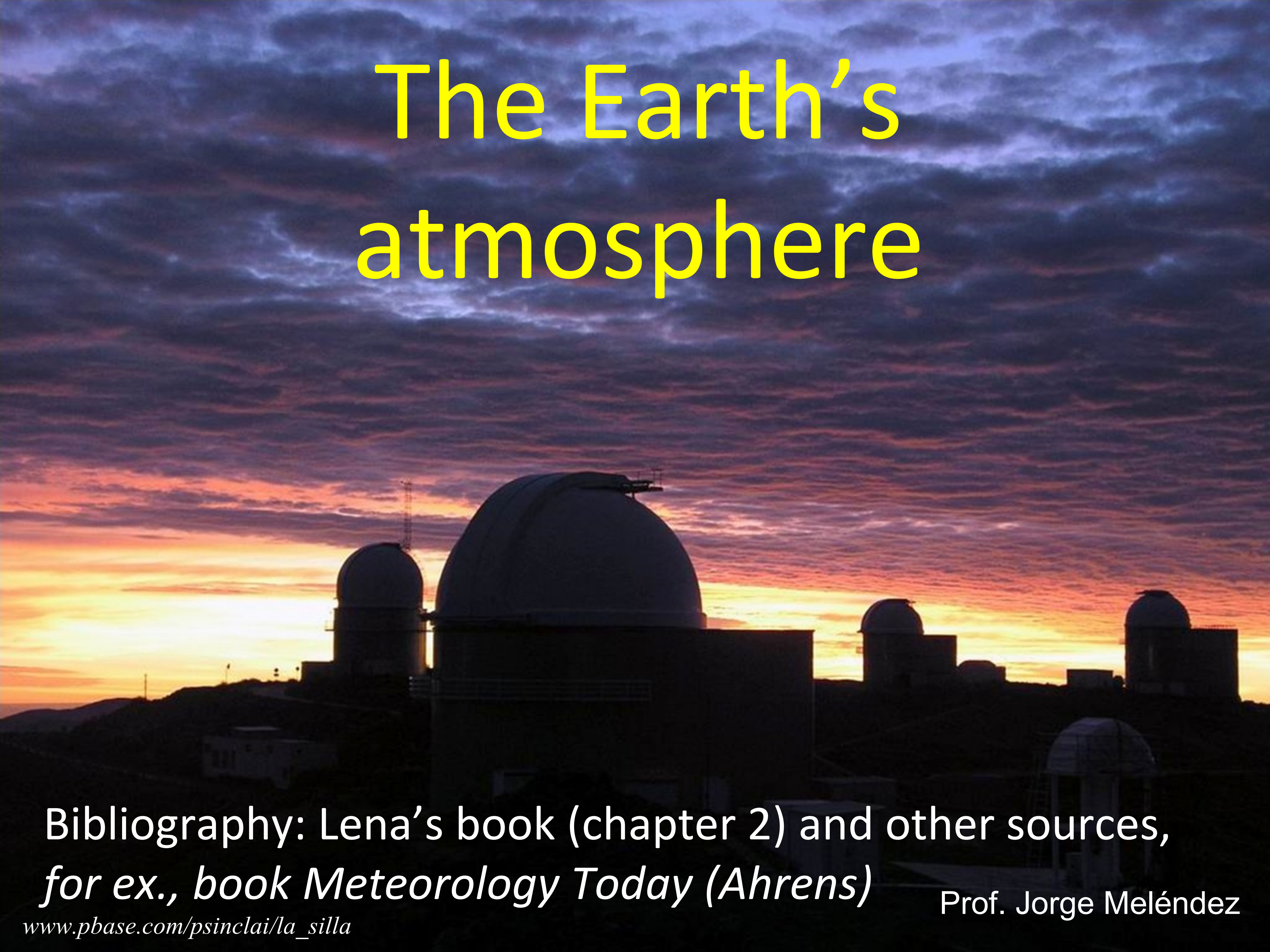


# The Earth's atmosphere

Bibliography: Lena's book (chapter 2) and other sources,
*for ex., book Meteorology Today (Ahrens)*

Prof. Jorge Meléndez

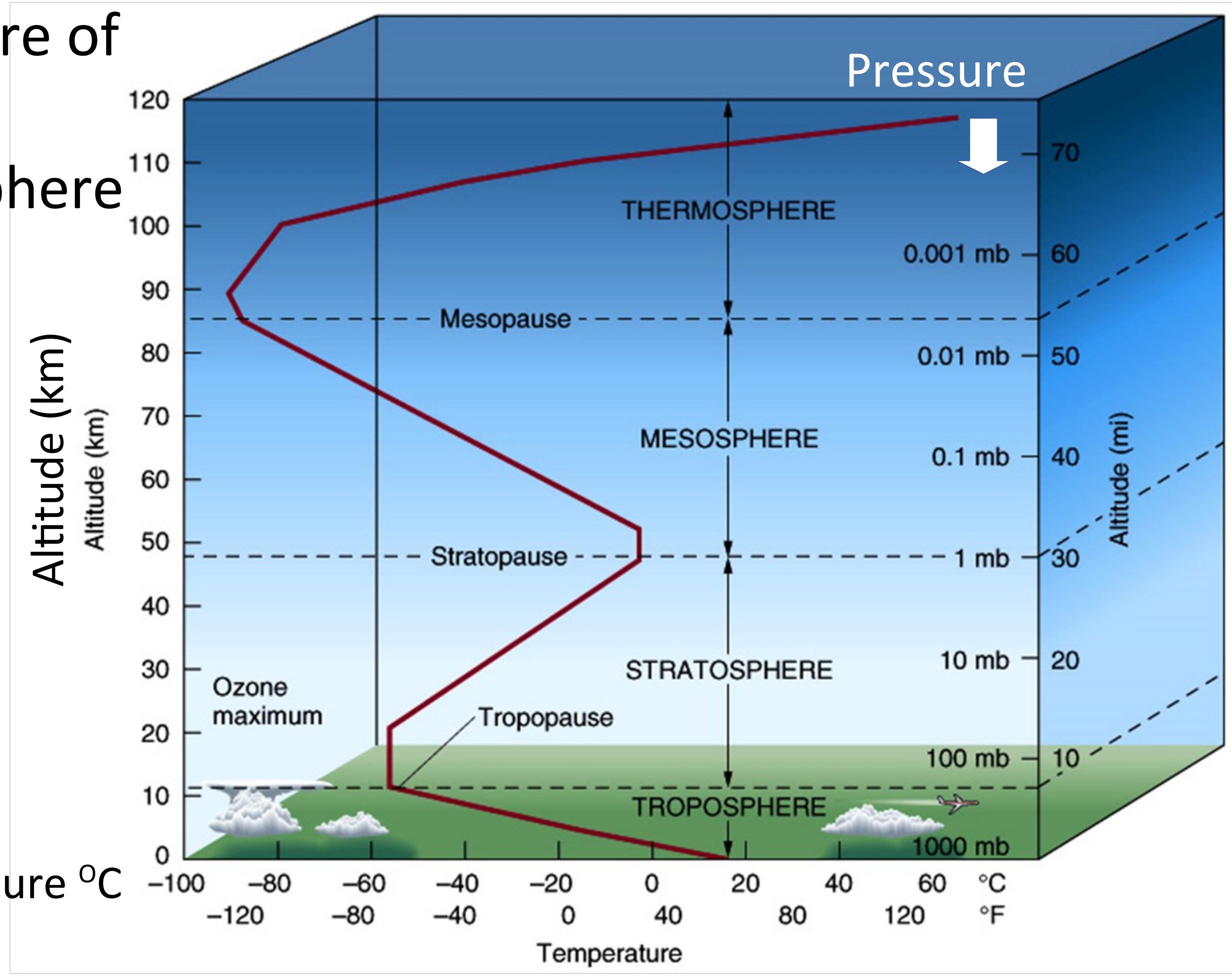
*www.pbase.com/psinclai/la_silla*

# Earth's atmosphere is a fine layer of gas that surrounds Earth and that is kept by gravity

© Meteorology Today (Ahrens)

• FIGURE 1.2 The earth's atmosphere as viewed from space. The atmosphere is the thin blue region along the edge of the earth.

# Structure of Earth’s atmosphere




Temperature $^{O}$C

burro.cwru.edu/Academics/Astr201/Atmosphere/atmosphere1.html

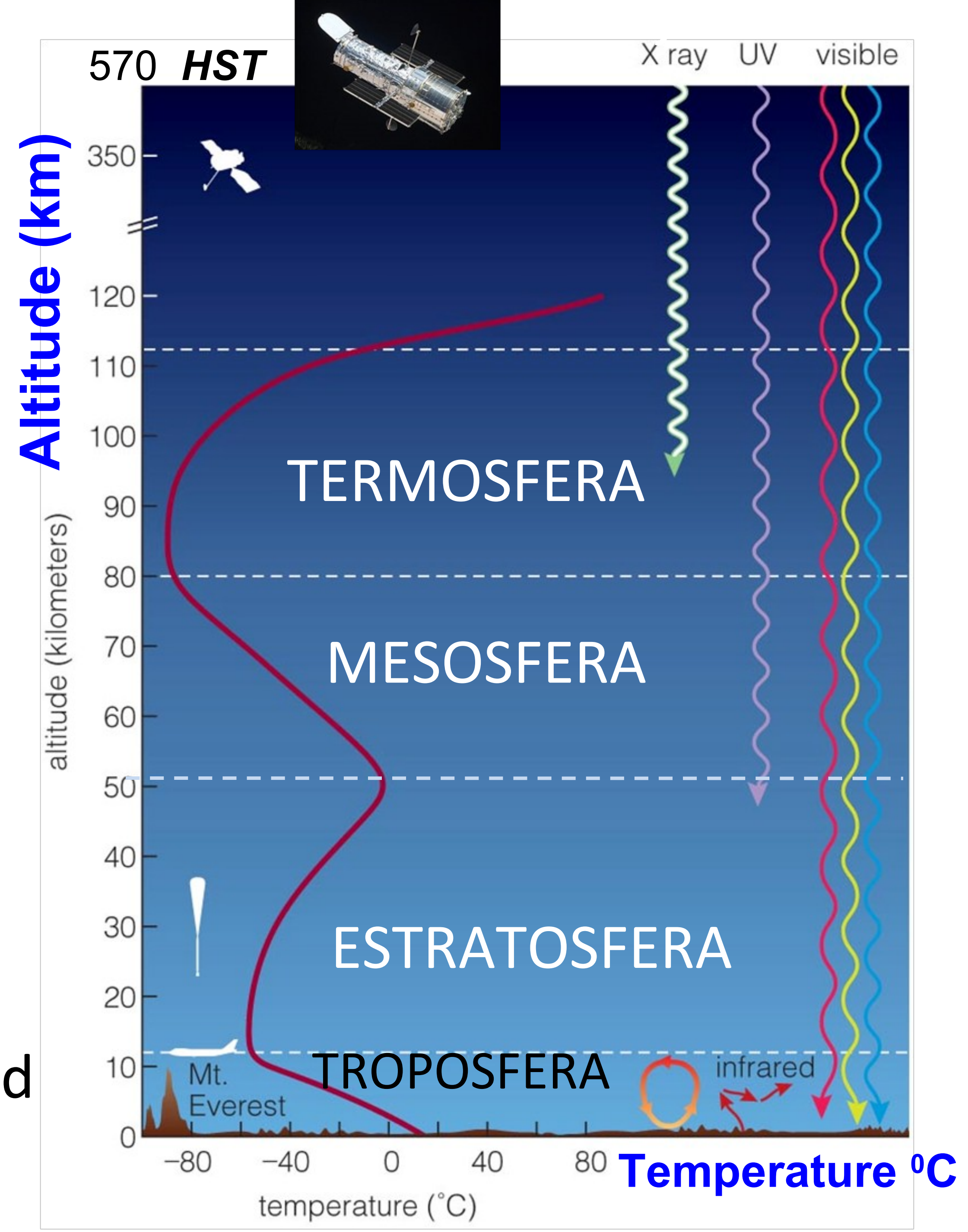
# Temperature profile

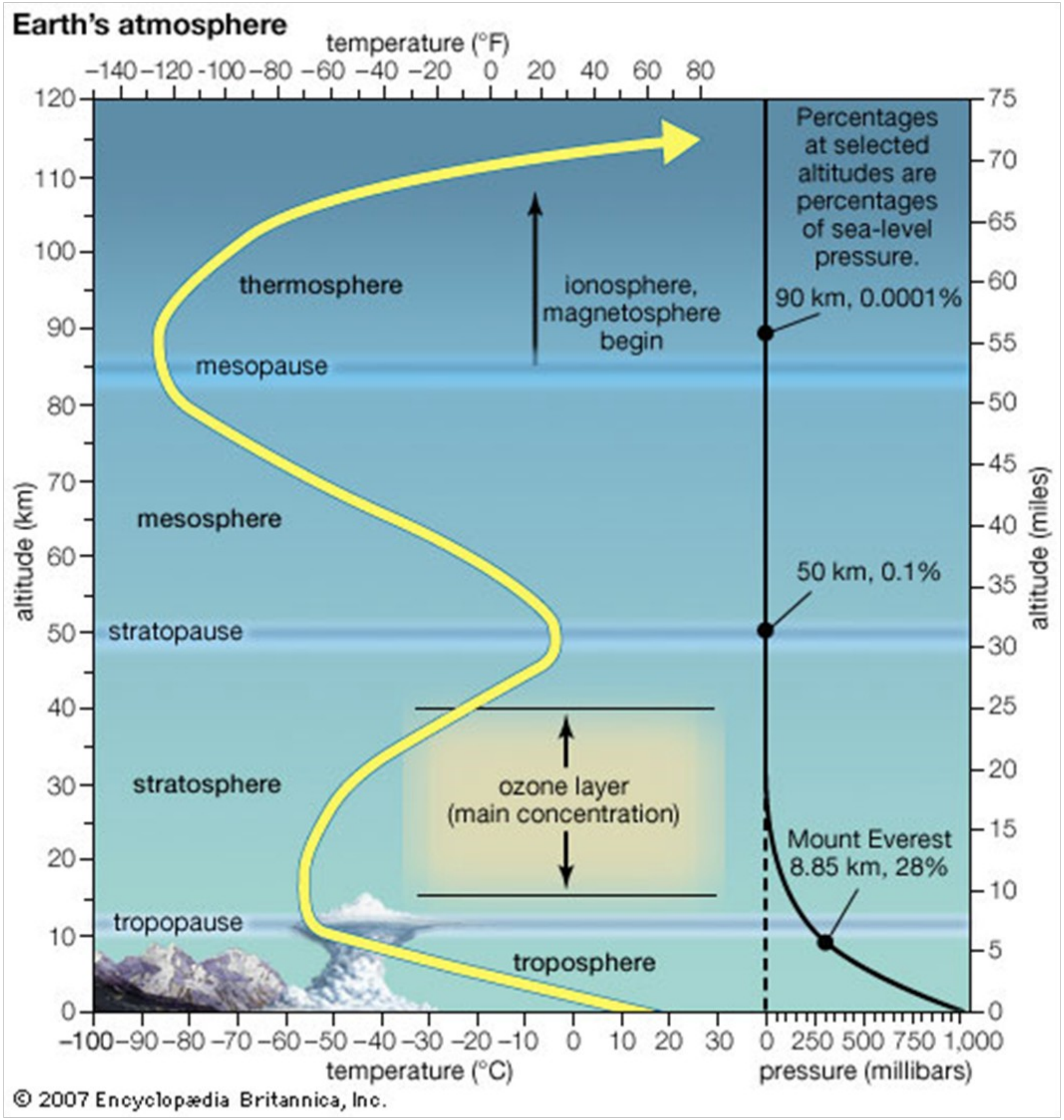
Solar UV light and X-rays heat and ionize gas

Ozone decreases

Warm by ozone UV absorption

Warm by the ground and convection







# Pressure:

decrease exp. with height z

$$P(z) = P_0 \exp(-z/H)$$

H: height scale ($=RT_m/M_0 g$)

Chemical composition aprox. constant until 90 km

$$\rho = \frac{MP}{kT}$$

$H = RT_m/M_0g$

(scale height)

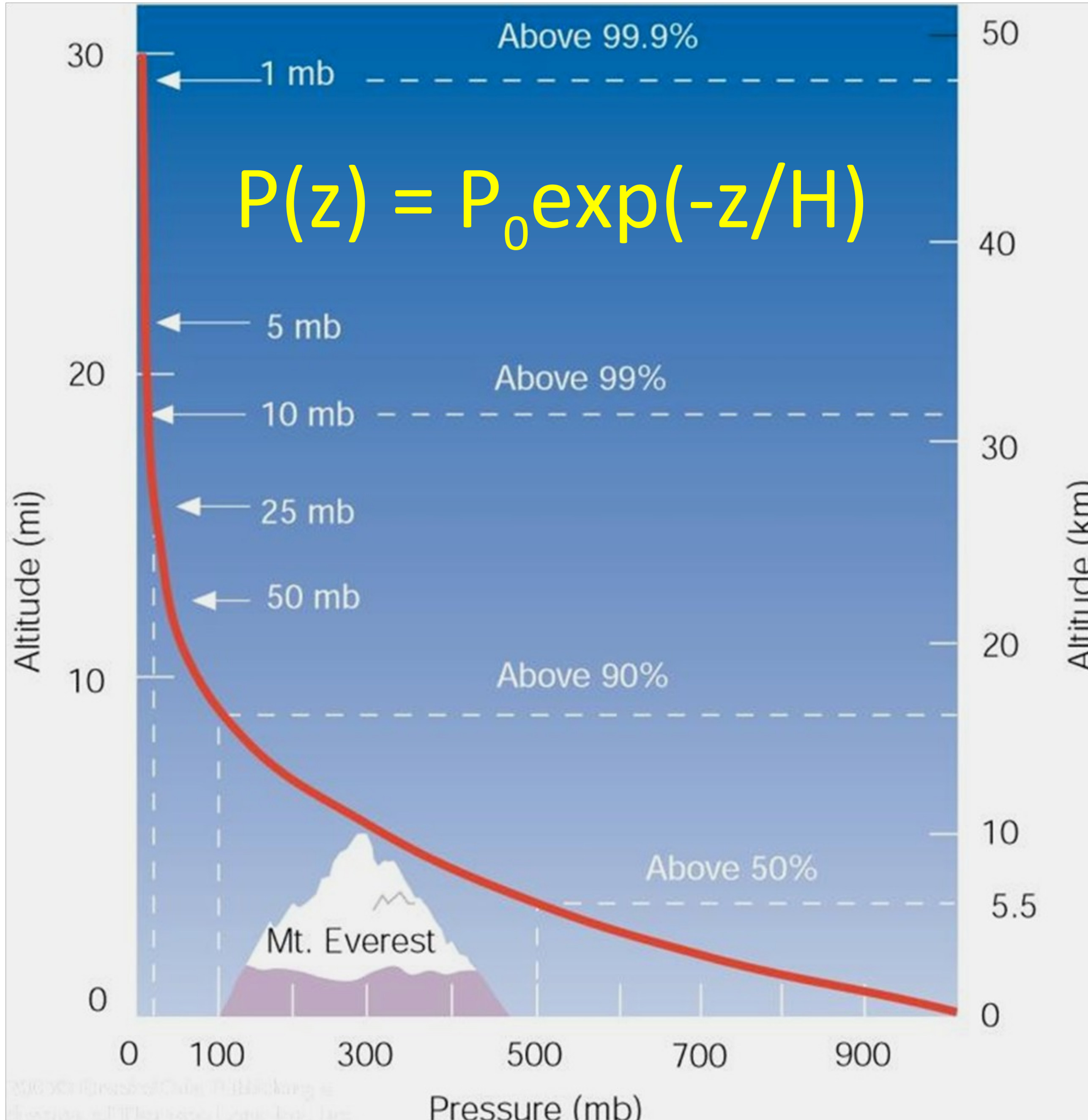
R: gas constant ($8.23\ J\ K^{-1}\ mol^{-1}$)

$T_m$: mean temp. ($0^0$ C)

$M_0$: mean mol. mass (0.029kg)

g: gravity

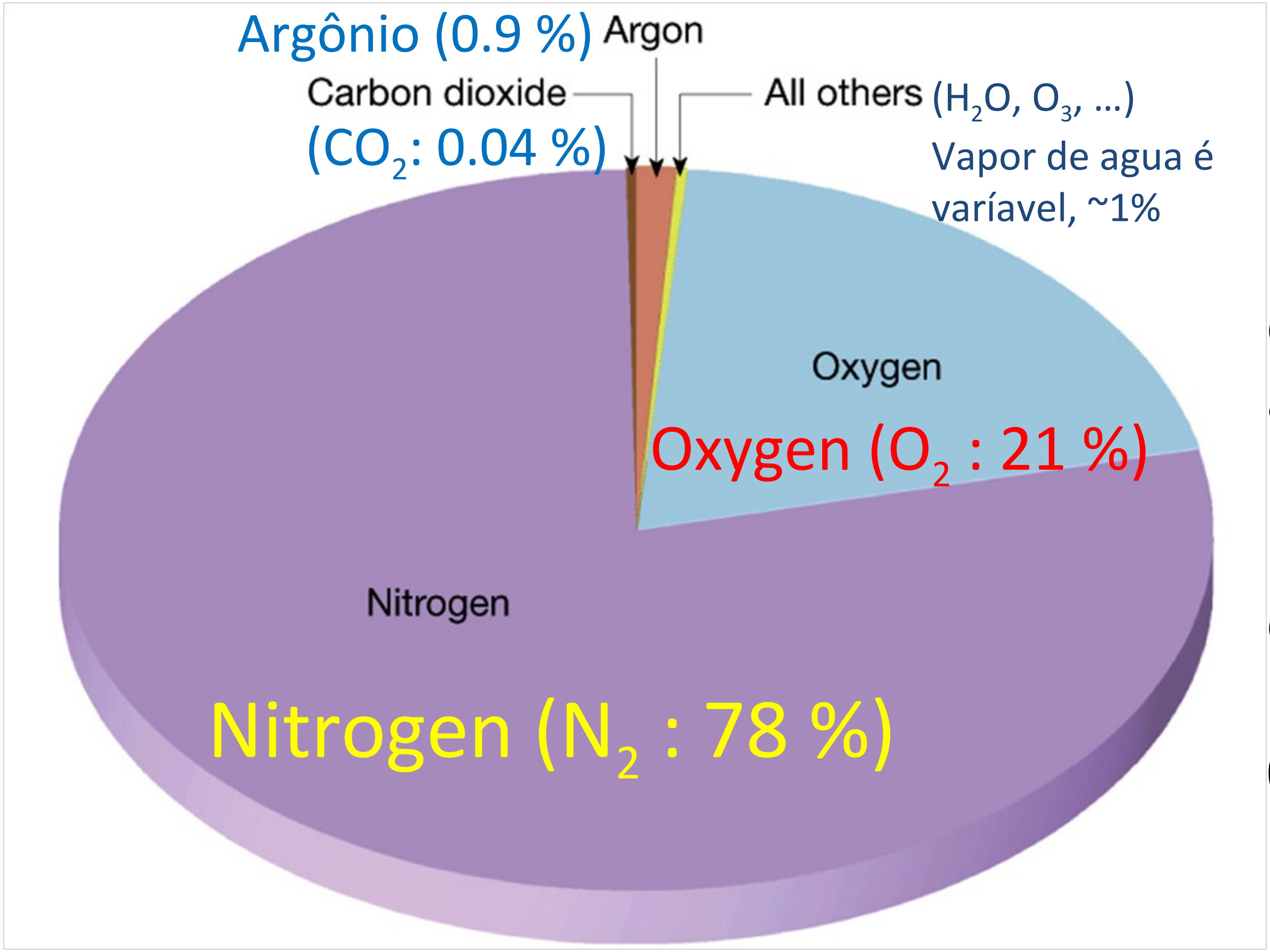
**H = 8 km**




1 bar = $10^5$ Pa

1 atmosfera = 1,01 x $10^5$ Pa

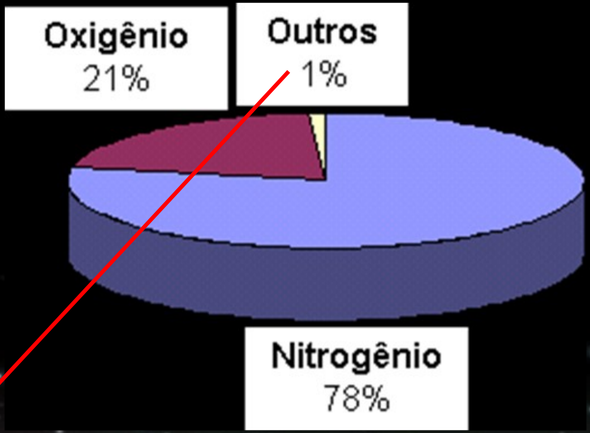
# Constituents of the atmosphere



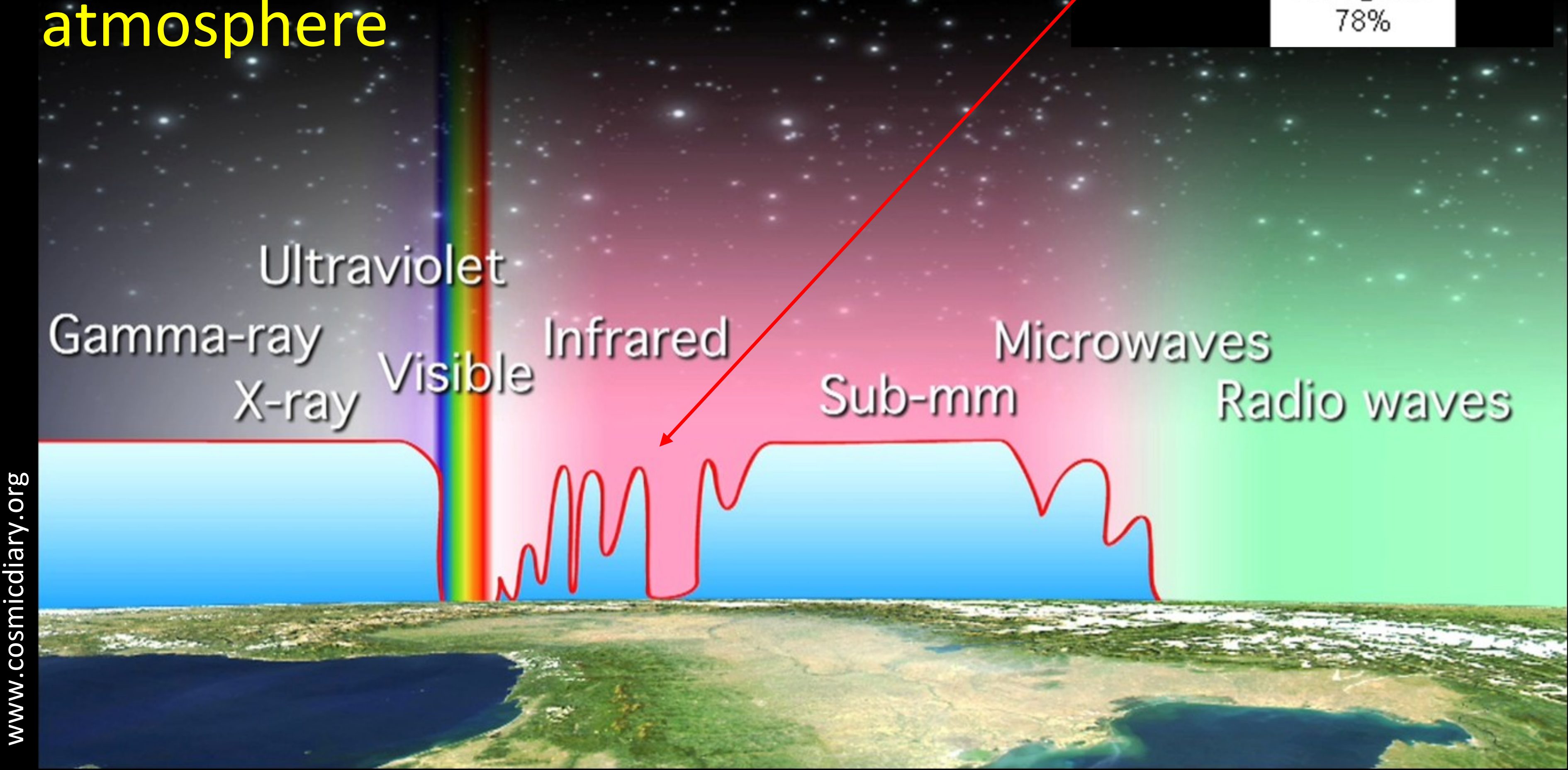

N & O are the main constituents and its proportion is relatively constant between 0-90 km

# Constituents of the atmosphere

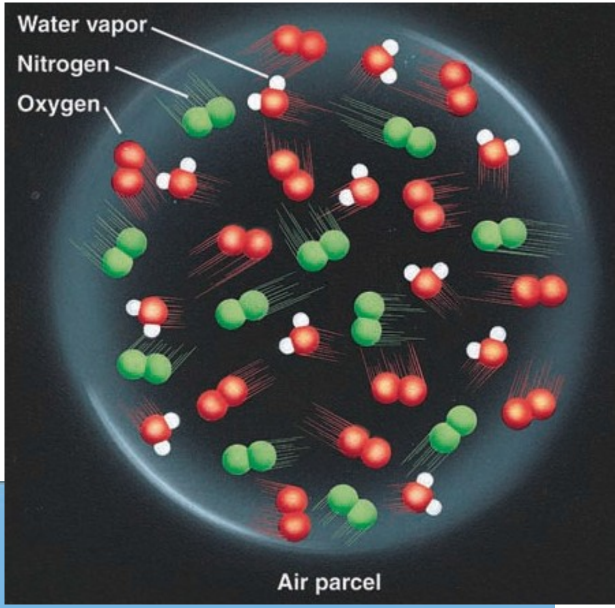
($CO_2$, $H_2O$, $O_3$,…)

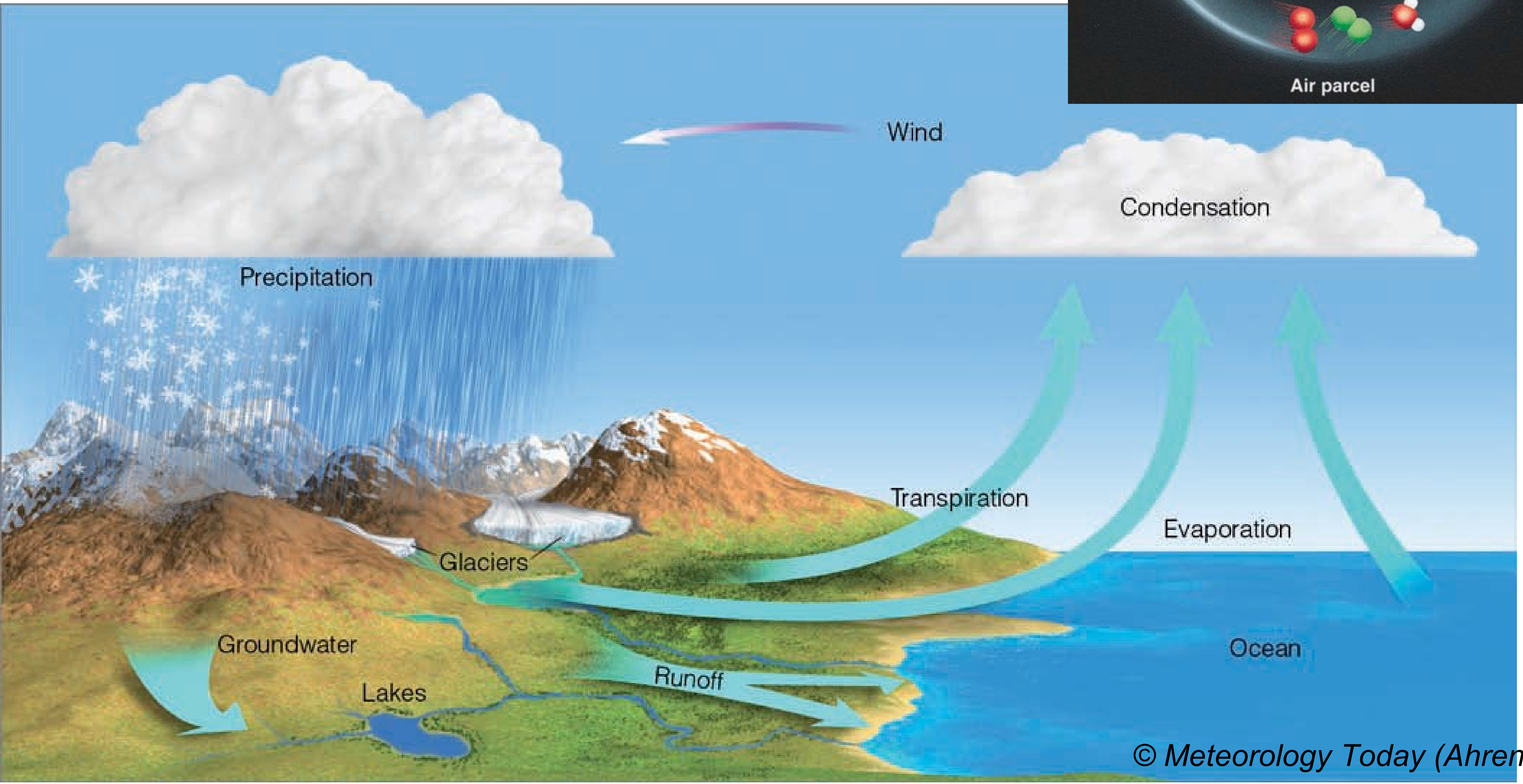



The minor (and variable) constituents are important sources of opacity in the atmosphere



# **Water vapor**: one of the most important sources of opacity



# Measurement of the water vapor content

The *fractional content*, *mixing ratio*, or *specific humidity* is:

$$r = \frac{\text{mass of } H_2O \text{ per m}^3}{\text{mass of air per m}^3}$$

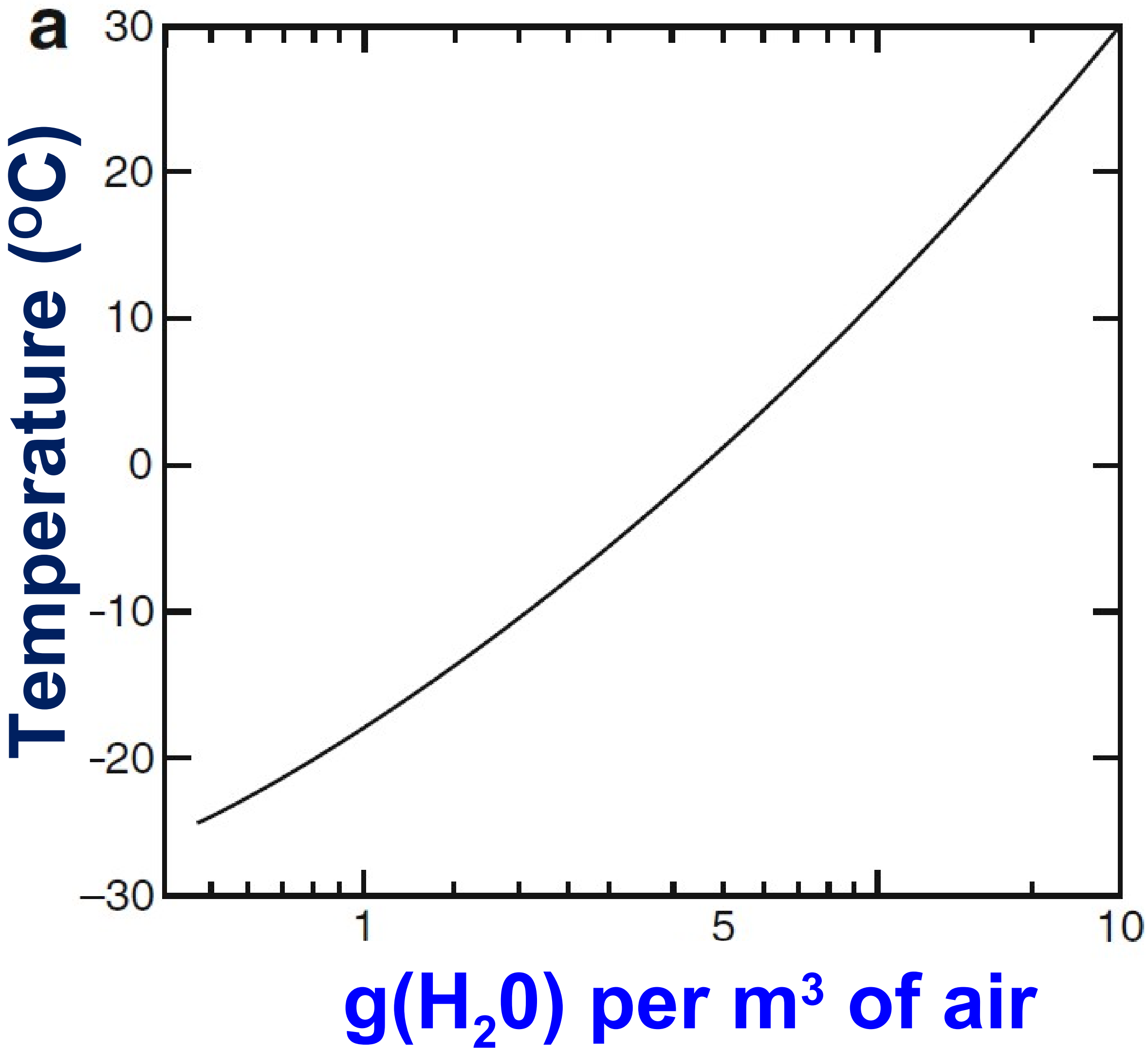
- $0 < r \leq r_s(T)$ (saturation)

$[r]$ = g/Kg

Very sensitive to:

- Temperature
- z (altitude)
- Latitude
- time

# Mass concentration of water vapor per volume of saturated air at normal pressure vs. temperature



# Mixing ratio vs. latitude

$$r = \frac{\text{mass of } H_2O \text{ per m}^3}{\text{mass of air per m}^3}$$

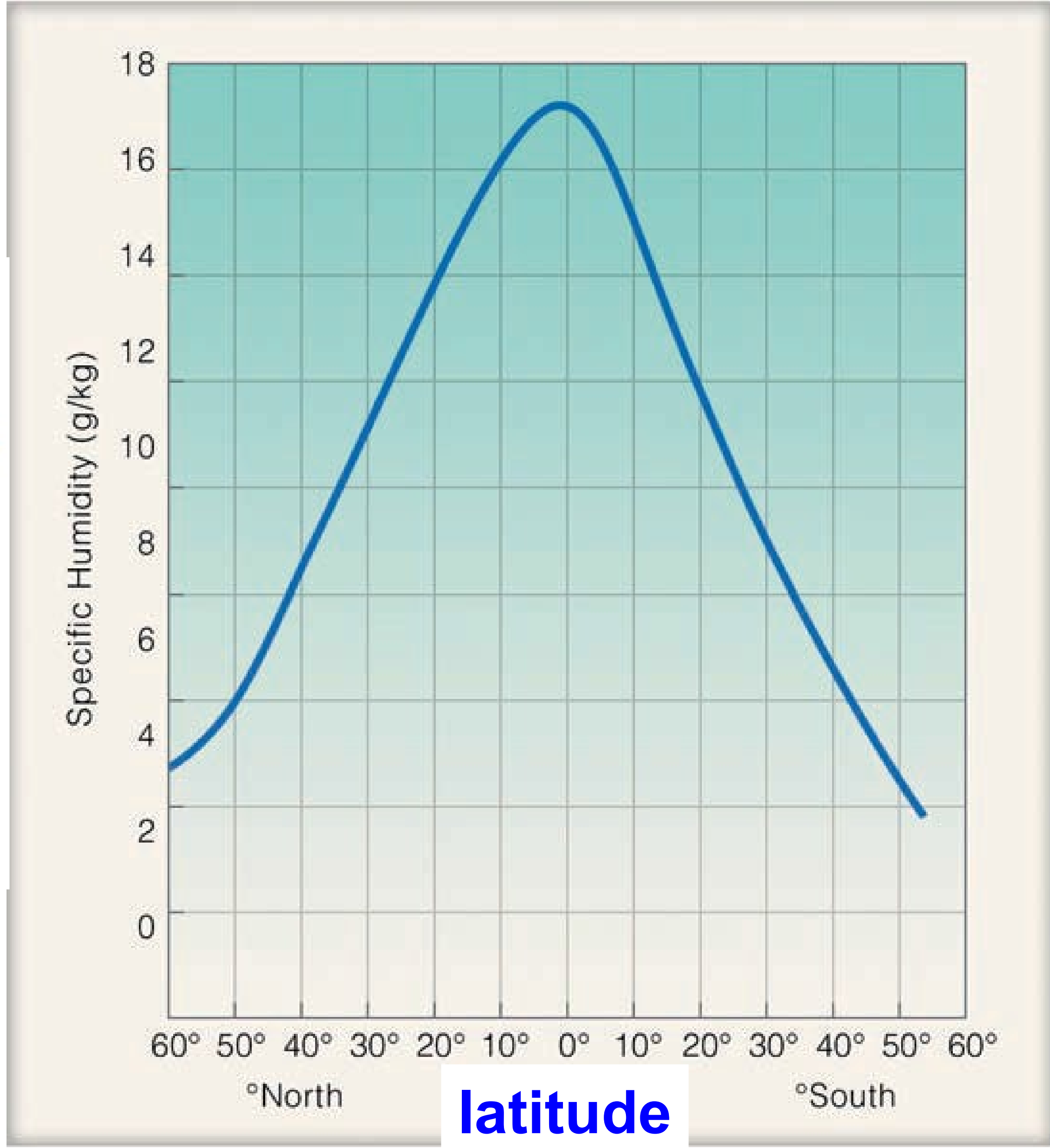
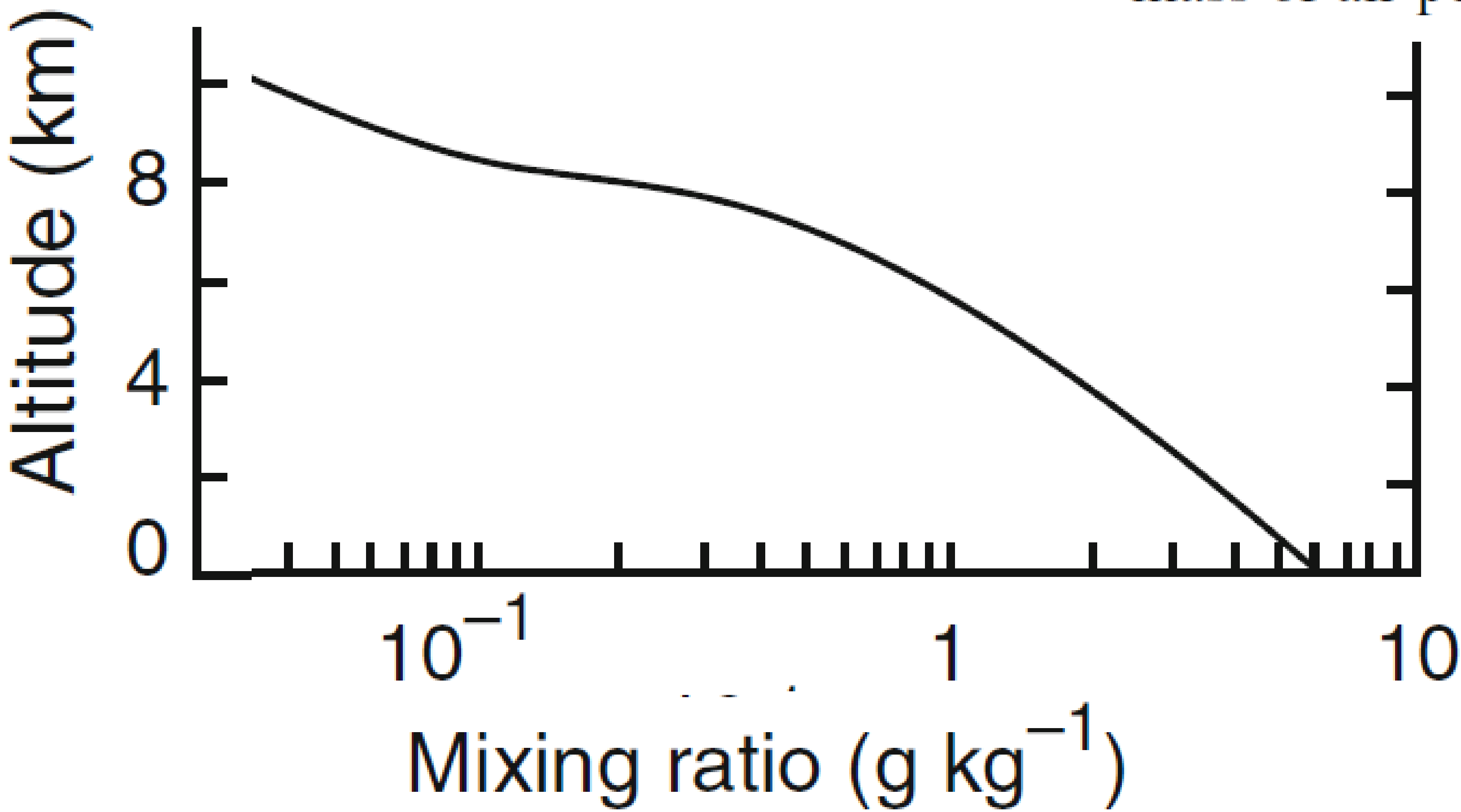



FIGURE 4.9 The average specific humidity for each latitude.

# Concentration of water vapor as a function of altitude

$$r = \frac{\text{mass of } H_2O \text{ per m}^3}{\text{mass of air per m}^3}$$



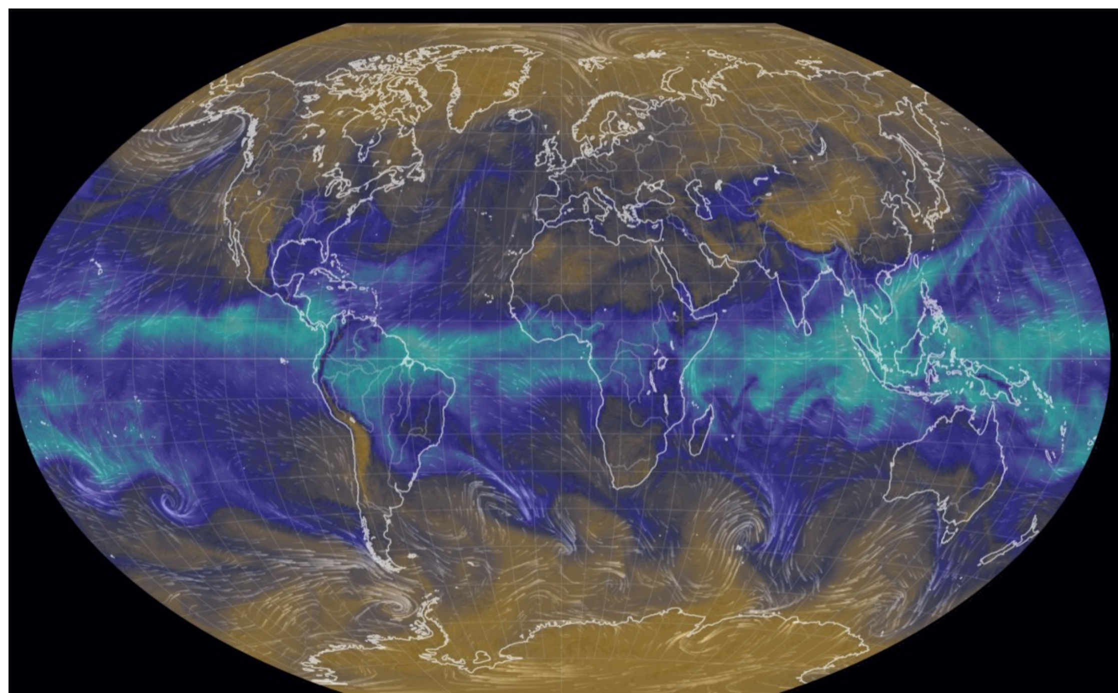
# Column of precipitable water vapor above altitude $z_0$

$$h_{\mathrm{H_2O}}\ [\mathrm{cm}] = \rho_0\ [\mathrm{g\,cm^{-3}}] \int_{z_0}^{\infty} r(z) e^{-z/H}\, dz,$$

where $\rho_0$ is air density at $z_0$

*r(z)* changes rapidly: scale height of water vapor is 3km << dry air (8 km)

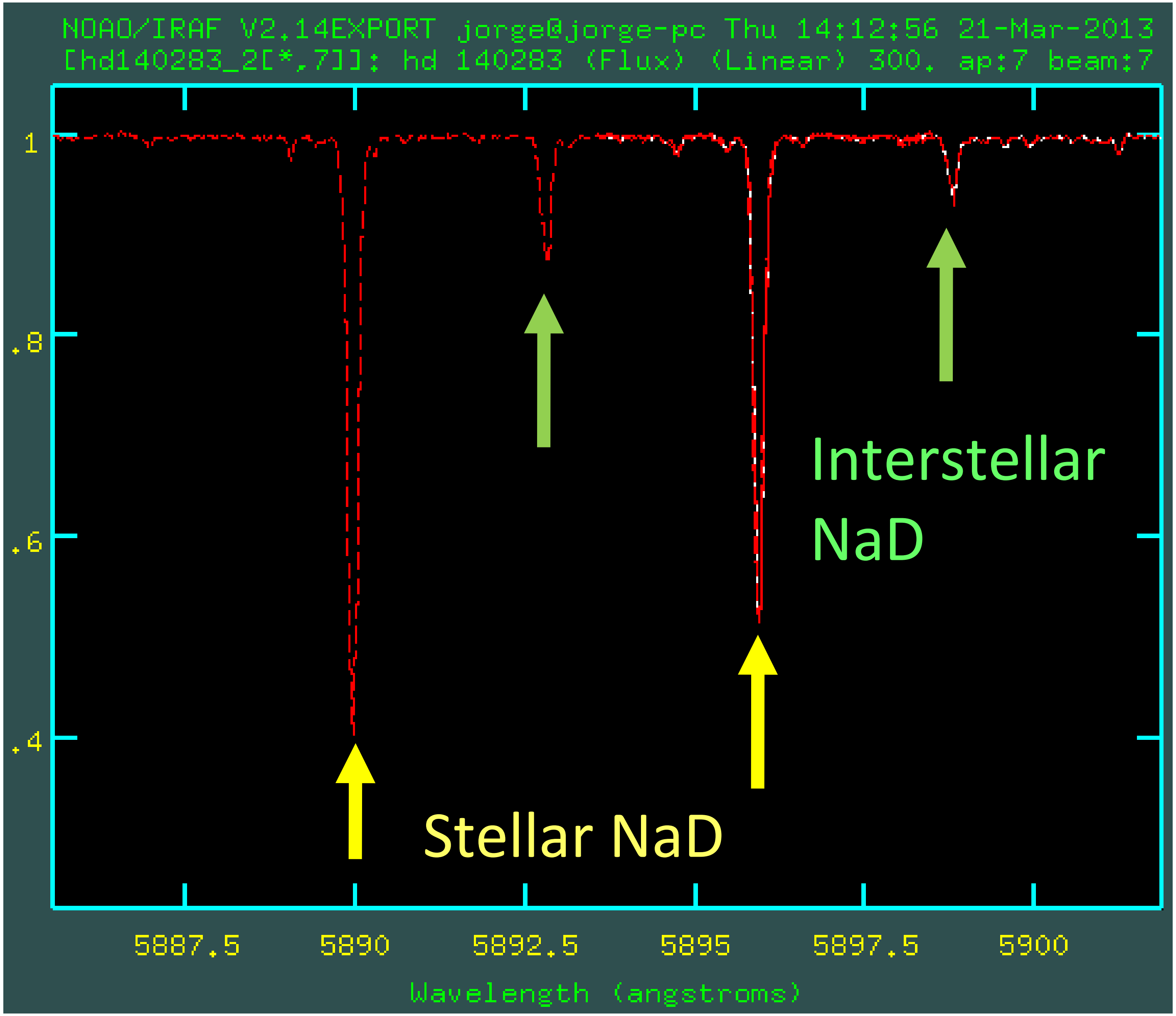
Global map of precipitable water 3/5/2022



https://earth.nullschool.net/#current/wind/surface/level/overlay=total_precipitable_water/winkel3/

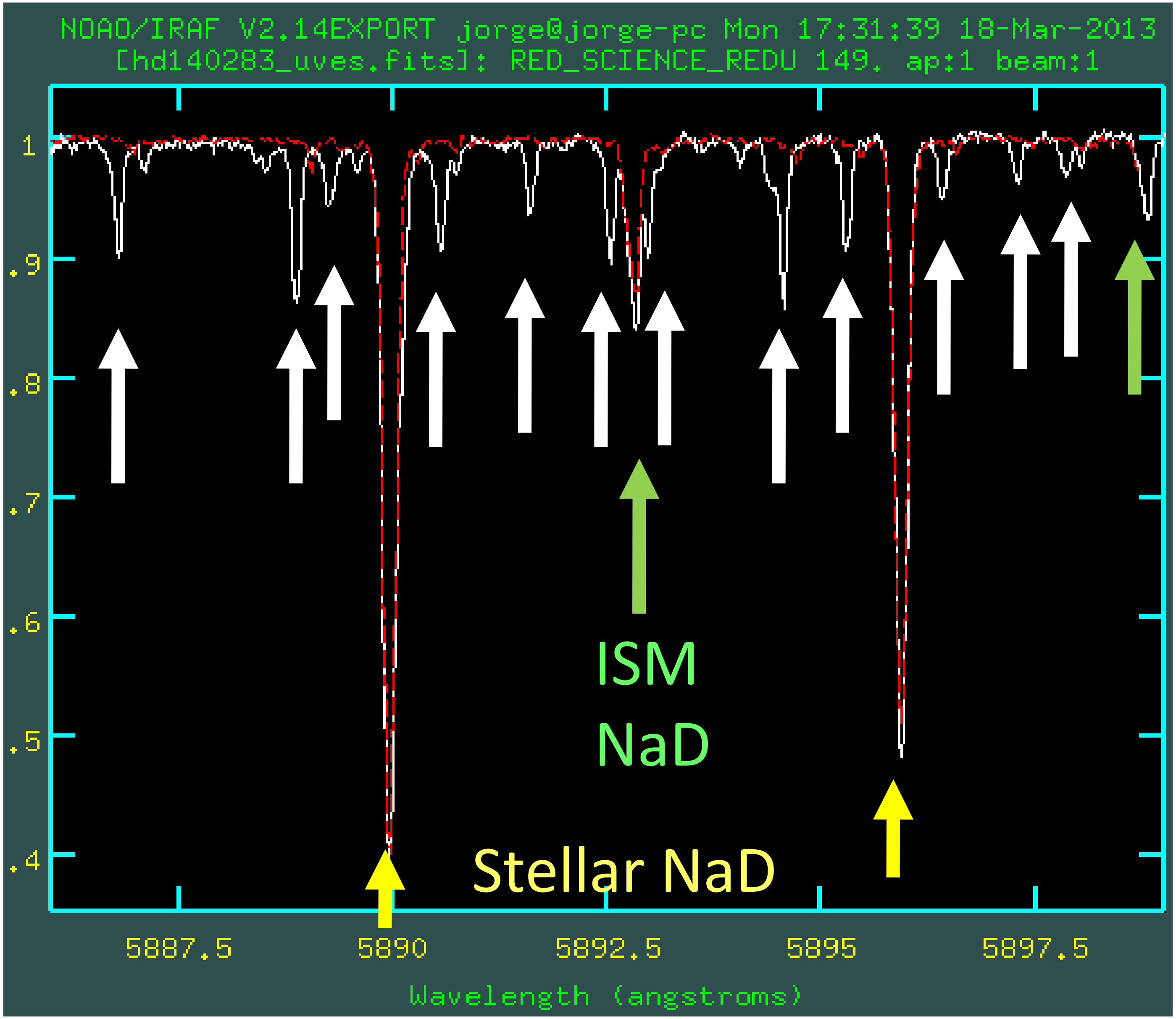
# Comparison of water vapor at 2 diferent observatories

# Keck (4.2km) spectrum of HD140283

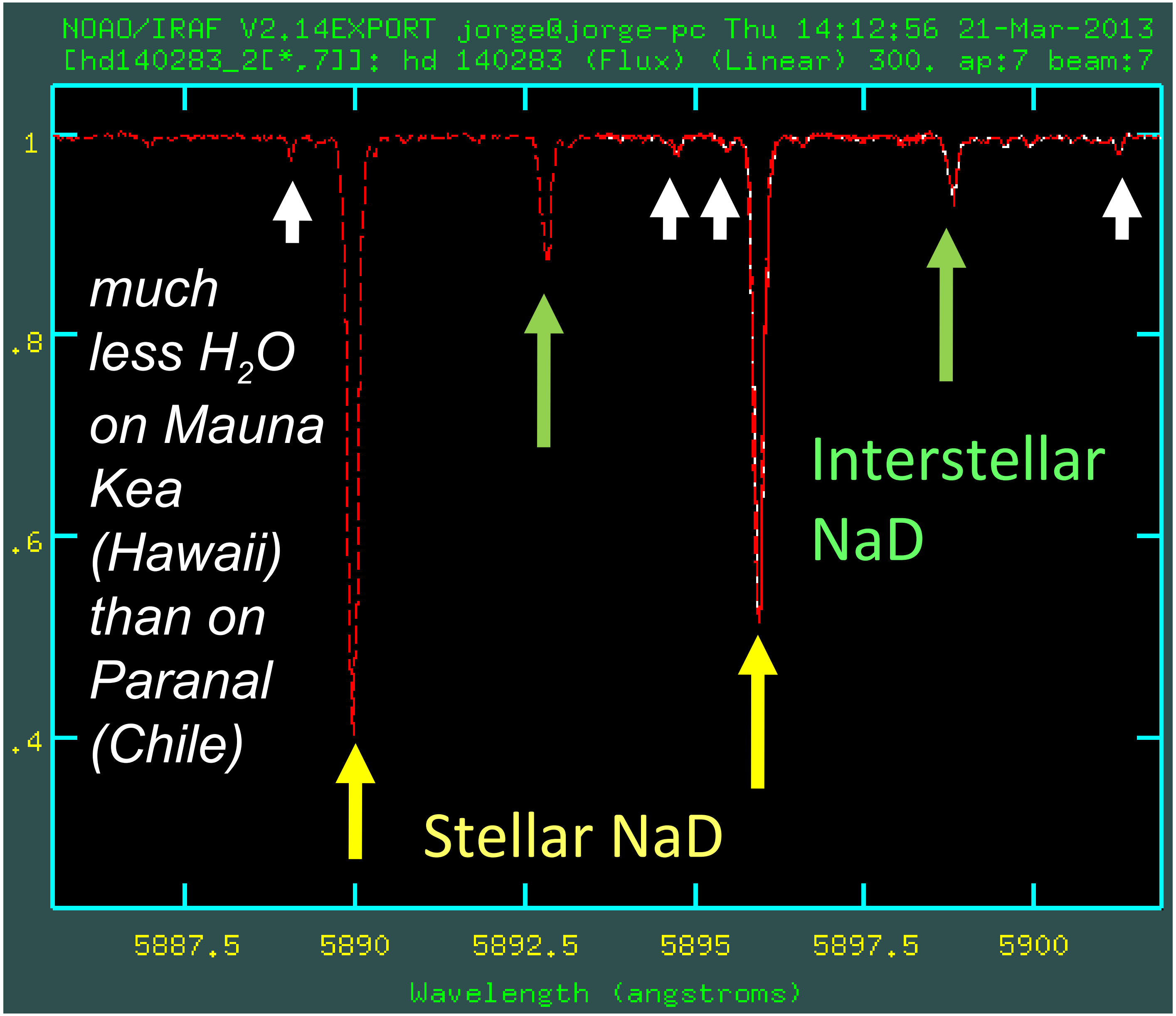


# Keck (4.2km) vs. VLT (2.7km)

Water vapor clearly present on Paranal (VLT)



# Keck (4.2km) spectrum of HD140283

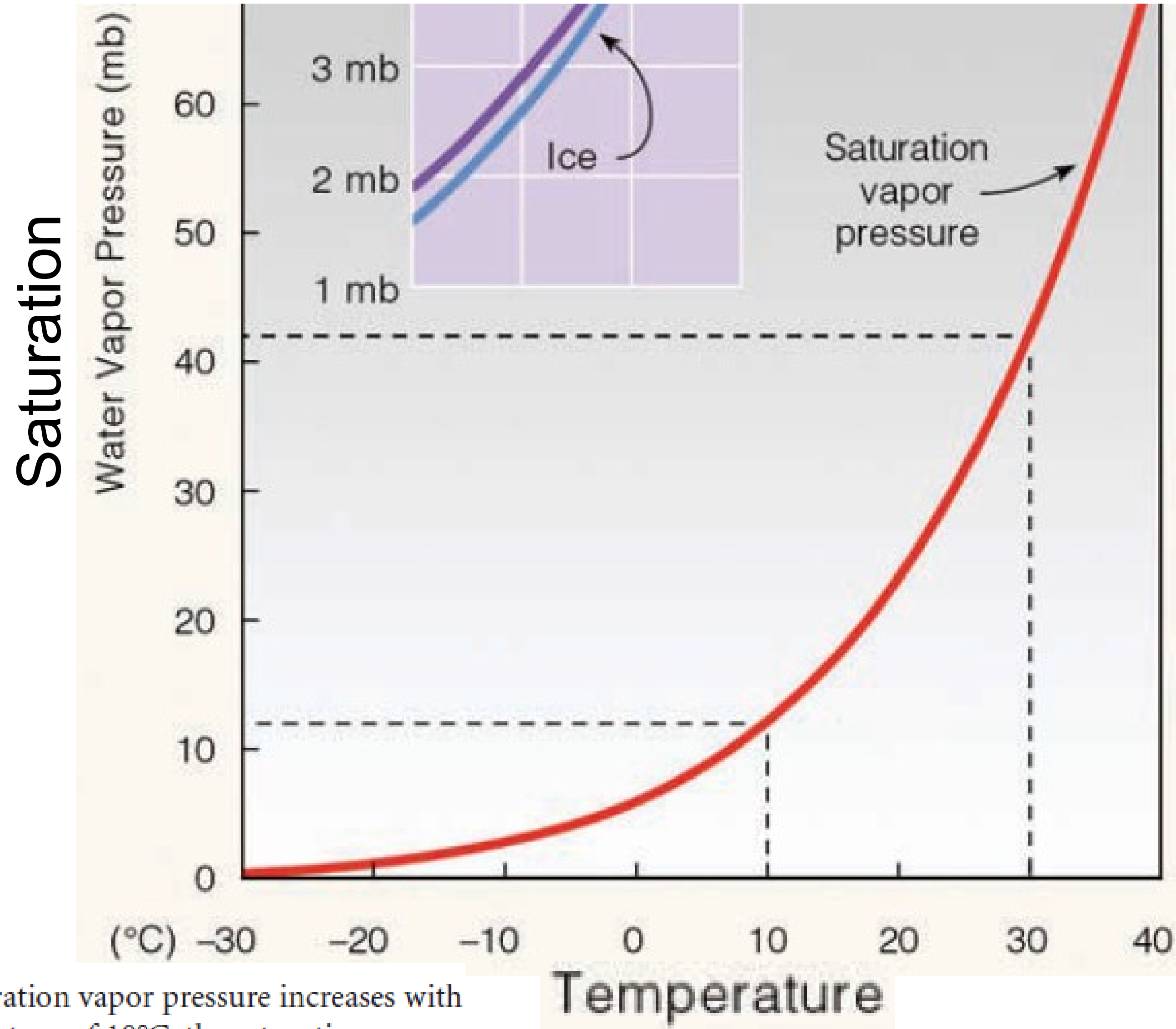


# Umidade relativa
# (Relative humidity: RH)

$$\mathrm{RH} = \frac{\text{water vapor content}}{\text{water vapor capacity}}$$

$$\mathbf{RH} = \frac{\textbf{water vapor content}}{\textbf{Maximum water vapor content for saturation at a given T}}$$

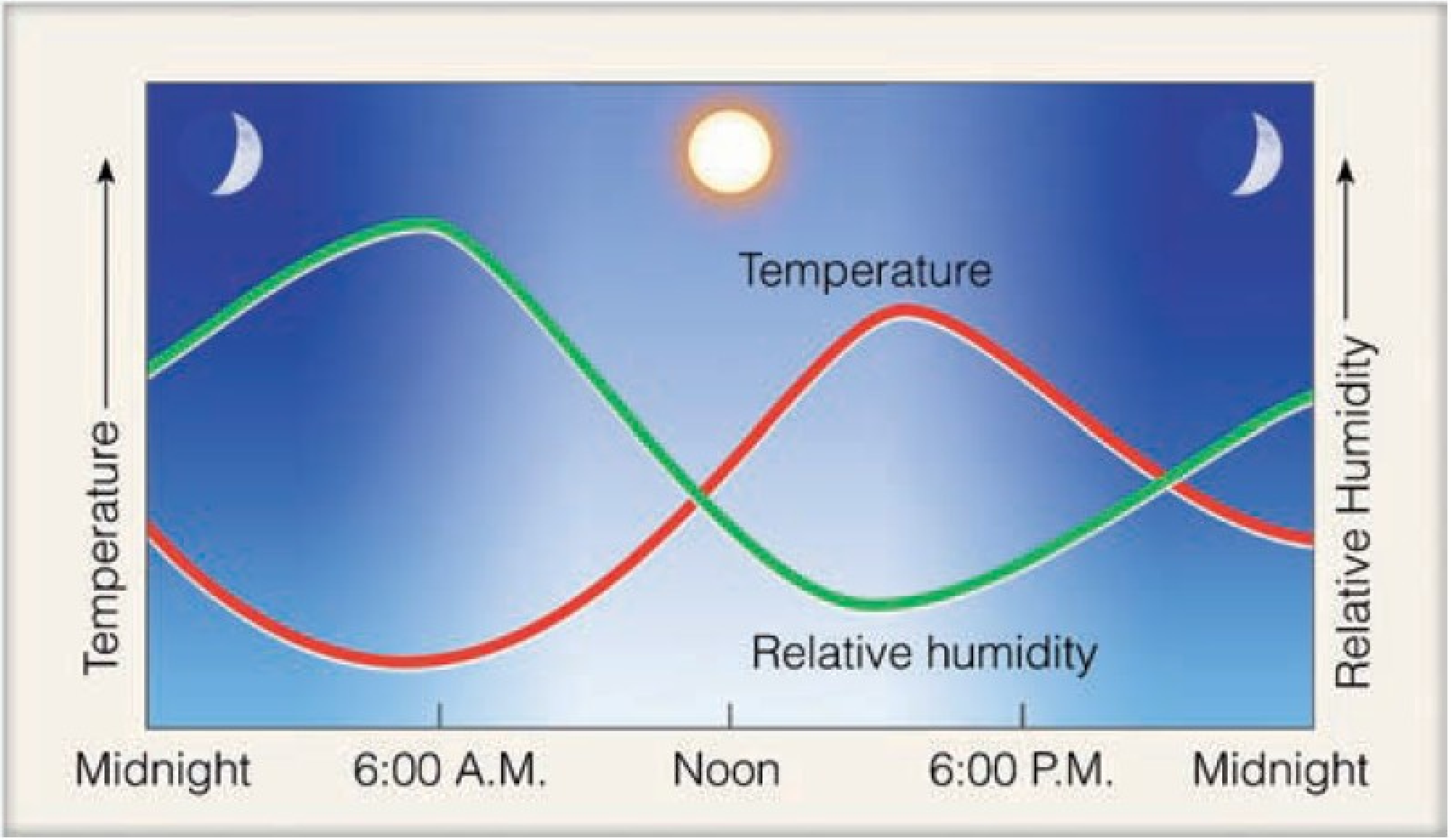
$$\text{RH} = \frac{\text{Water vapor content}}{\text{Maximum water vapor content for saturation}}$$






ACTIVE FIGURE 4.10 Saturation vapor pressure increases with increasing temperature. At a temperature of 10°C, the saturation vapor pressure is about 12 mb, whereas at 30°C it is about 42 mb. The insert

# Variation of relative humidity during the day



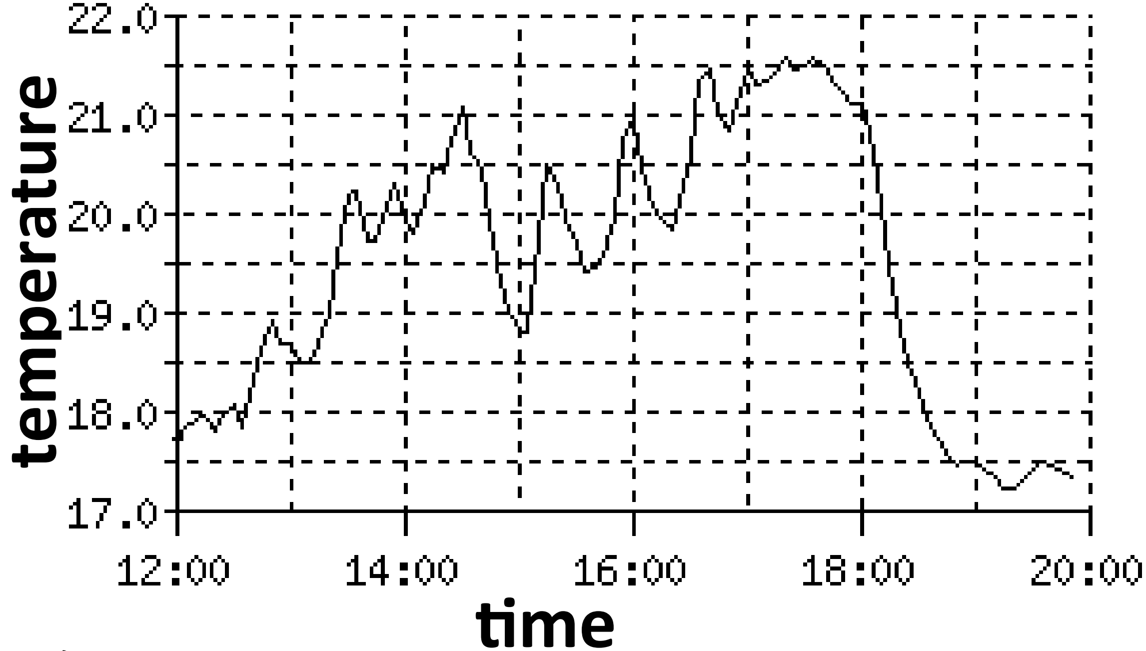

• FIGURE 4.12 When the air is cool (morning), the relative humidity is high. When the air is warm (afternoon), the relative humidity is low. These conditions exist in clear weather when the air is calm or of constant wind speed.

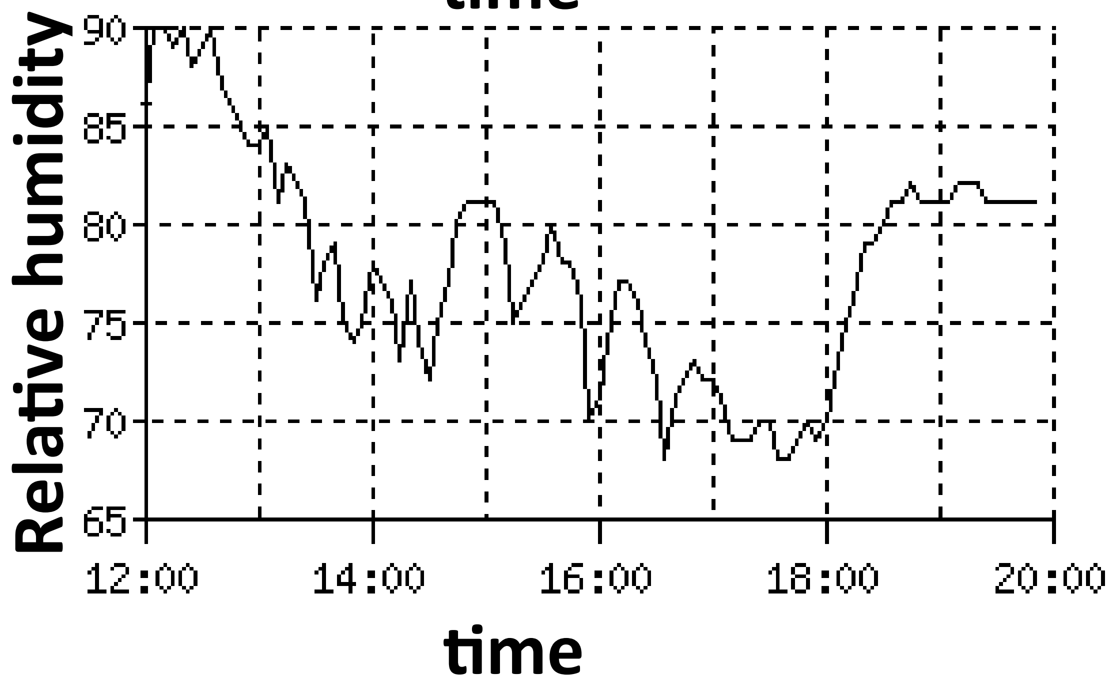
# Change in RH on 5/mar/2014, OPD observatory

**18h: 70%**
**20h: 80%**
**22h: 90%**
**0h: 100%**

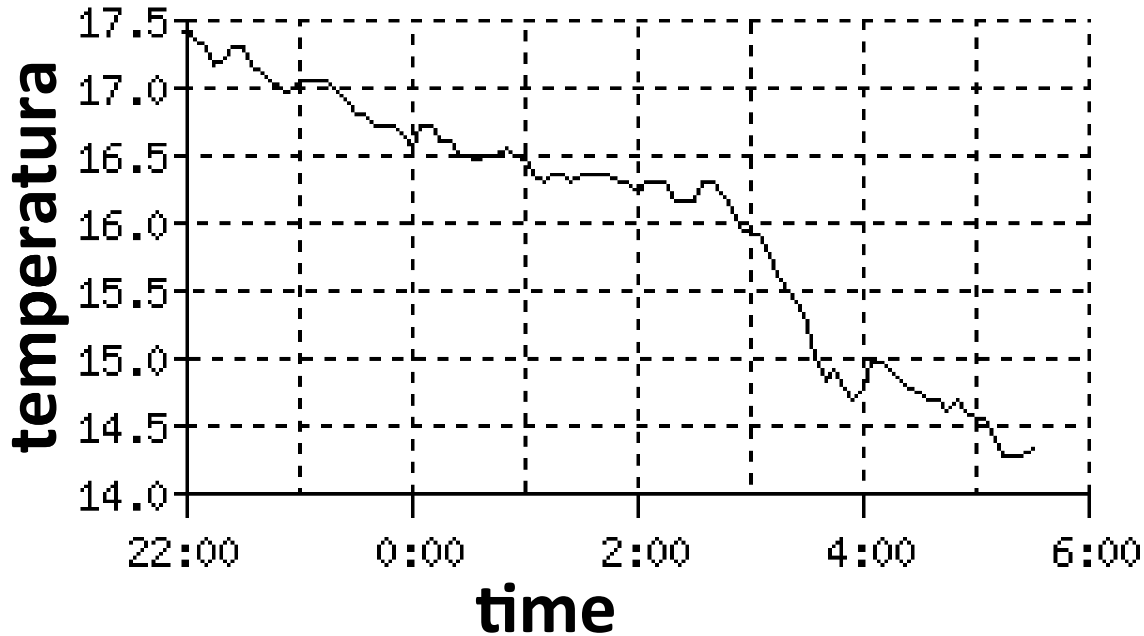
- Domes have to be closed when RH > 80% (ESO)
- Some observatories allow 90%
- OPD: 98% is OK

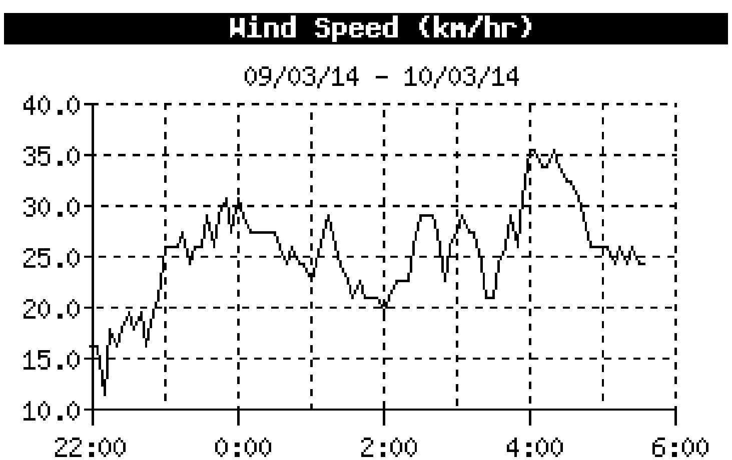
# Change in temperature and RH on 9/3/2014

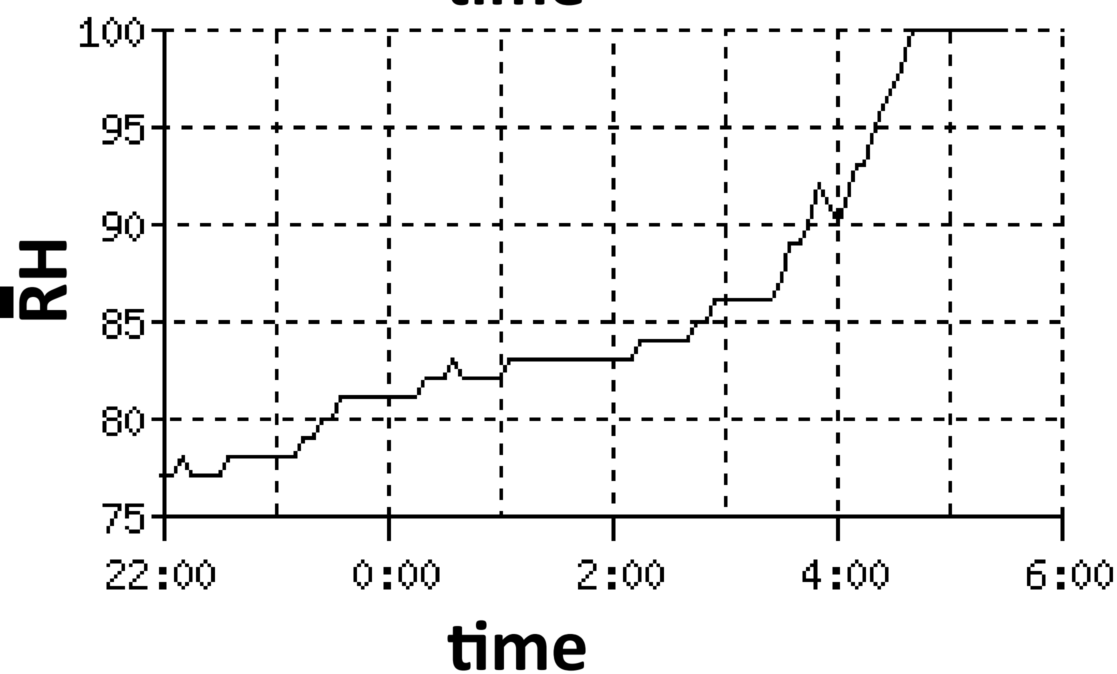


# Change in temperature and RH on 9/3/2014



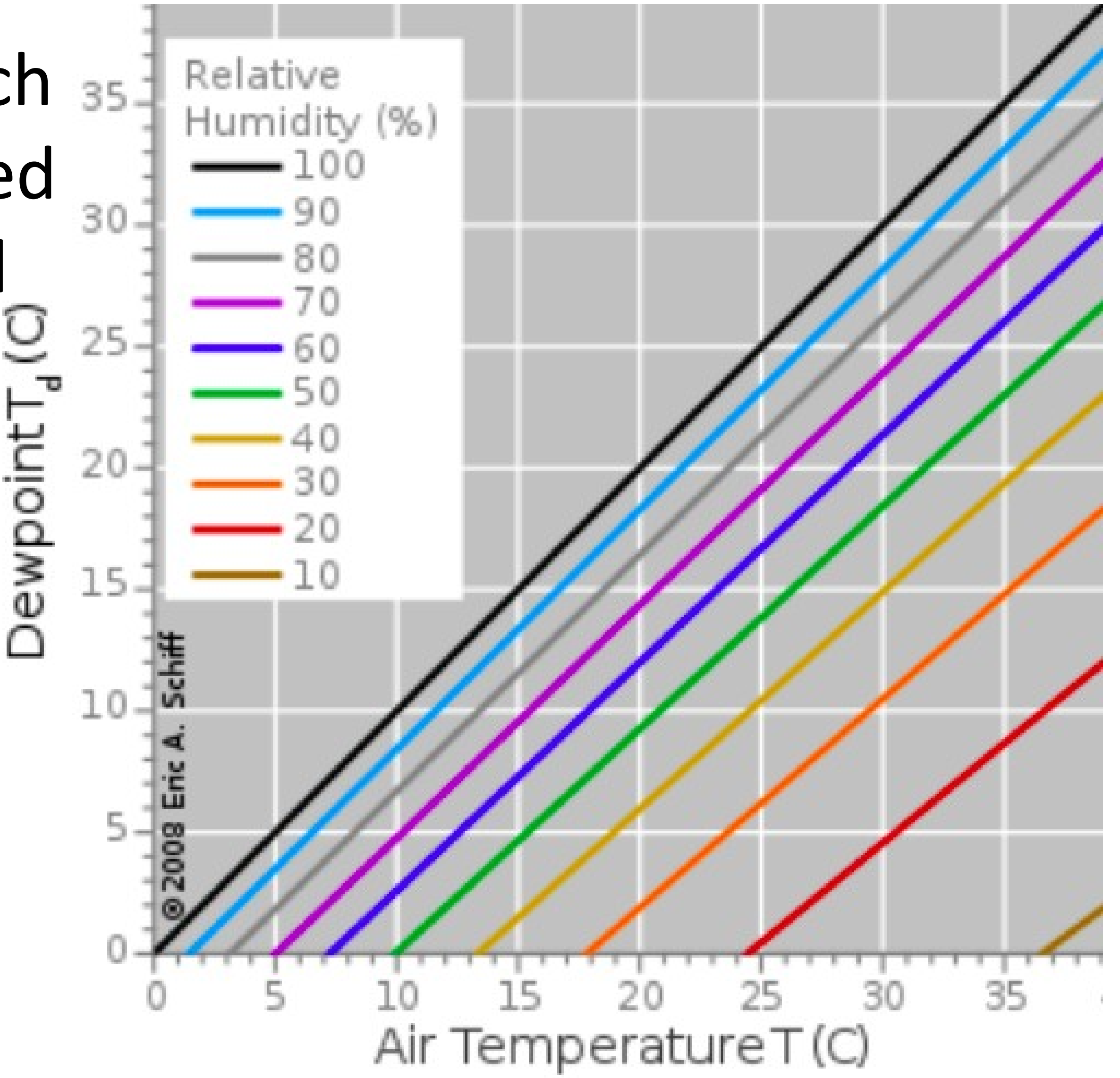



# Dew point

## Temperature to which the air must be cooled to become saturated with water vapor

Even if humidity is not very high, stop observations if the temperature difference between the coldest part of the telescope and the dew point drops below 2 degrees.



# Formação de nuvens

A formação de nuvem ocorre quando o vapor d'água se transforma em líquido (gotículas de água) ou sólido (cristais de gelo)

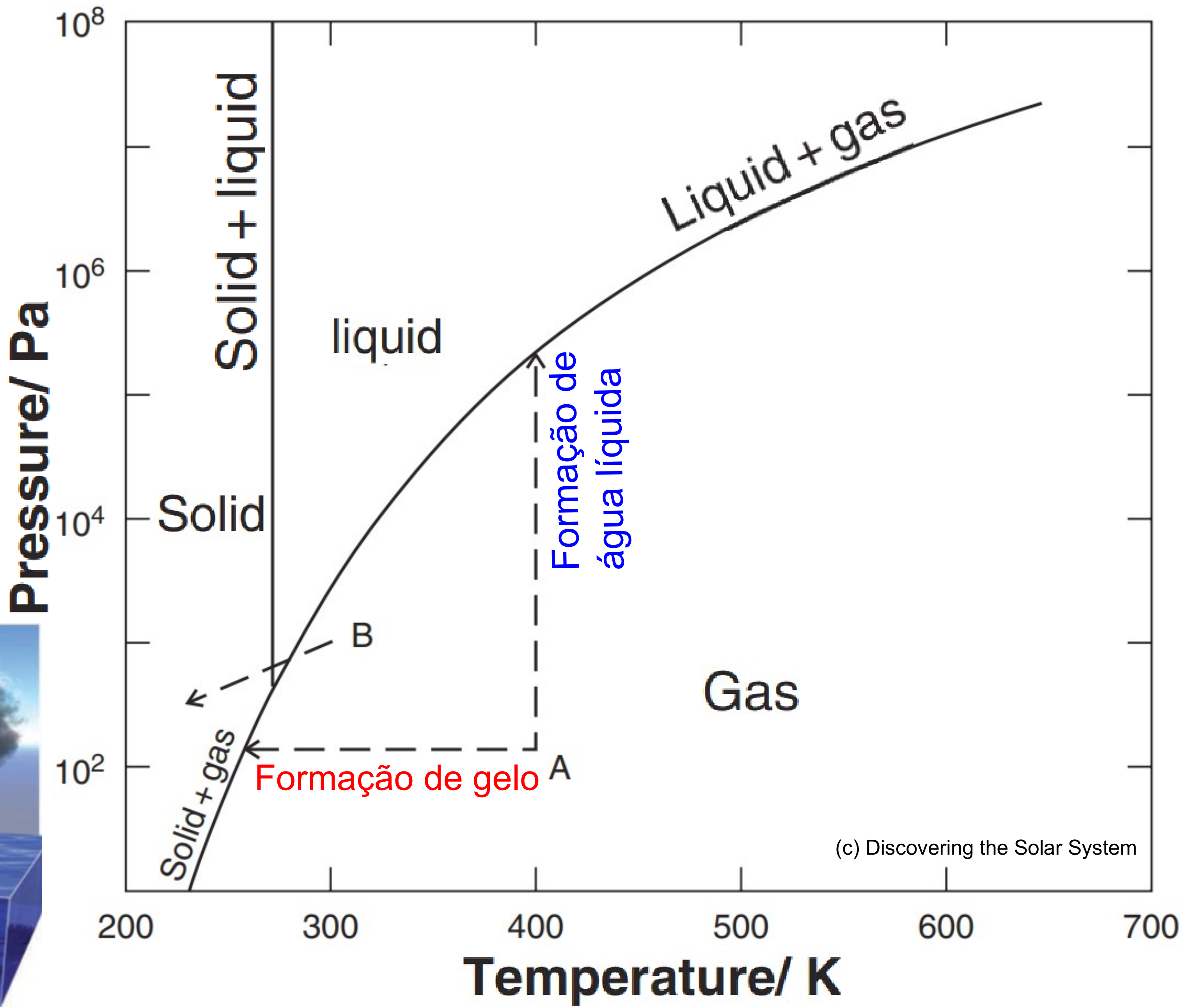
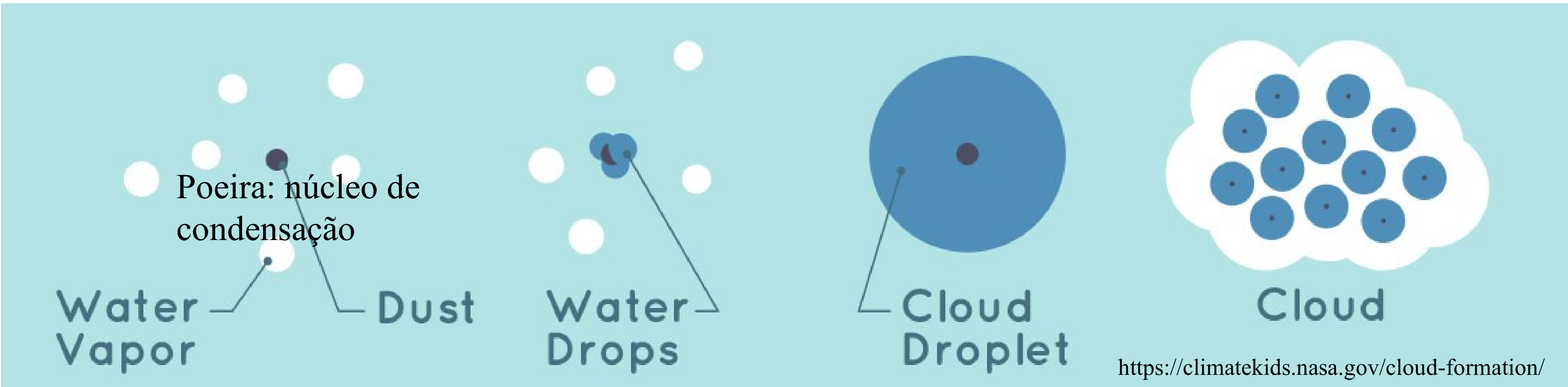


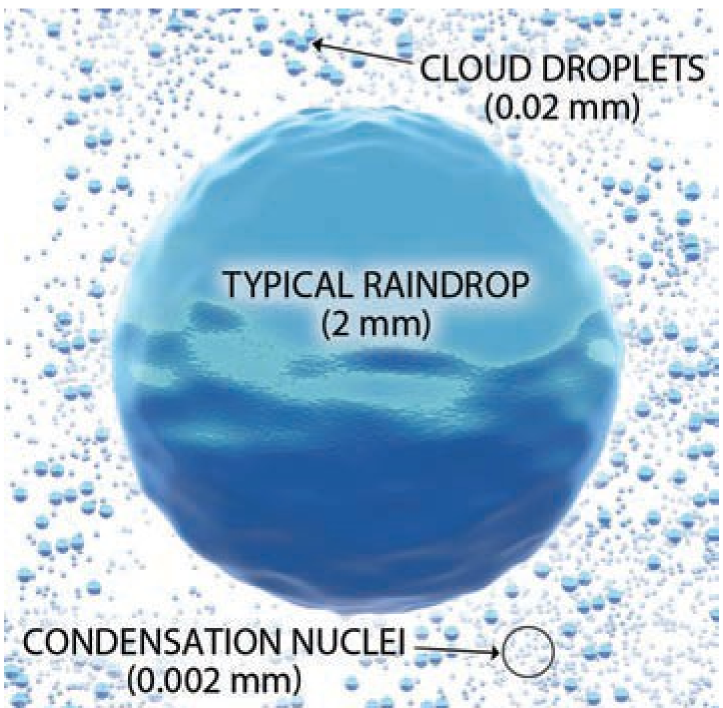

**Figure 9.9** Phase diagram of water. Note that water is unusual in that the solid + liquid line slopes to the left, though this is barely apparent on the scale here. The triple point is at 273.16 K, 610 Pa.

# Formação de nuvens

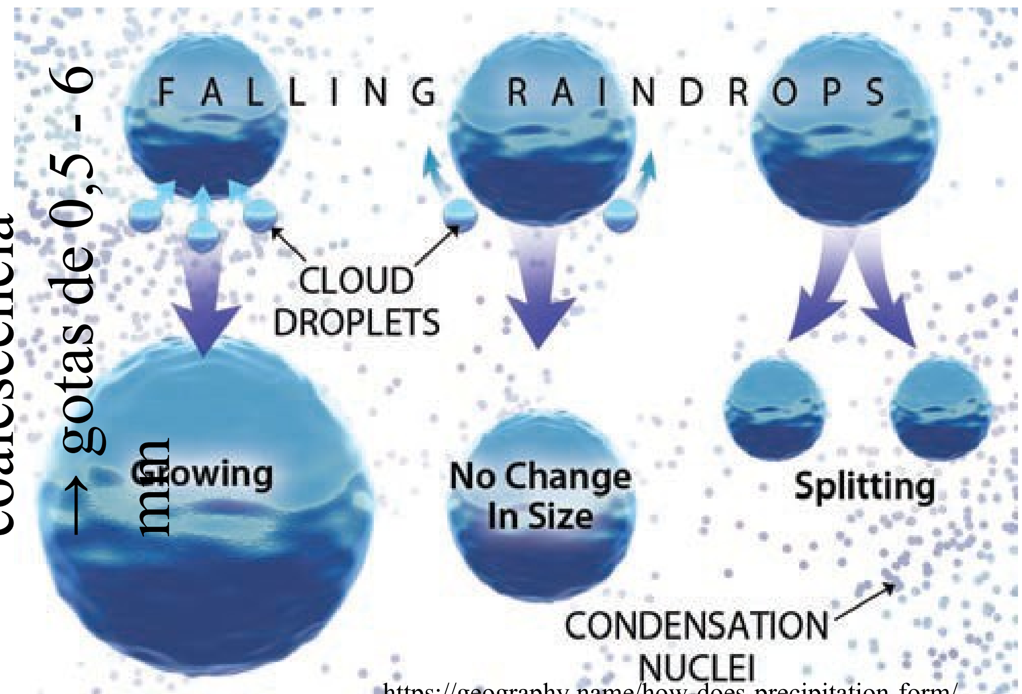
A formação de gotículas de água ou cristais de gelo é favorecida na presença de partículas microscópicas, como poeira, que atuam como núcleos de condensação.




https://climatekids.nasa.gov/cloud-formation/

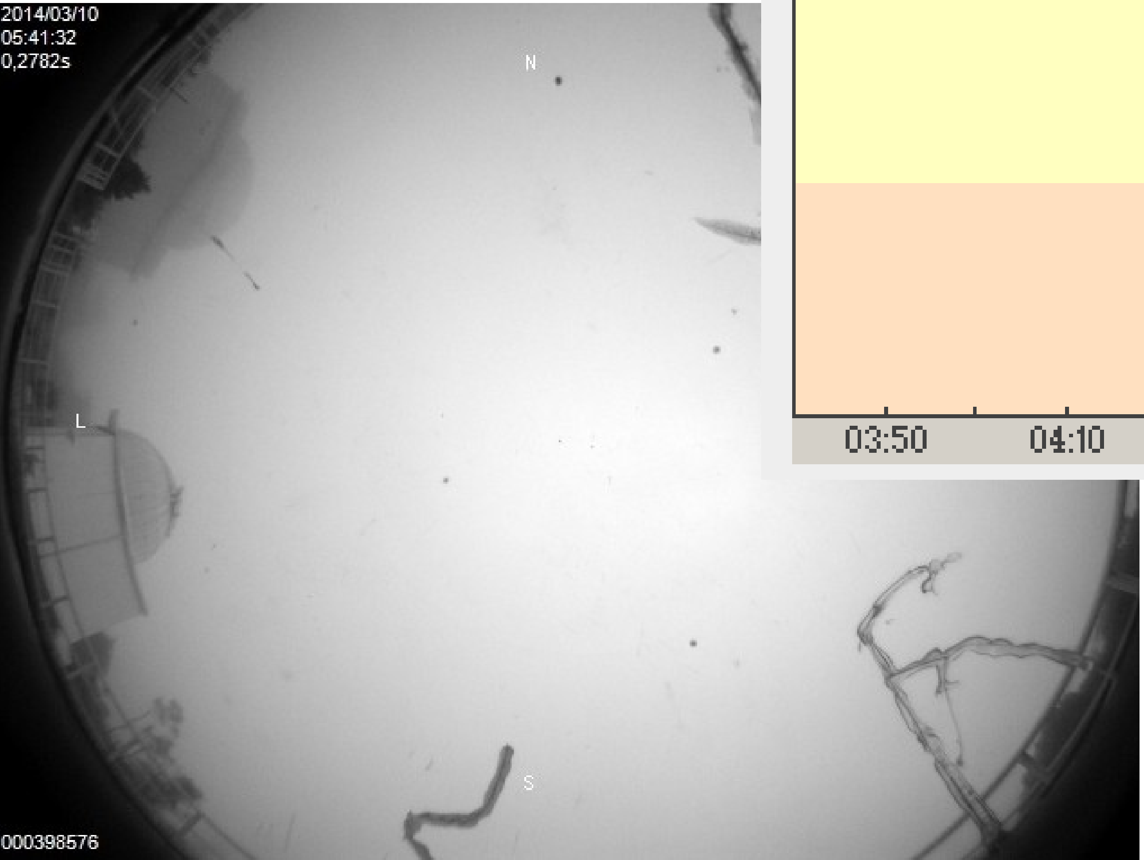


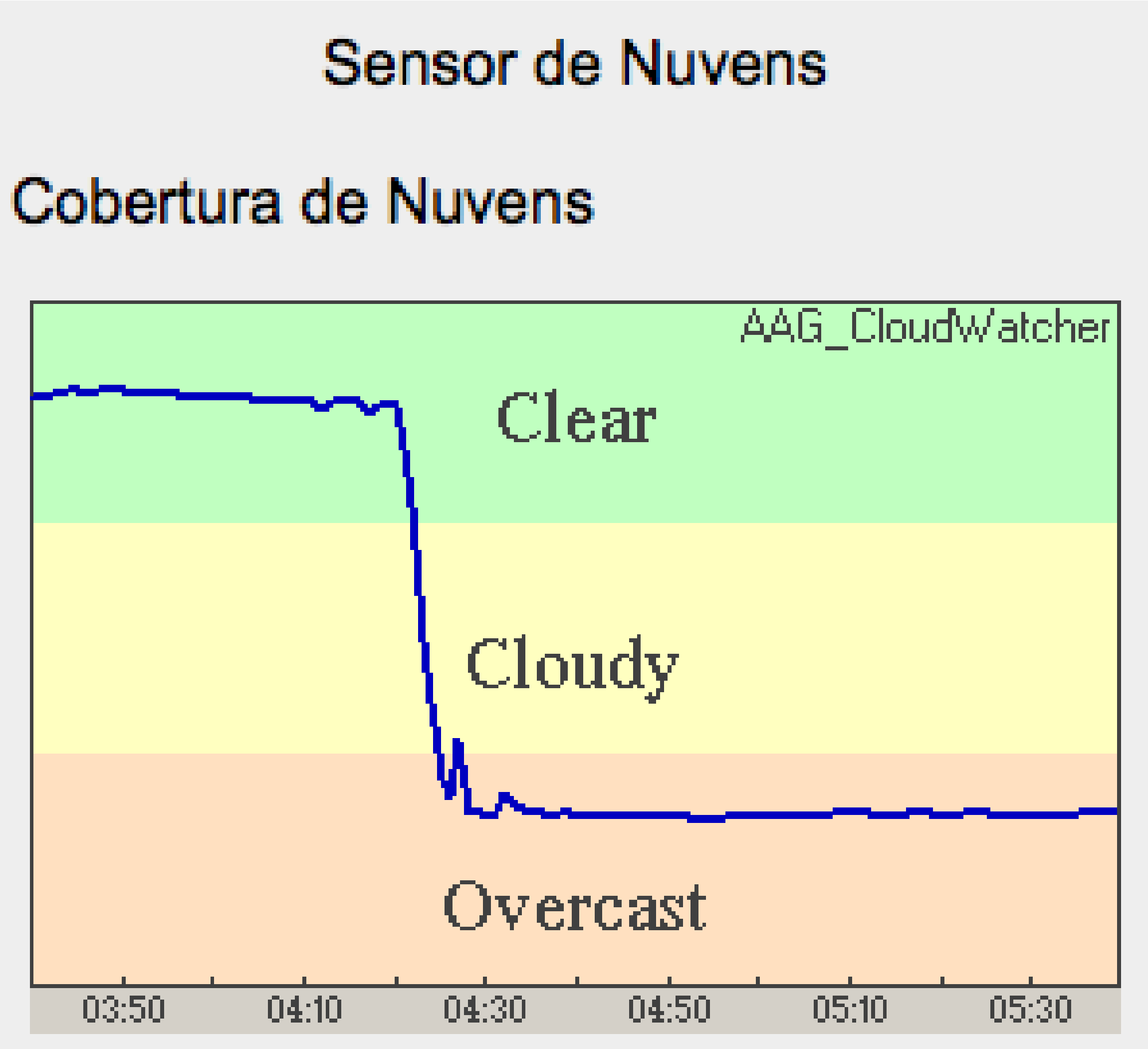

Colisão e coalescência → gotas de 0,5 - 6 mm




https://geography.name/how-does-precipitation-form/

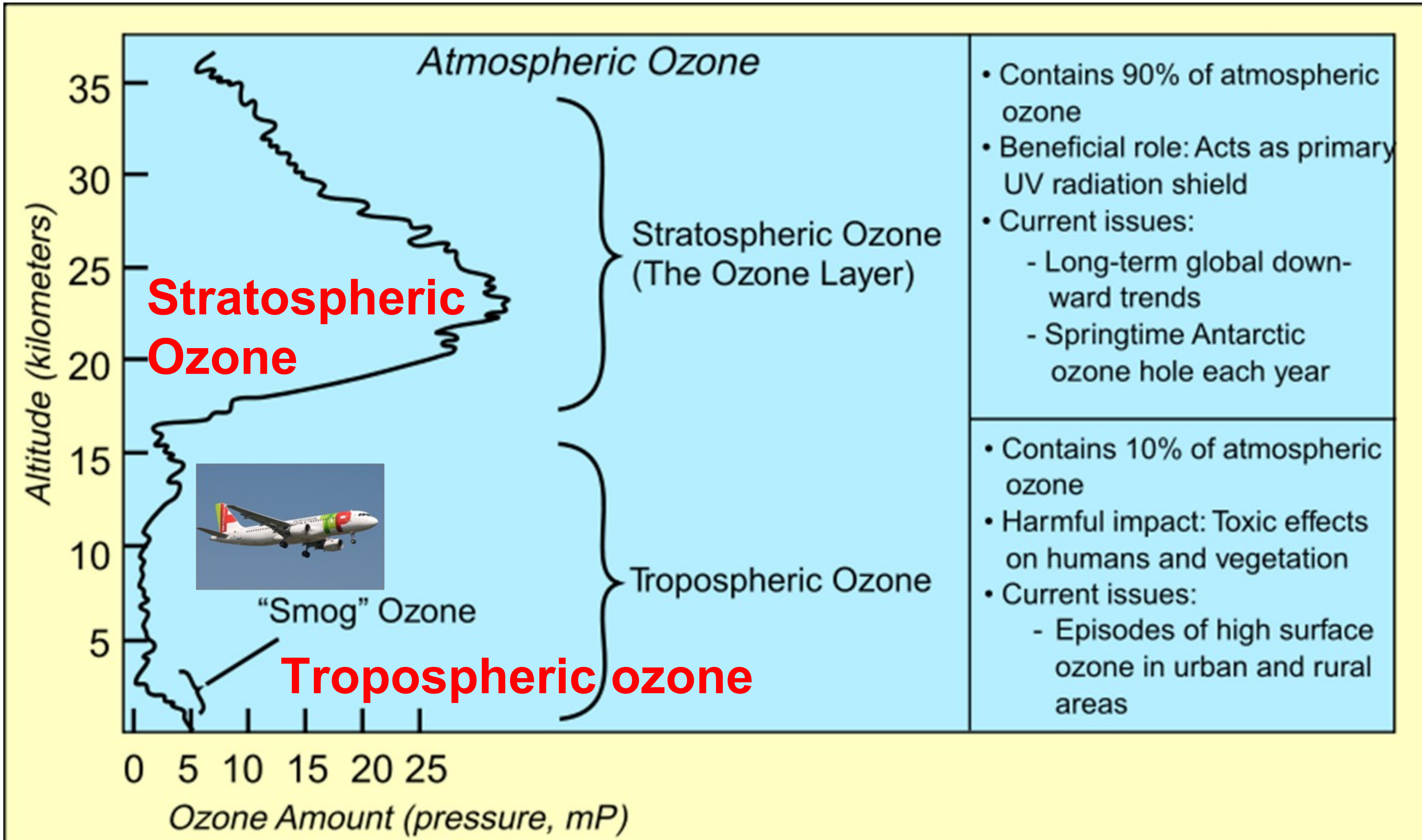
# Cloud coverage 10/Mar/2014




time

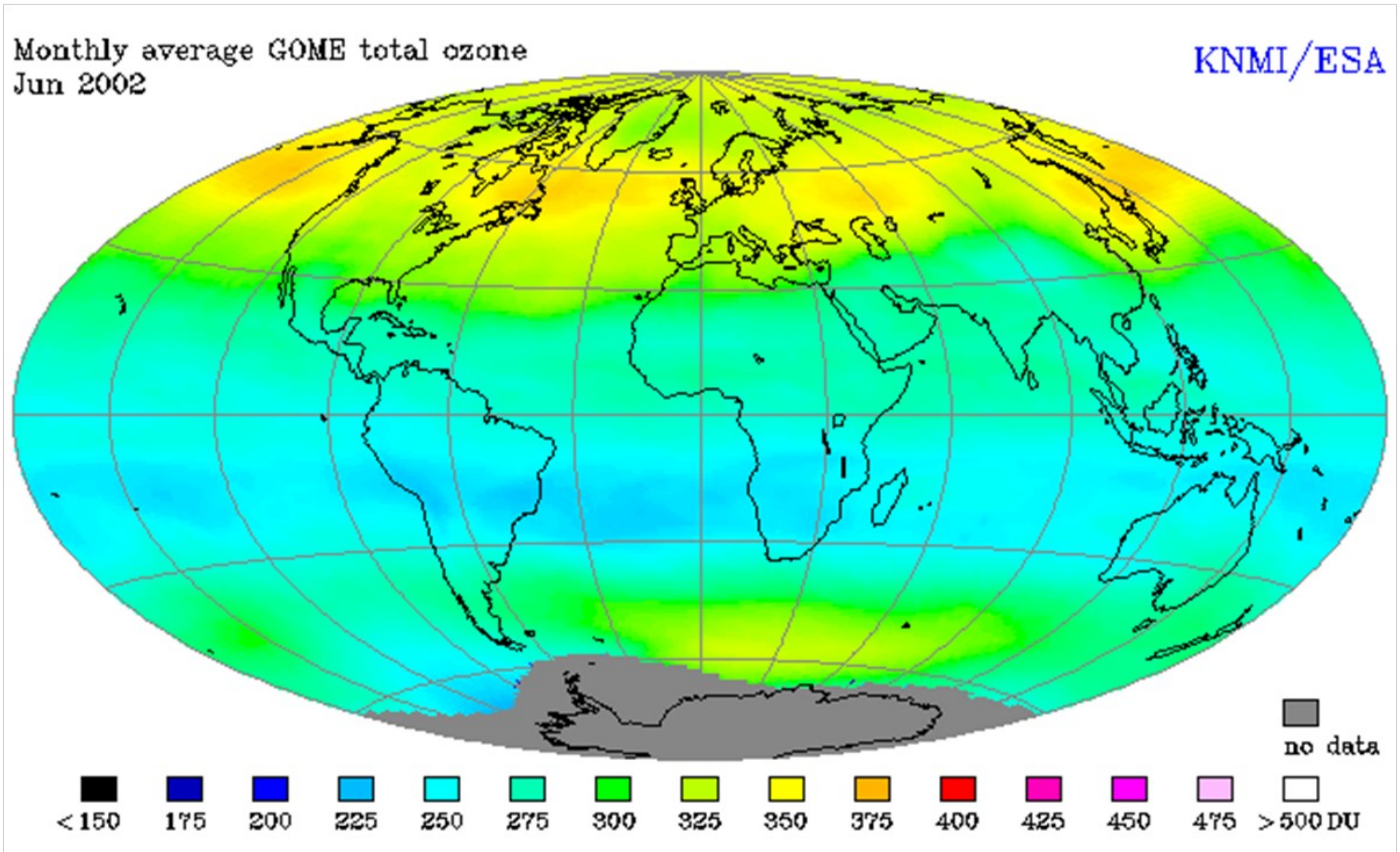
# Ozone ($O_3$): Vertical structure of $O_3$ changes a lot (latitude, season of the year), with maximum ~23 km



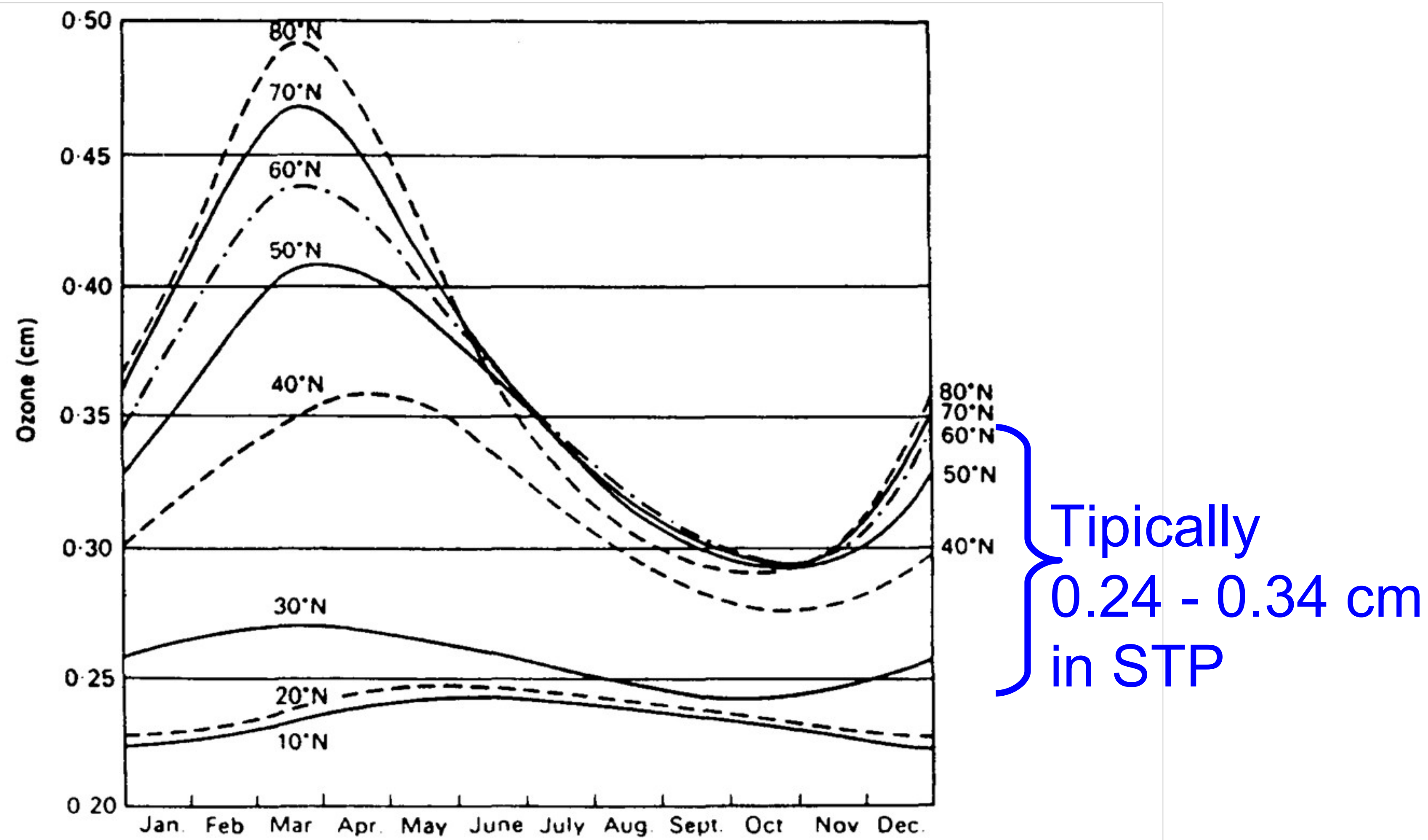

Andrew Ryzhkov

# Ozone ($O_3$)

## Northern hemisphere has larger concentration of ozone



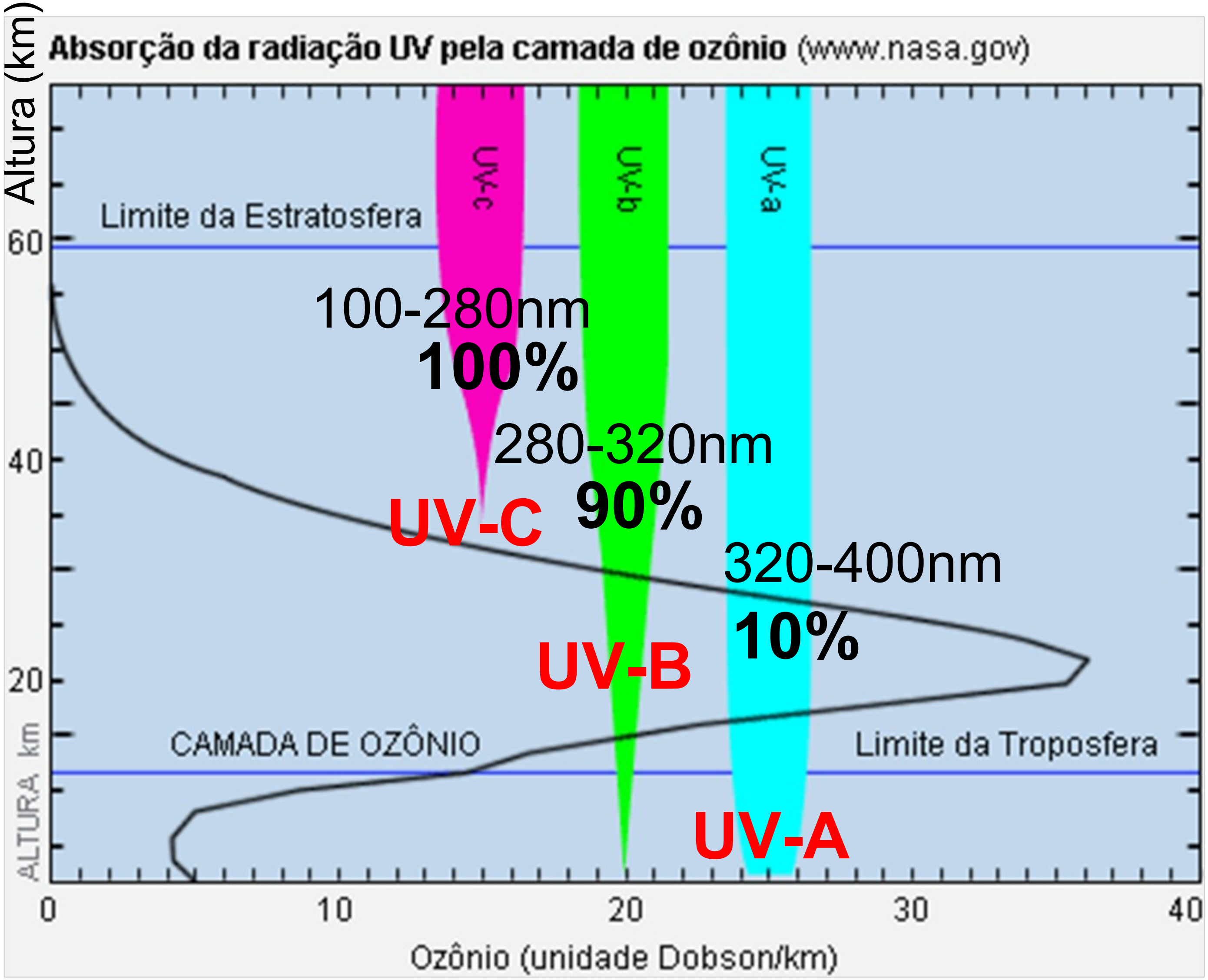
# Ozone ($O_3$) has an annual cycle

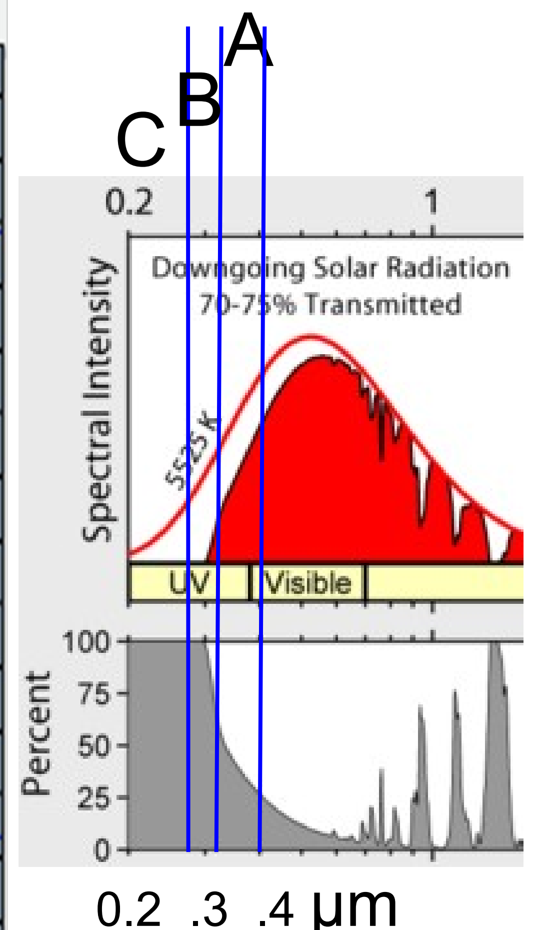



**Mar Apr** **Oct Nov**

Figure 1. Annual Variation of Total Ozone for Each 10° of N Latitude

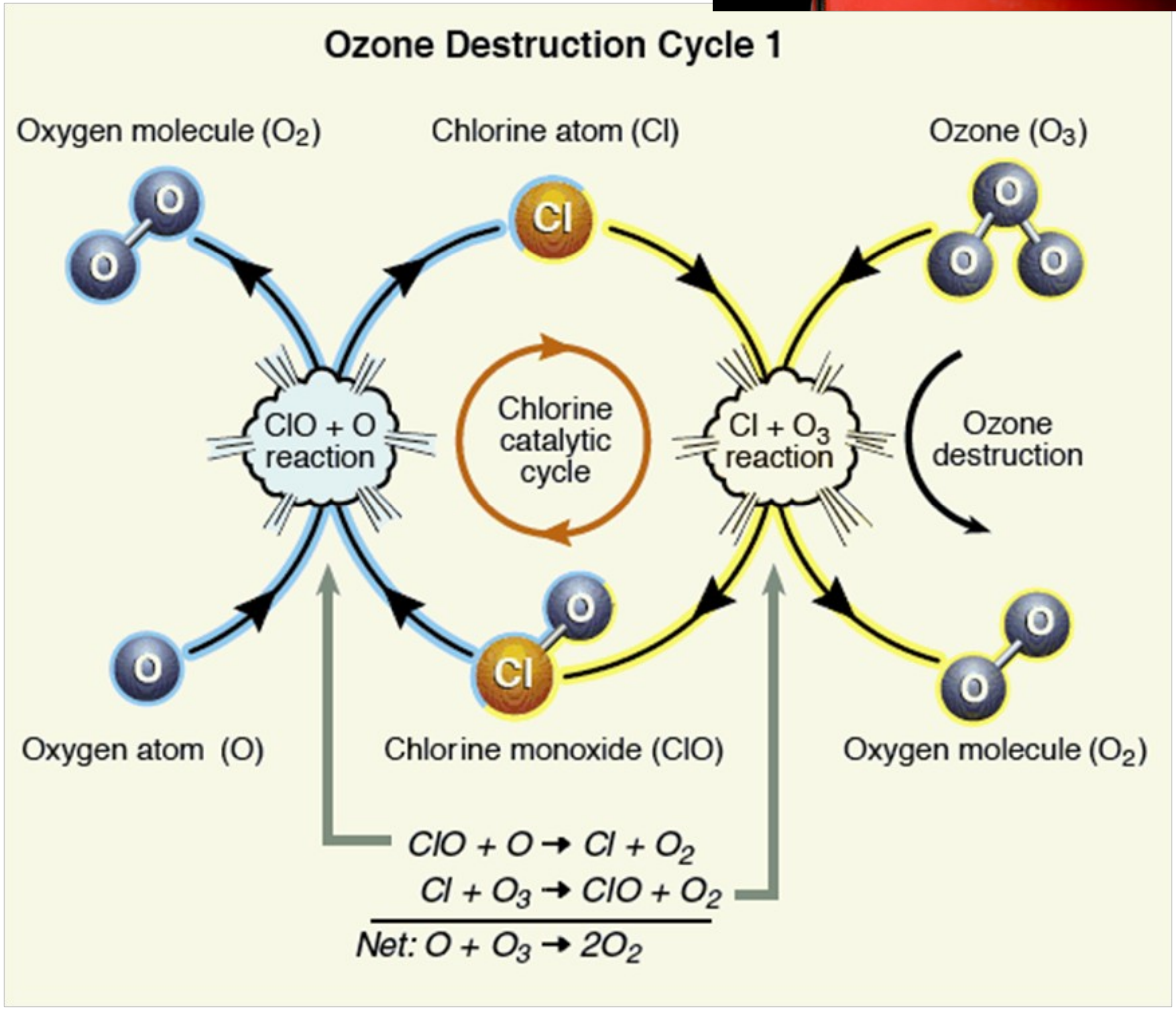
# Ozone: principal protection for UV solar radiation



# Ozone destruction

- Minor constituents (Cl, NO) destroy $O_3$
- Cloroflour-carbonates, CFCs, can reach the stratosphere and destroy ozone

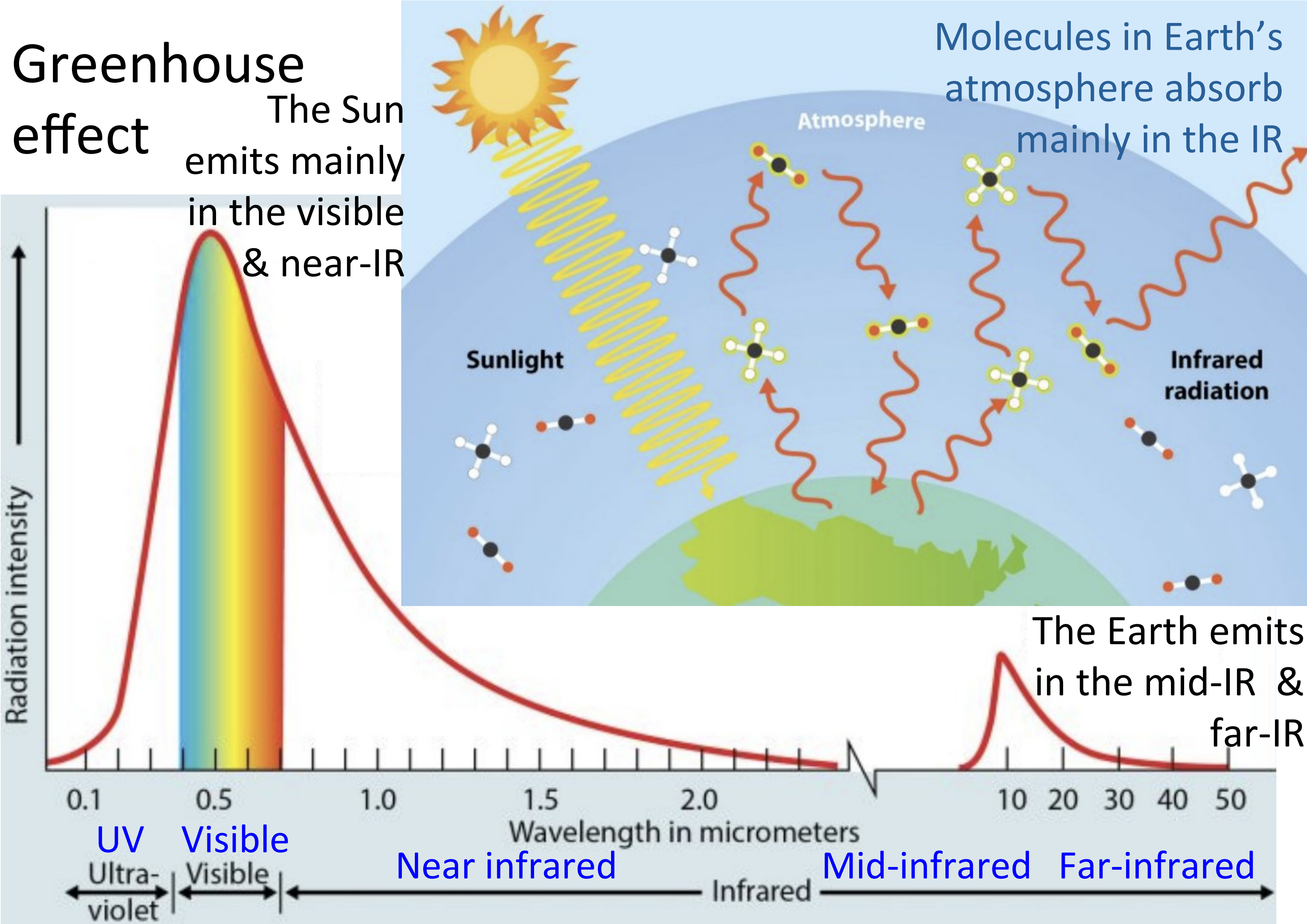


# Greenhouse effect

The Sun emits mainly in the visible & near-IR

Molecules in Earth's atmosphere absorb mainly in the IR

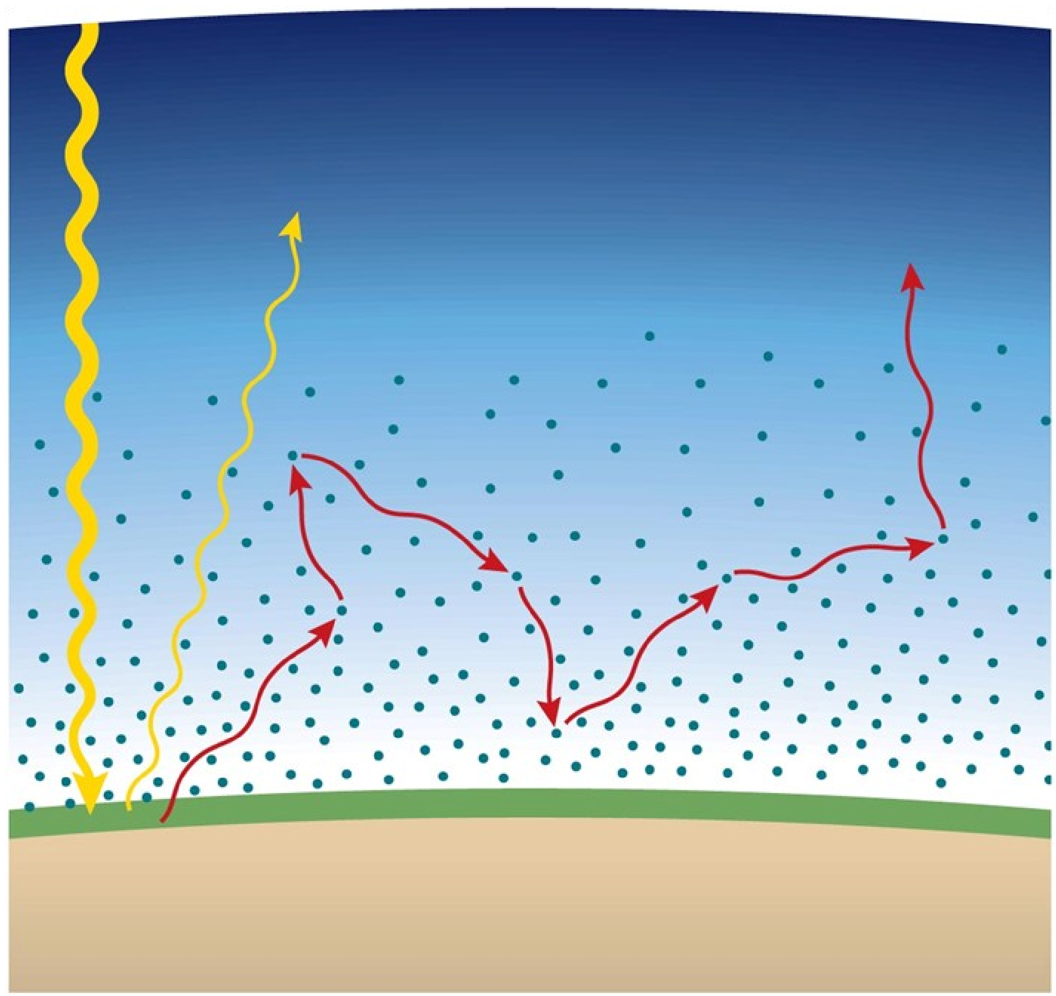
The Earth emits in the mid-IR & far-IR




https://ugc.berkeley.edu/background-content/re-radiation-of-heat/ Adapted by Jorge Meléndez (IAG-USP)

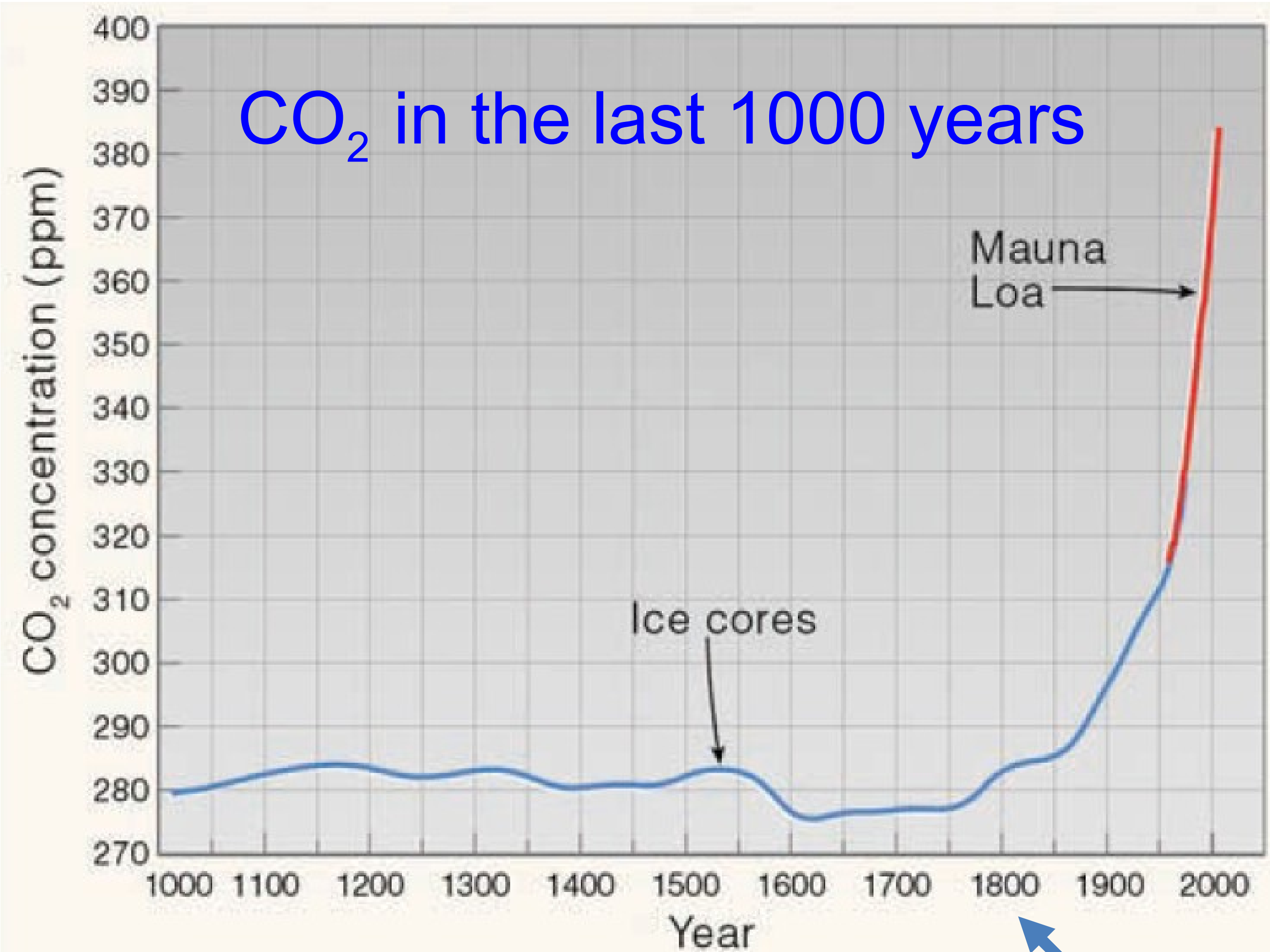
# $CO_2$ and global warming

Visible light pass through atmosphere and heats the surface. Gases ($CO_2$, $H_2O$ & $CH_4$) in atmosphere absorb the reflected IR light, re-emitting in random directions

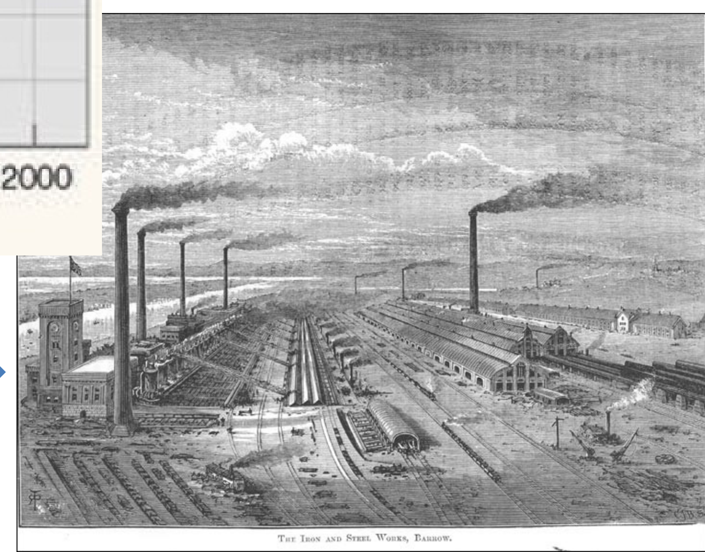


$CO_2$ is the second source of global warming (after $H_2O$)

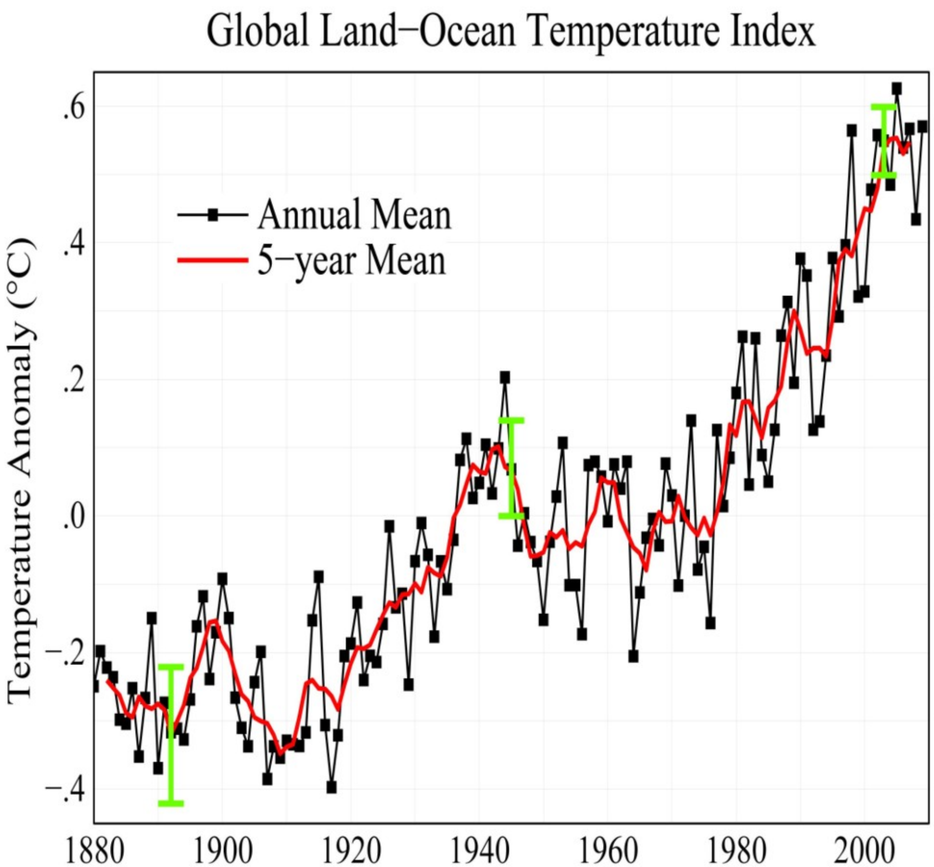
# $CO_2$ and global warming

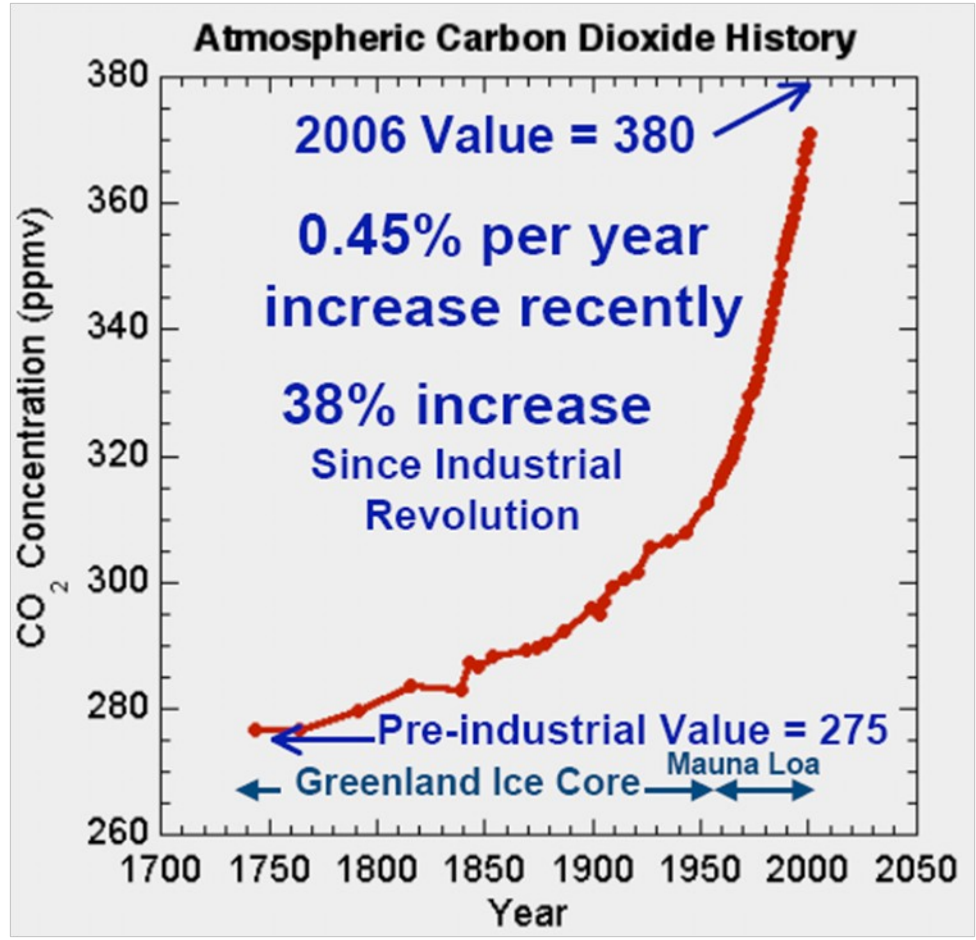



● FIGURE 1.6 Carbon dioxide values in parts per million during the past 1000 years from ice cores in Antarctica (blue line) and from Mauna Loa Observatory in Hawaii (red line). (Data courtesy of Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory.)

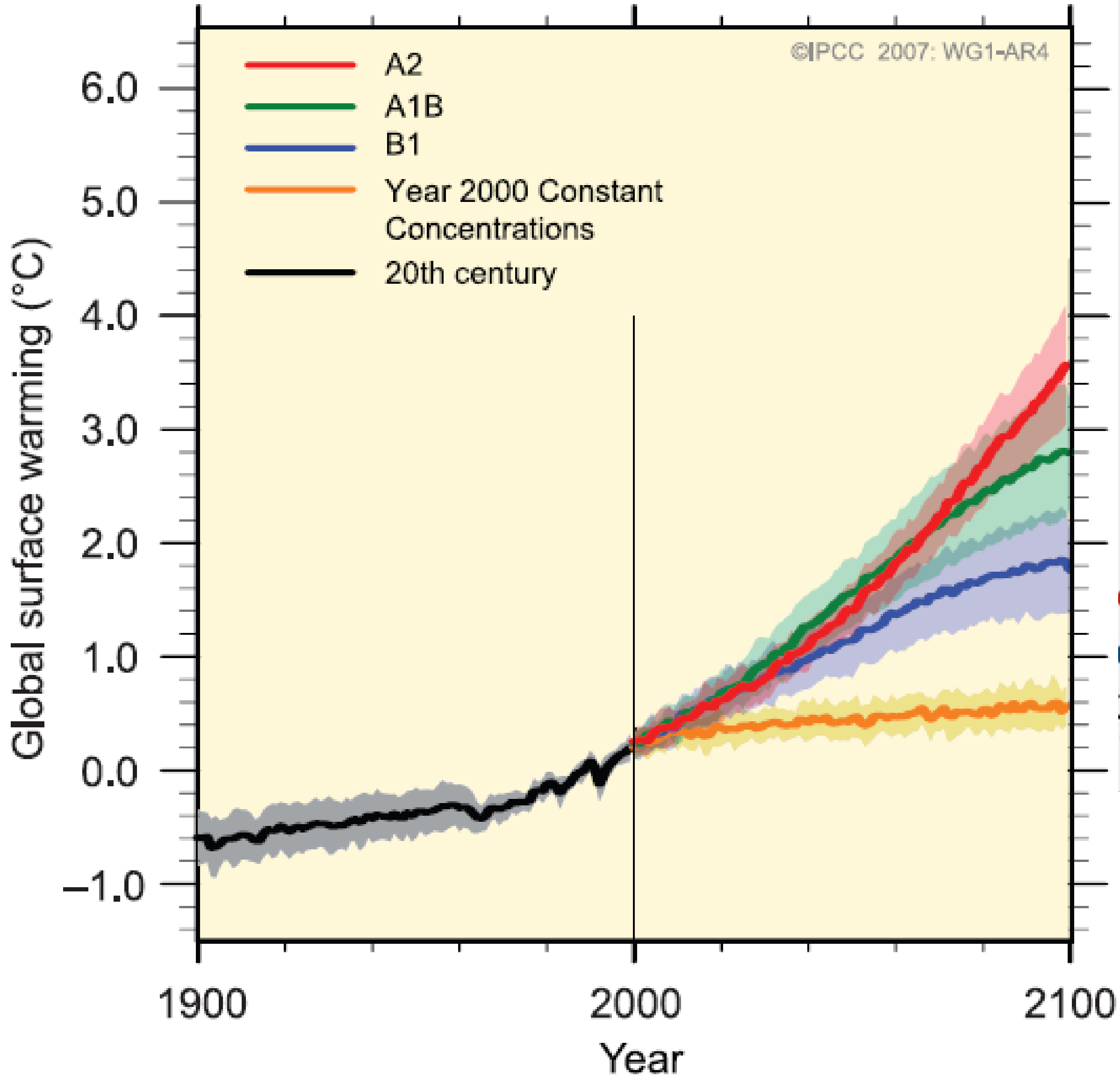


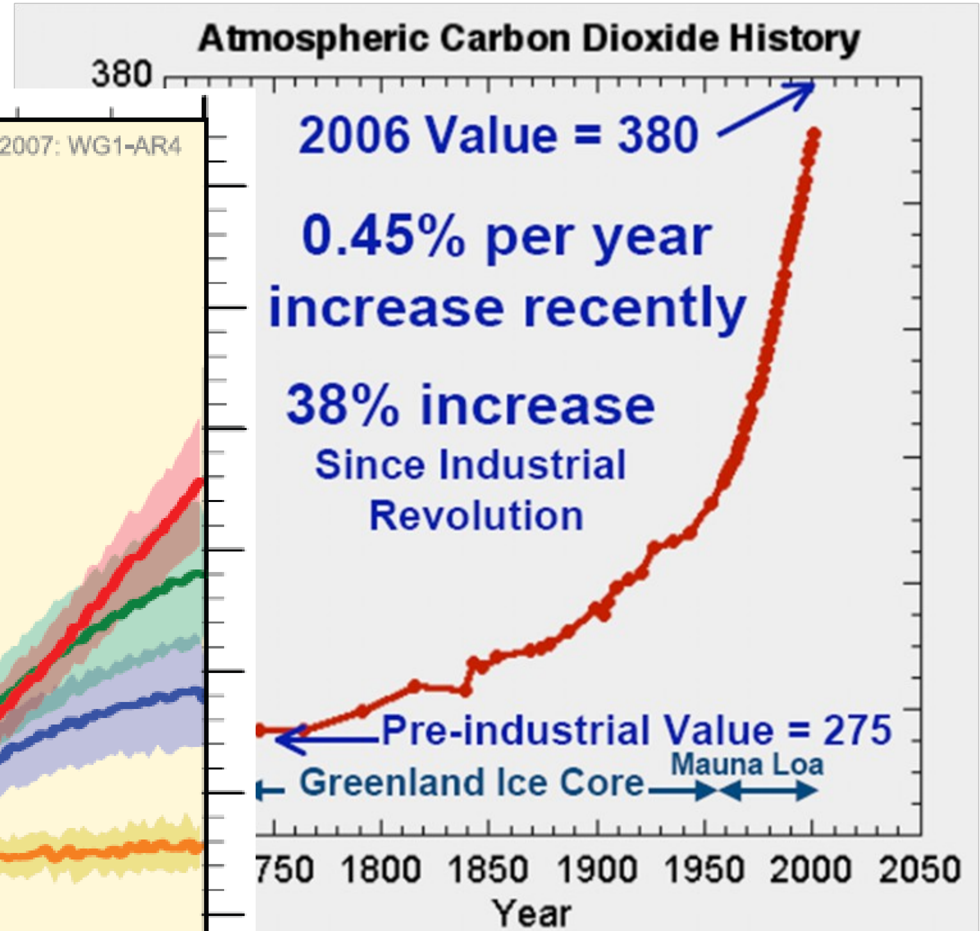
# $CO_2$ and global warming



# $CO_2$ and global warming



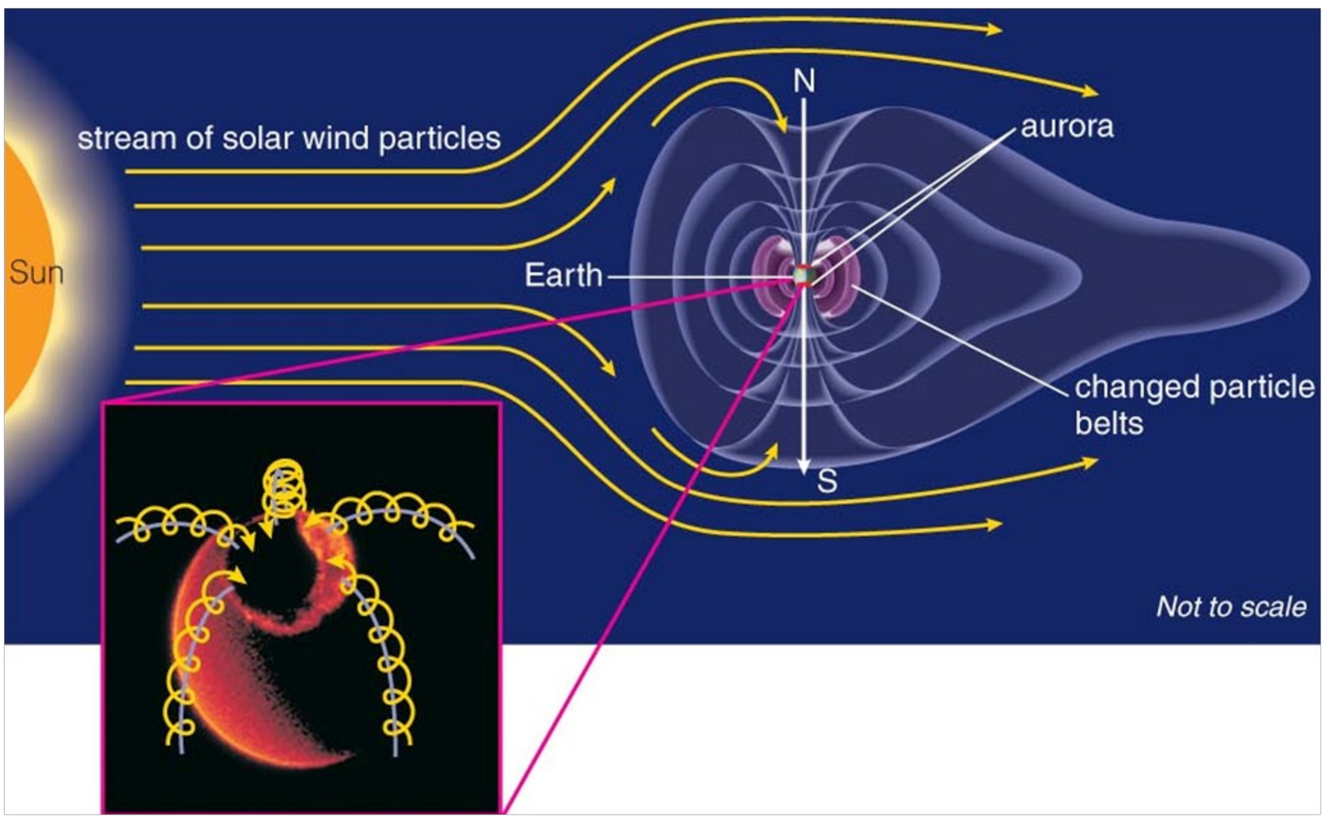



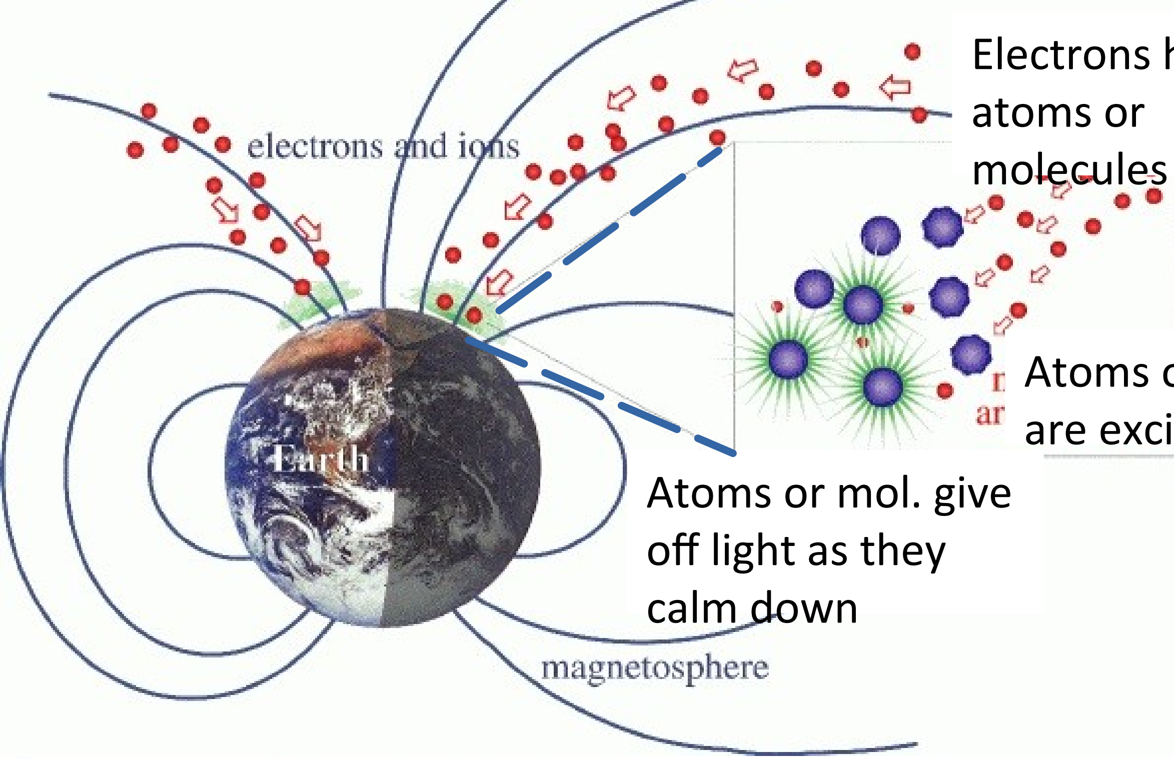
# Ions

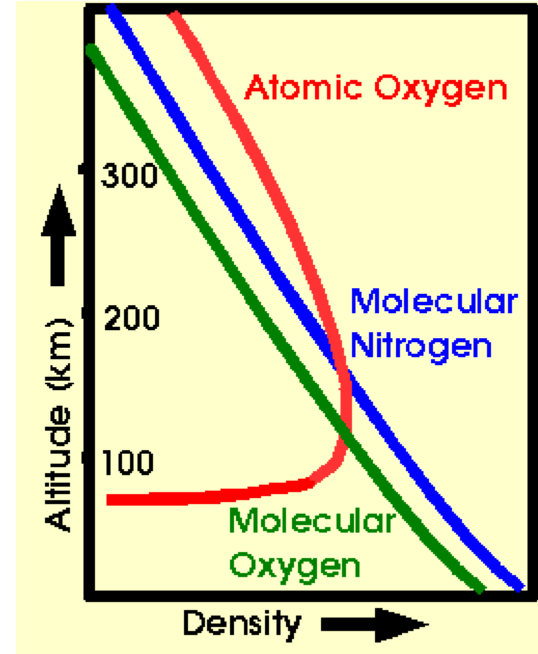
•Above 60km, solar UV radiation ionizes the atmosphere

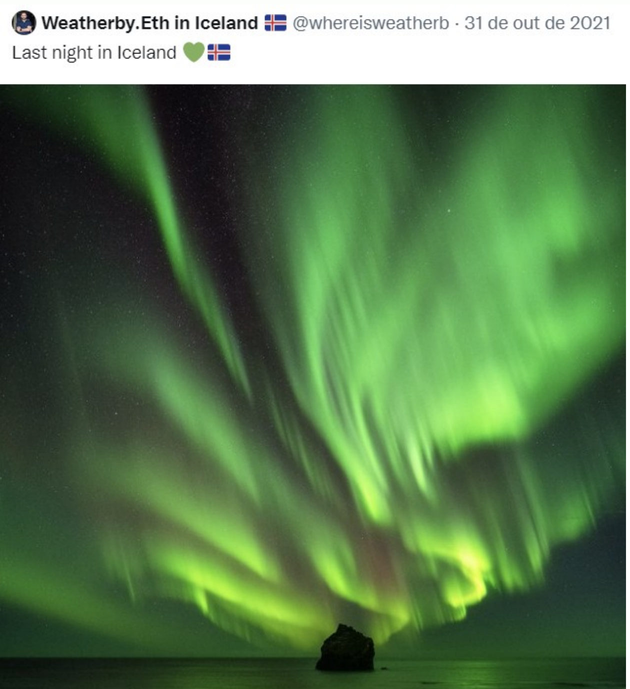
•Ionization changes with altitude, solar illumination, solar activity

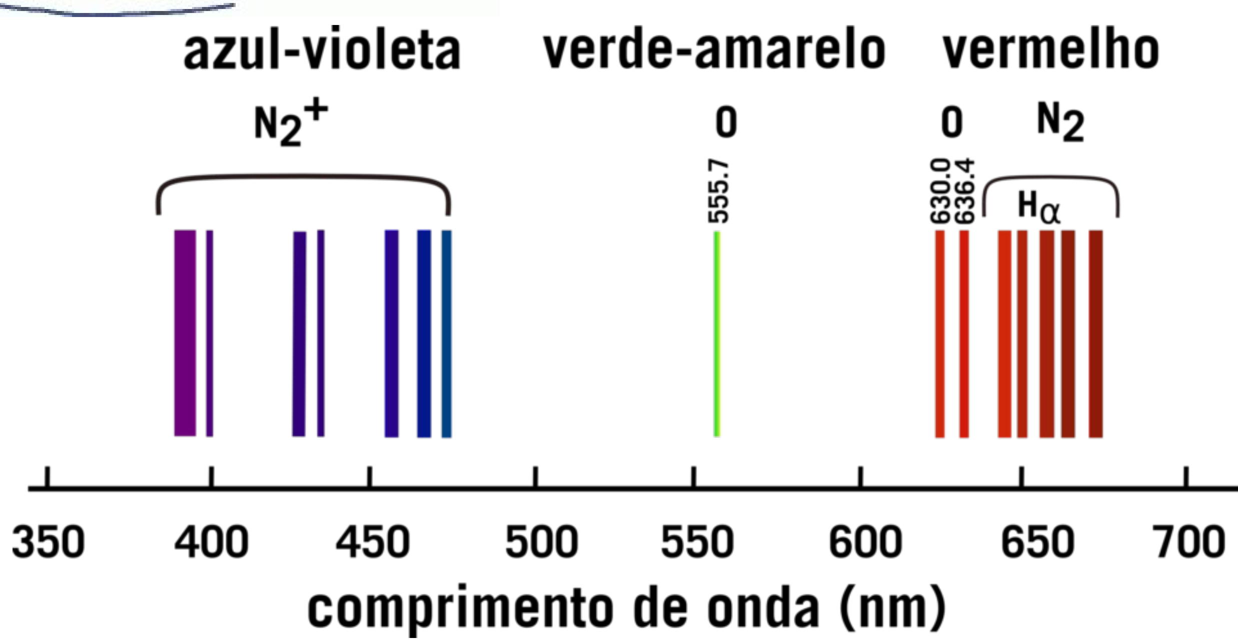
•At high latitudes, electron cascades enter magnetic poles, causing auroras

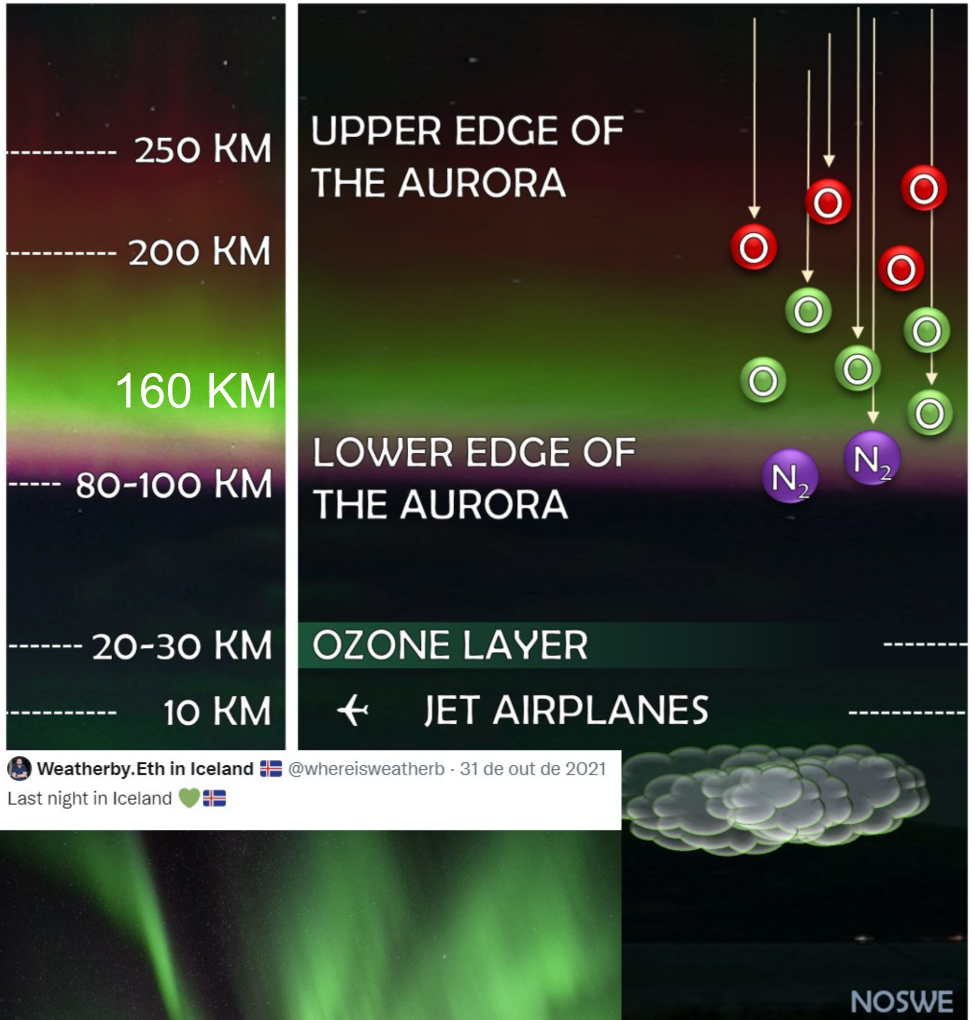


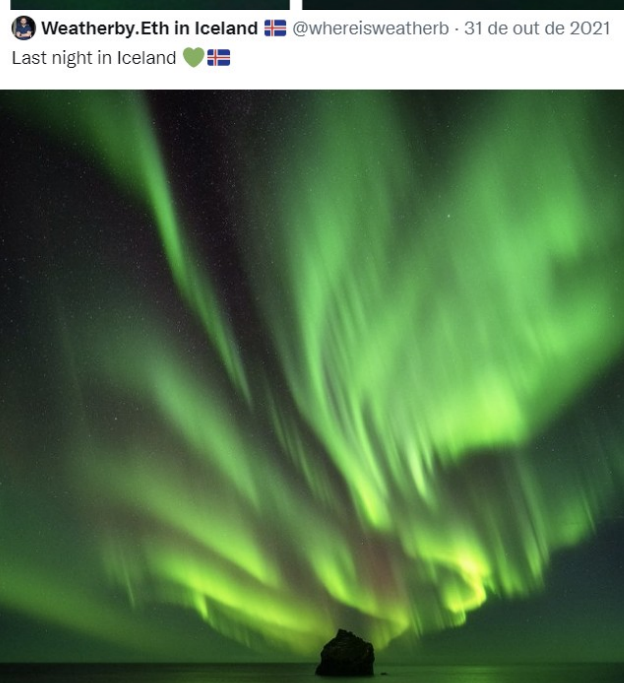

electrons and ions
Earth
magnetosphere
Electrons hit atoms or molecules
Atoms or mol. are excited
Atoms or mol. give off light as they calm down

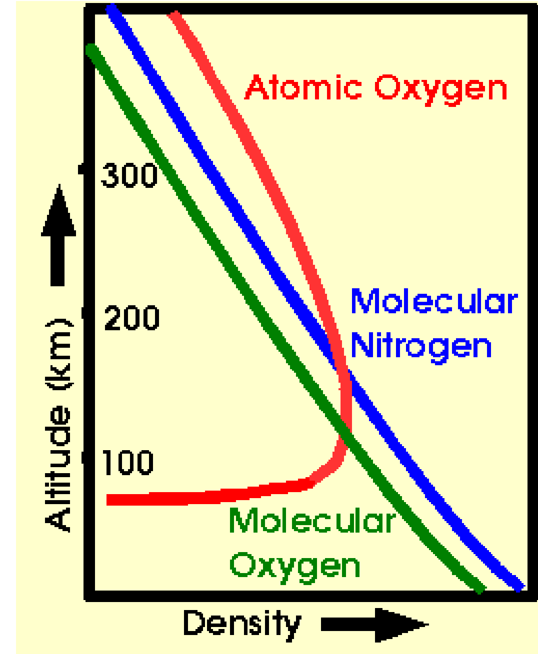

Atomic Oxygen
Molecular Nitrogen
Molecular Oxygen
300
200
100
Altitude (km)
Density

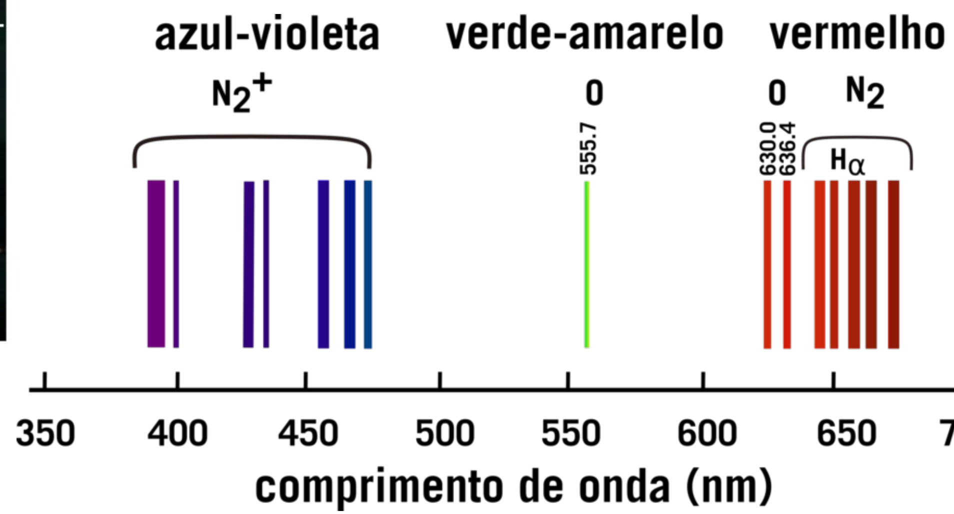

Weatherby.Eth in Iceland @whereisweatherb · 31 de out de 2021
Last night in Iceland


azul-violeta
verde-amarelo
vermelho
N2+
O
O
N2
555.7
630.0
636.4
Hα
350
400
450
500
550
600
650
700
comprimento de onda (nm)


250 KM
200 KM
160 KM
80-100 KM
20-30 KM
10 KM
UPPER EDGE OF THE AURORA
O
N2
LOWER EDGE OF THE AURORA
OZONE LAYER
JET AIRPLANES
NOSWE


Weatherby.Eth in Iceland @whereisweatherb · 31 de out de 2021
Last night in Iceland


Atomic Oxygen
Molecular Nitrogen
Molecular Oxygen
300
200
100
Altitude (km)
Density


azul-violeta
verde-amarelo
vermelho
N2+
0
0
N2
555.7
630.0
636.4
Hα
350
400
450
500
550
600
650
comprimento de onda (nm)


Suécia
Aurora em Kiruna, 28/2/2019
(c) Mia Stålnacke


Noruega
www.arcticphoto.no
1/2012

# Ions

- Typical reactions:

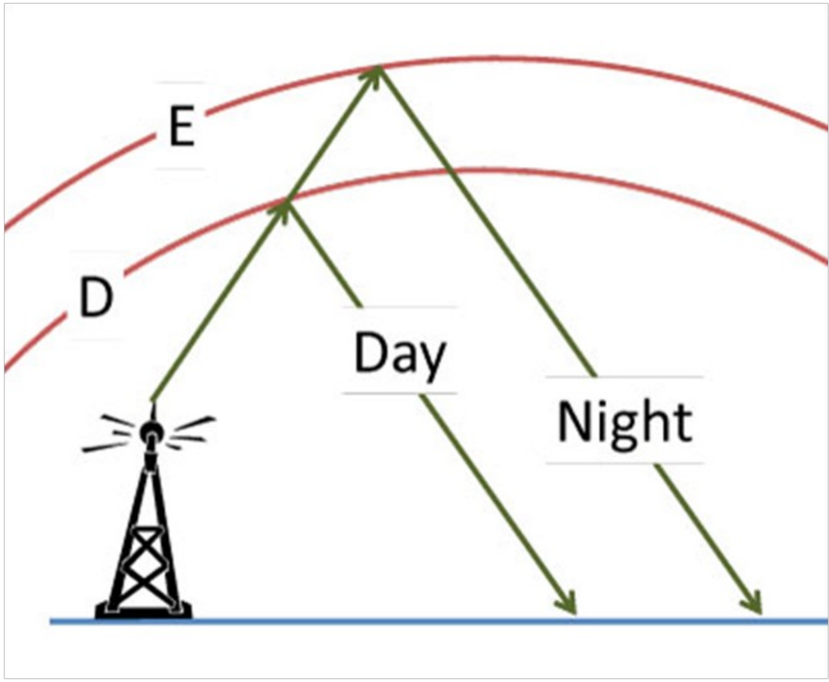
$$\boxed{O_2 + h\nu \rightarrow O_2^+ + e^-}$$

$$\boxed{O_2 + h\nu \rightarrow O^+ + O + e^-}$$

- Variation of eletronic densities:

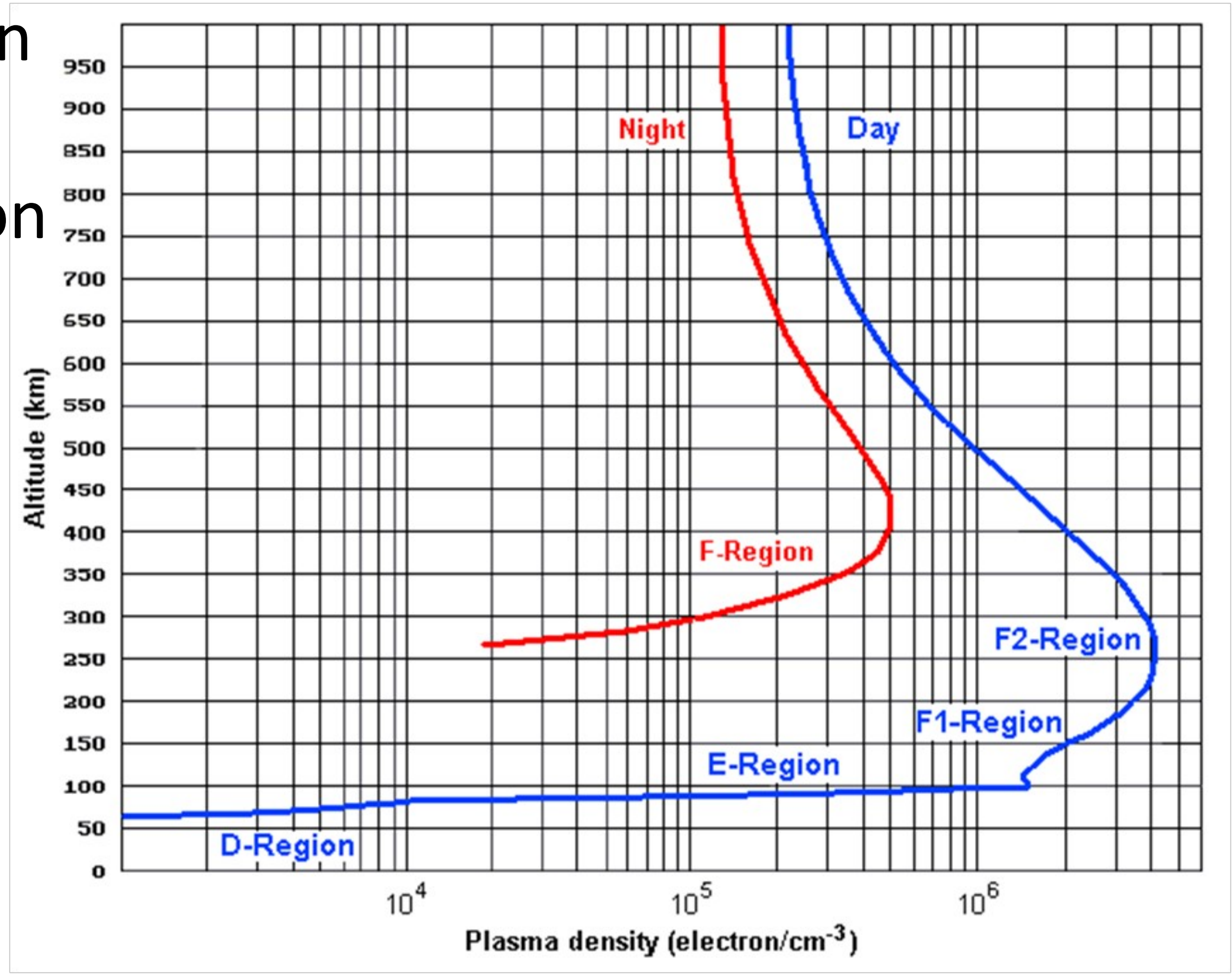
| Layer | z(km) | $N_e[cm^{-3}]$ |
| --- | --- | --- |
| D | 60 | $10^3$ |
| E | 100 | $10^5$ |
| F | 150-300 | $2x10^6$ |
| | > 2000 | $10^4$ |

- D almost dissapears at night
- Interference in radio waves



# Ionospheric plasma

Ionized layers have an index of refraction *n* related to the electron density *Ne*




- $n^2 = 1 - \omega_p{}^2/\omega$

  $= 1 - (\lambda/\lambda_p)^2$

- $\nu_p[Hz] = \omega_p/2\pi$

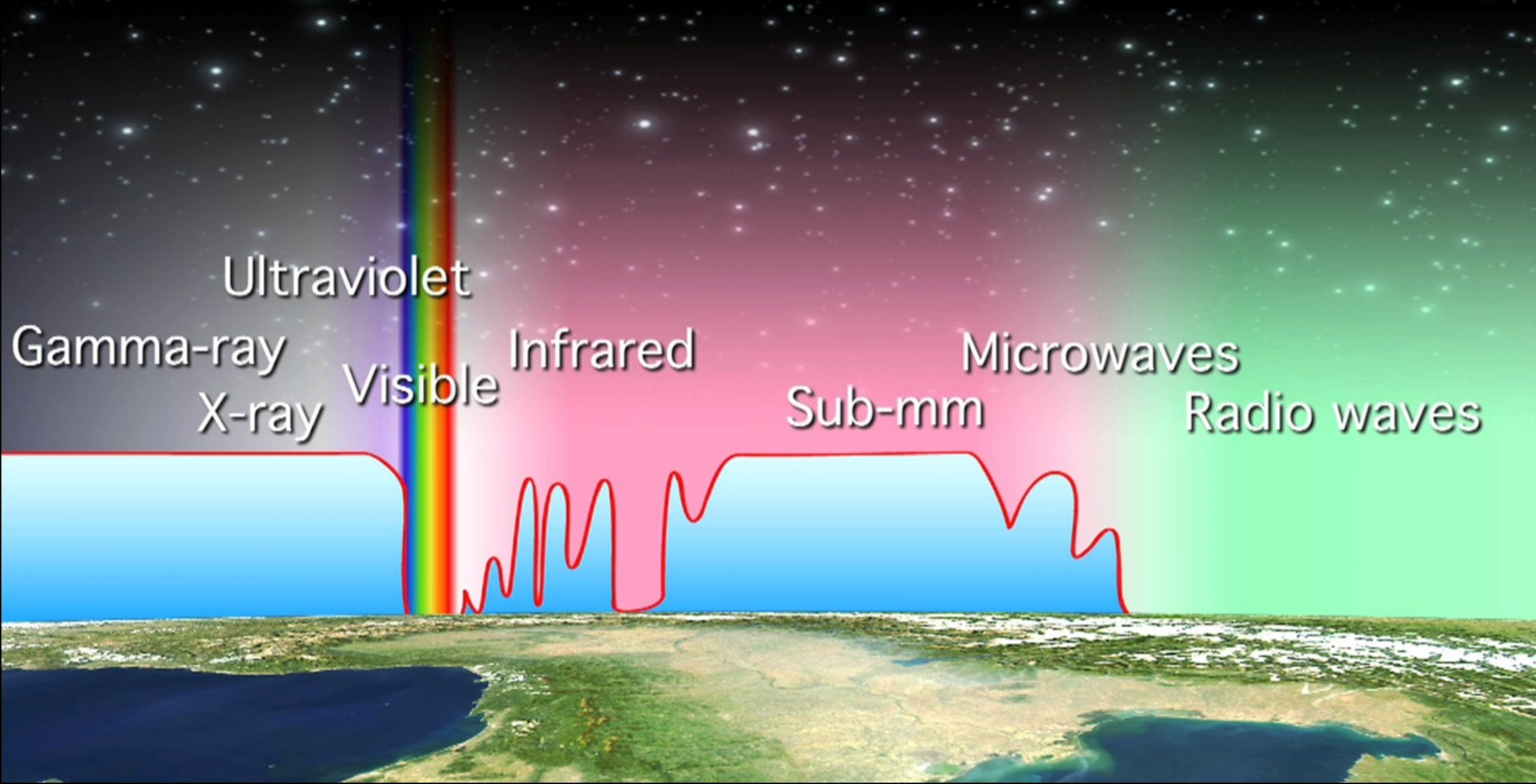
  $= 9\ x10^3 N_e{}^{1/2}$

## Total internal reflection

For *F* layer ($N_e$ = 2x10$^6$ cm$^{-3}$), $\lambda_p = 23.5m\ (\nu_p = 12\ MHz)$

# Absorption of Radiation

- The absorption by the atmosphere could be total or partial



# Atomic & Molecular absorption

Atomic: O, N

Molecular:

- Electronic

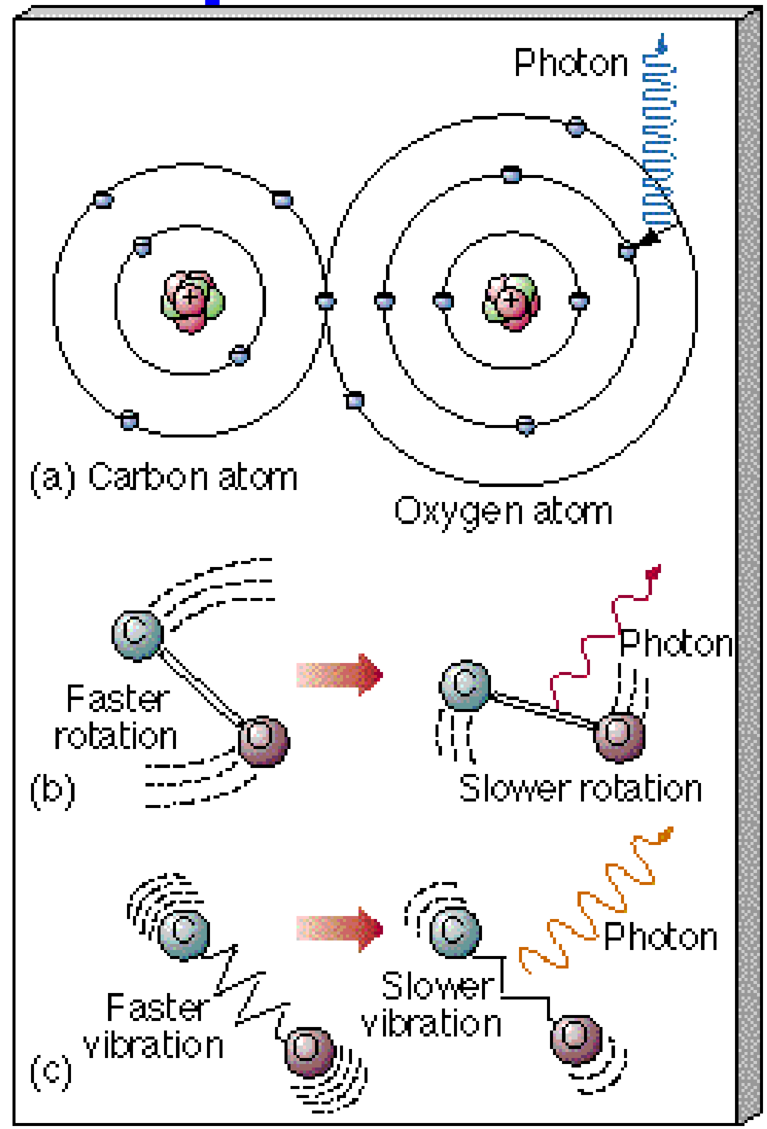
  $CH_4$, CO, $H_2O$, $O_2$, $O_3$, ...

- Rotacional:

  $H_2O$, $CO_2$, $O_3$, ...

- Vibrational-Rotational:

  $CO_2$, NO, CO ...

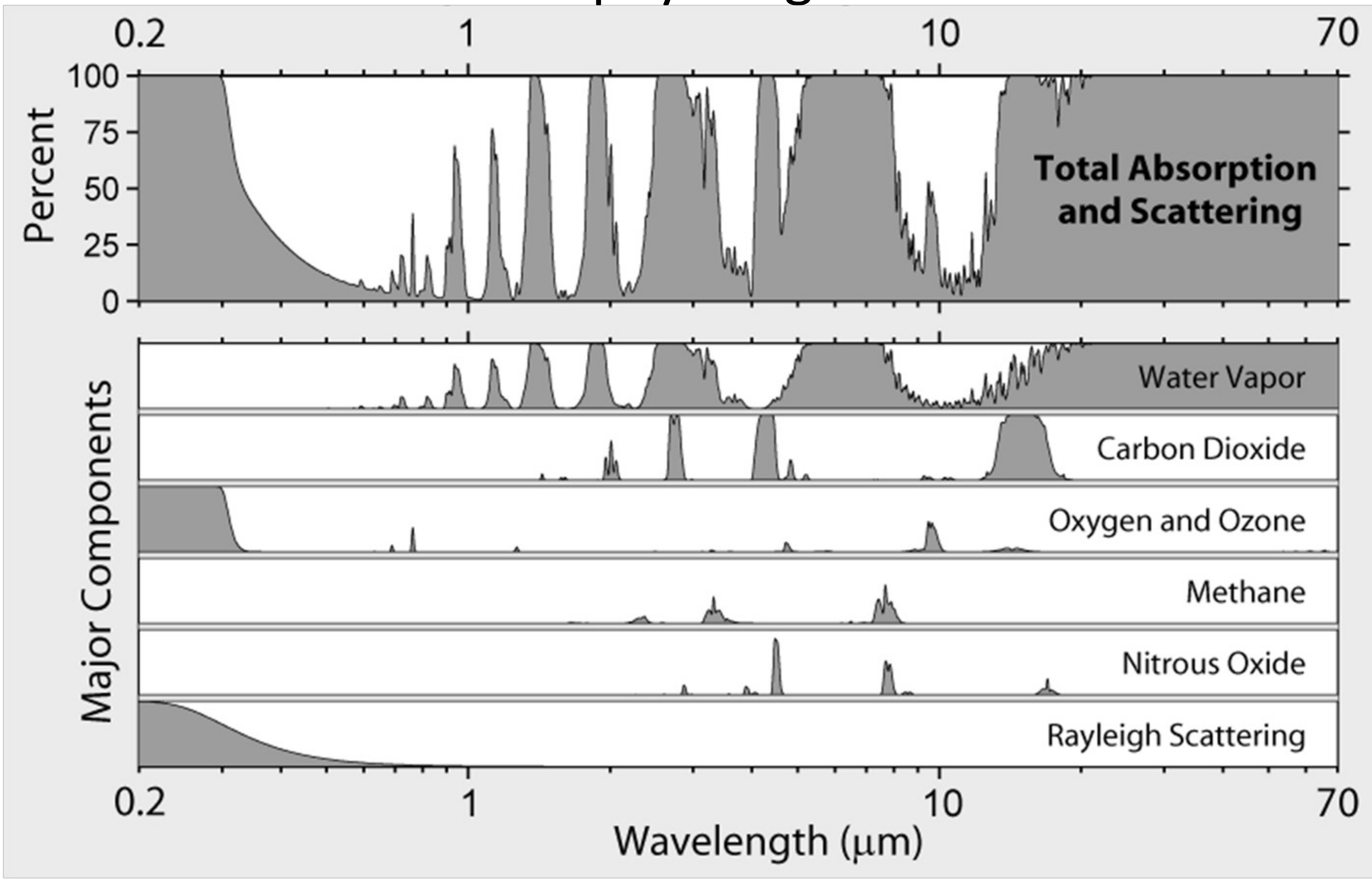



$$E_{el,v'',J''} = [T_e + G_v + F_v(J)]\, hc$$

# Atmospheric absorption bands

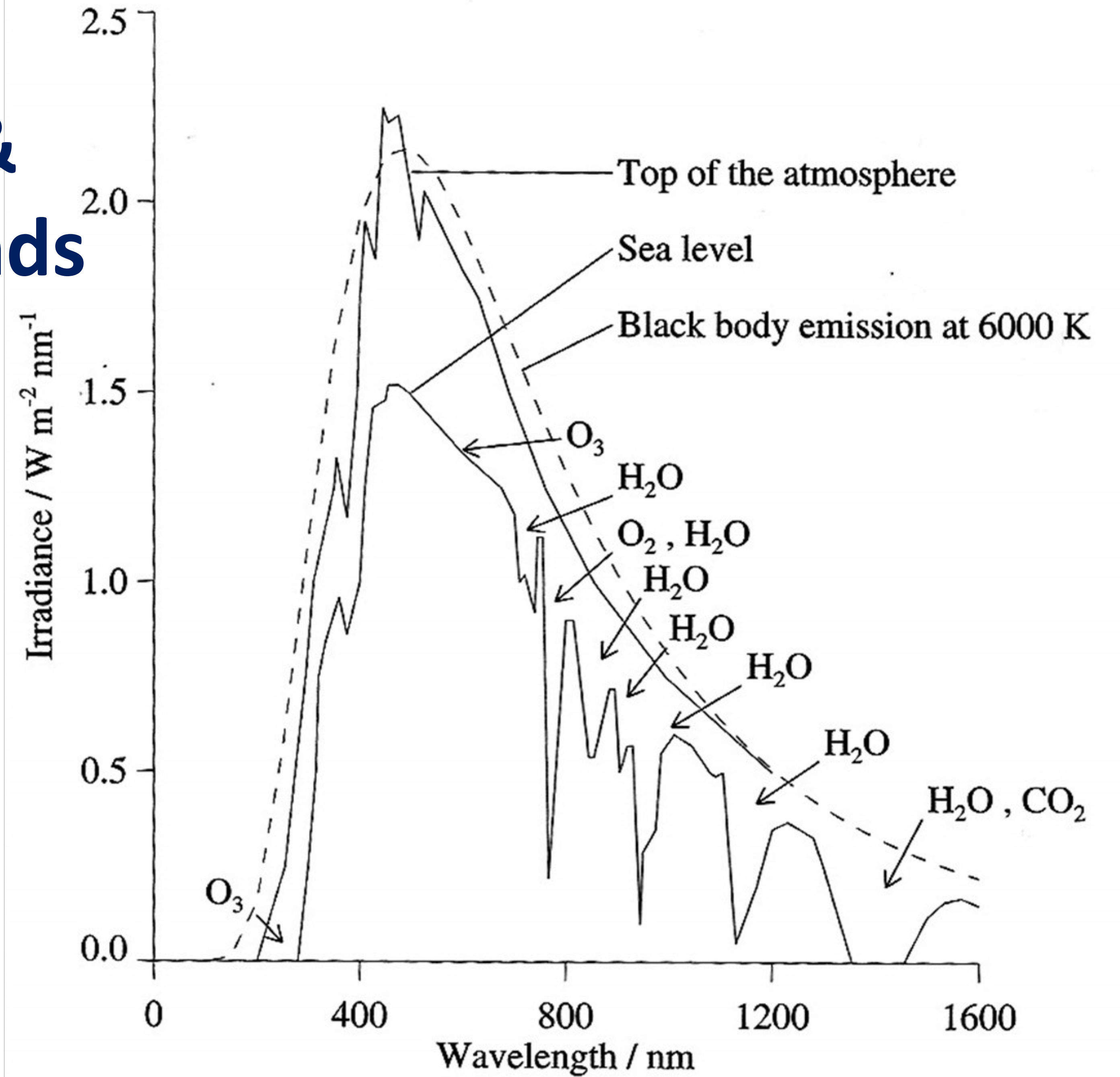
## *Telluric bands*

Atomic & molecular physics gives κ or σ for each



# Solar spectrum & telluric bands

In the optical & near infrared, $O_3$, $H_2O$ & $CO_2$ cause strong absorption bands in Earth's atmosphere



# γ **Cas** and telluric bands

At the near infrared, $H_2O$ cause strong absorption bands in Earth's atmosphere

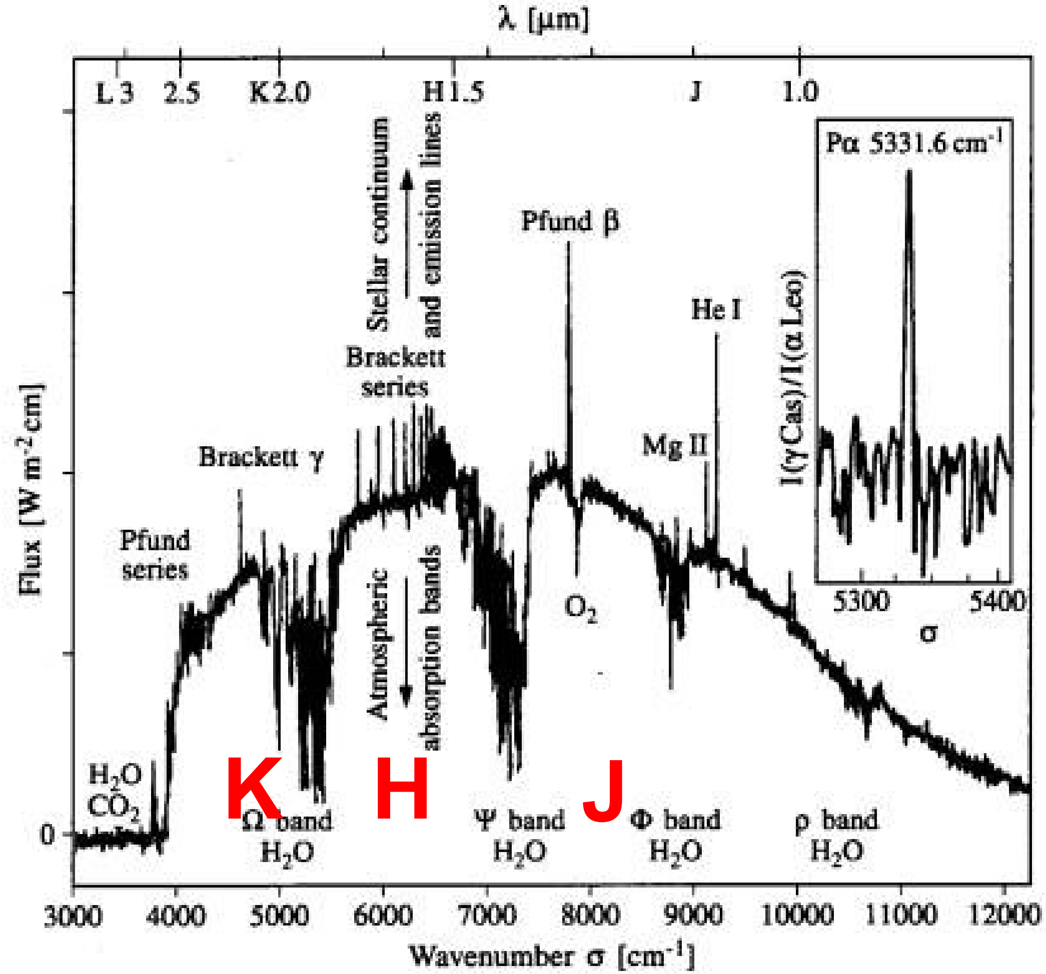
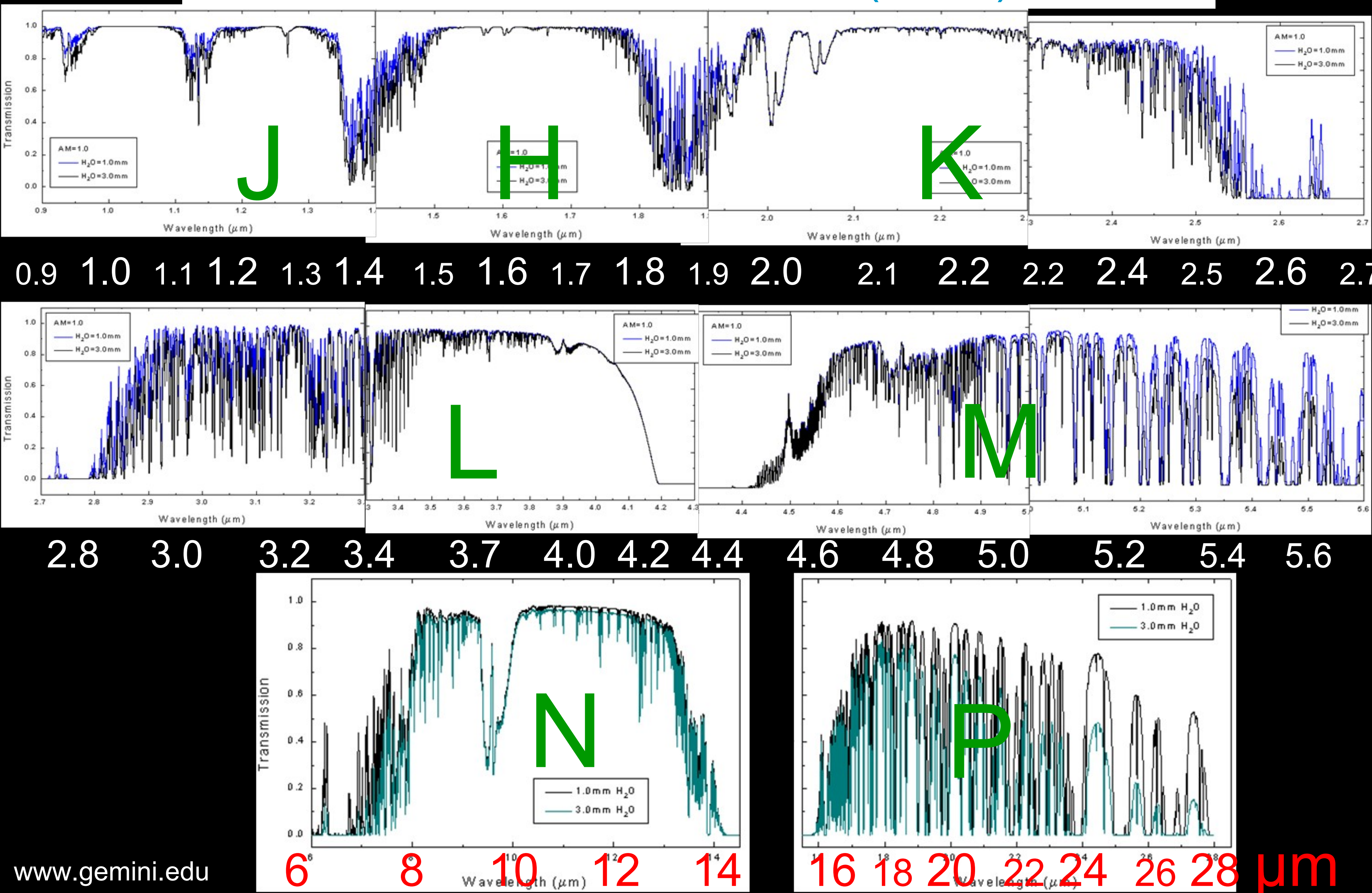



**Fig. 2.5.** Telluric absorption and spectroscopy: the spectrum of the star $\gamma$ Cas. The spectrum was obtained using the 3.6 m Canada-France-Hawaii telescope at the summit of Mauna Kea, Hawaii, USA. (4 200 m), with a Fourier transform interferometer (cf. Sect. 5.3.4), in the near infrared atmospheric transmission window, with a resolution of $\Delta\sigma = 0.5\,\mathrm{cm}^{-1}$. (Chalabaev A., Maillard J.-P., Ap. J. **294**, 640, 1984.) Atmospheric absorption bands are indicated, together with photometric windows I,J and K (cf. Sect. 3.3). The star has both a continuum and emission lines (mainly H recombination lines). The inset shows the 3–4 Paschen $\alpha$ line (5331.6 cm$^{-1}$) extracted from a heavily absorbed part of the spectrum: the spectrum of $\gamma$ Cas was divided by that of a reference star ($\alpha$ Leo) to eliminate atmospheric bands. As $\alpha$ Leo (spectral type B7) also has hydrogen lines, the absolute value of P$\alpha$ is not significant. Observation of P$\alpha$ would be impossible at lower altitude. (With the kind

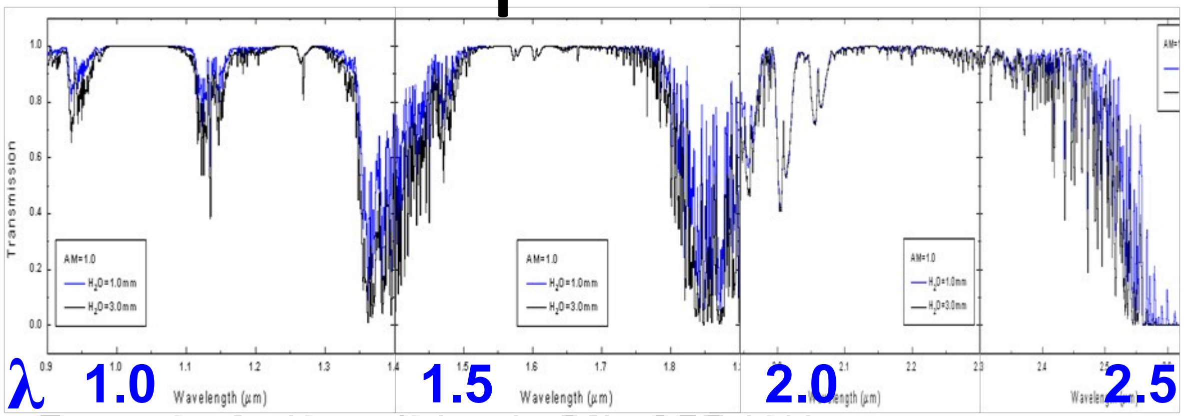
# Atmospheric transmission

Mauna Kea com H2O = 1mm(1mm) & 3mm

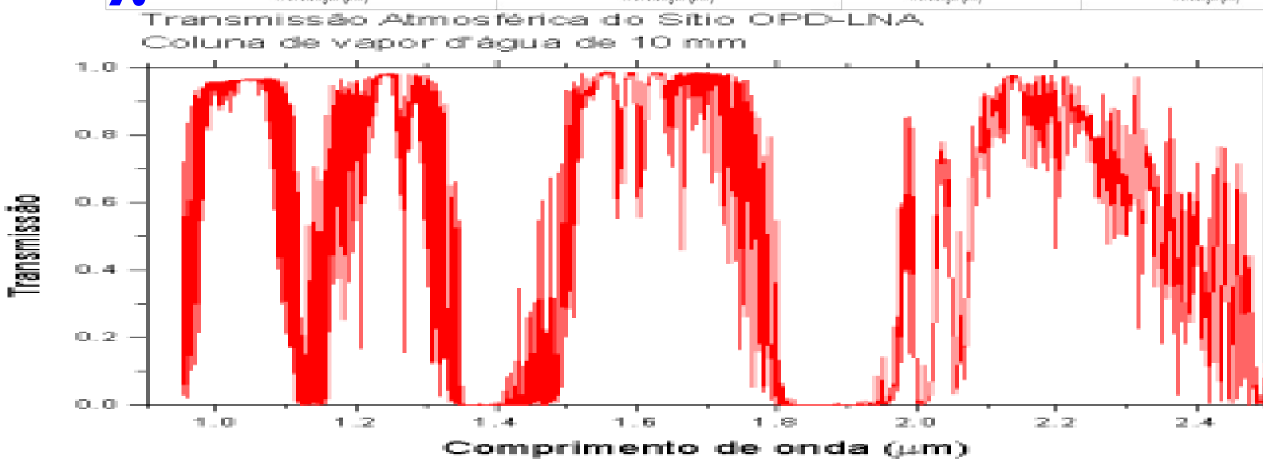



www.gemini.edu

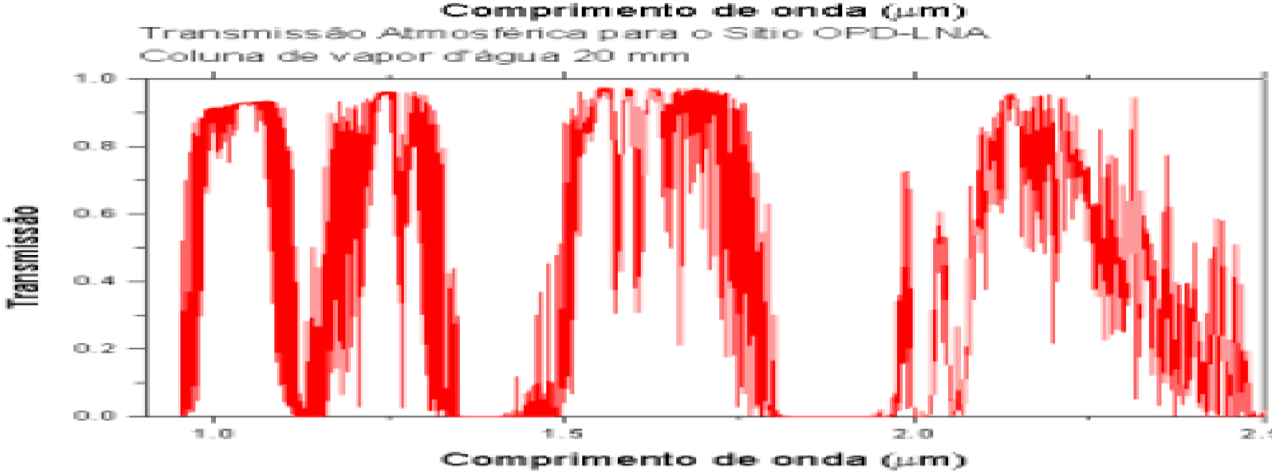
# Water Vapor: Mauna Kea vs OPD




Mauna Kea
h(1mm ,3mm)




OPD/LNA
h(10mm)
*Barbosa(2000)*




OPD/LNA
h(20mm)
*Barbosa(2000)*

# Optical depth

The optical depth along a vertical line, of a constituent *i* with mixing ratio $r_i(z)$ is:

$$\boxed{\tau(\lambda, z_0) = \int_{z_0}^{\infty} r_i(z)\rho_0(z)k_i(\lambda)dz}$$

The attenuation of an incident ray of intensity $I_0$ (top of the atmosphere) received at altitude $z_0$ and at an angle θ from the zenith, is:

$$\boxed{\frac{I(z_0)}{I_0(\infty)} = exp\left\{-\frac{1}{cos\theta}\sum_i \tau_i(\lambda, z_0)\right\}}$$

The sum is over all species that absorb

# Atenuation of radiation with altitude

Atmosphere totally opaque for $\tau = 10$

Ideally observatories are feasible for $\tau < 0.5$ (transmission > 61%)

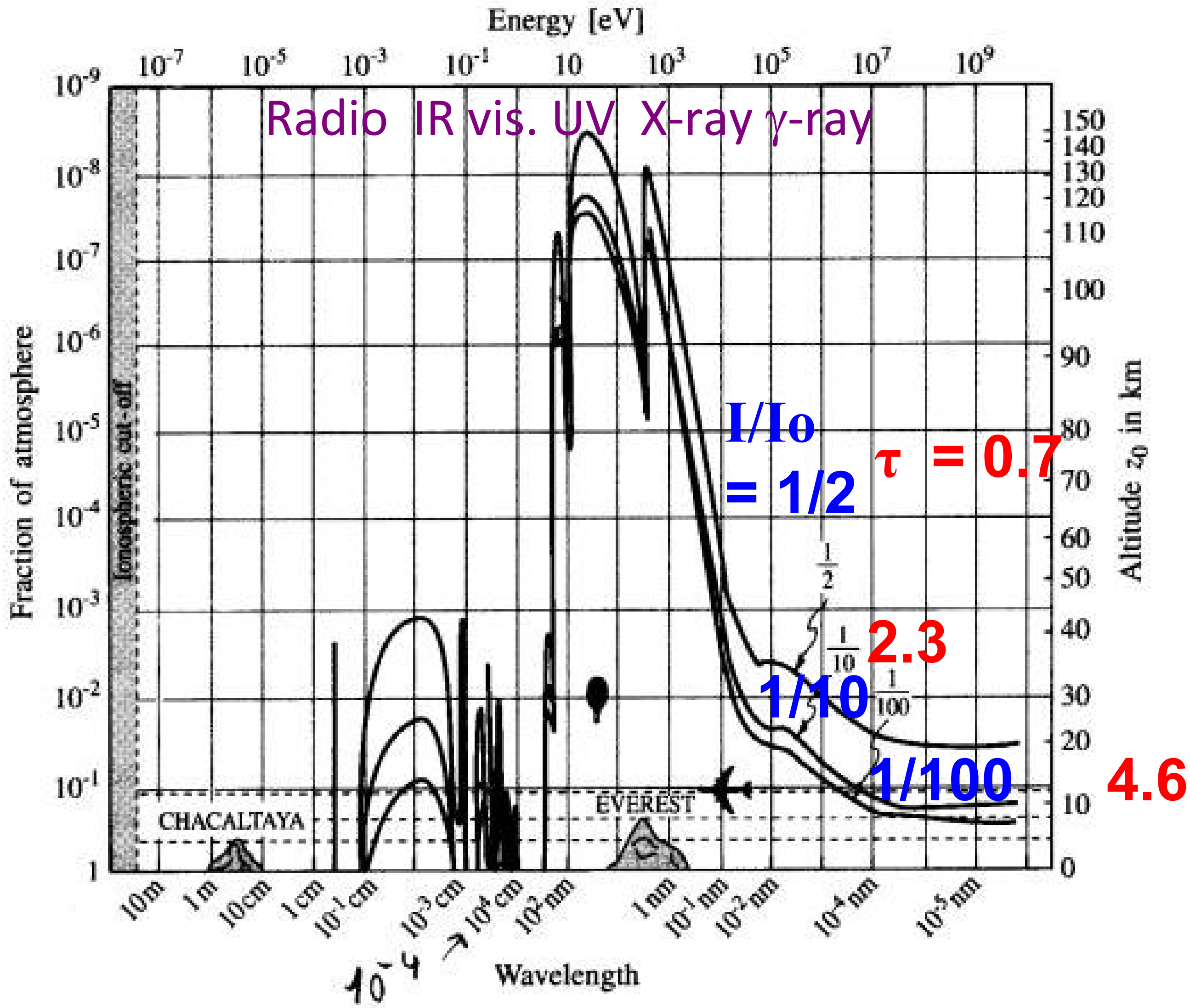


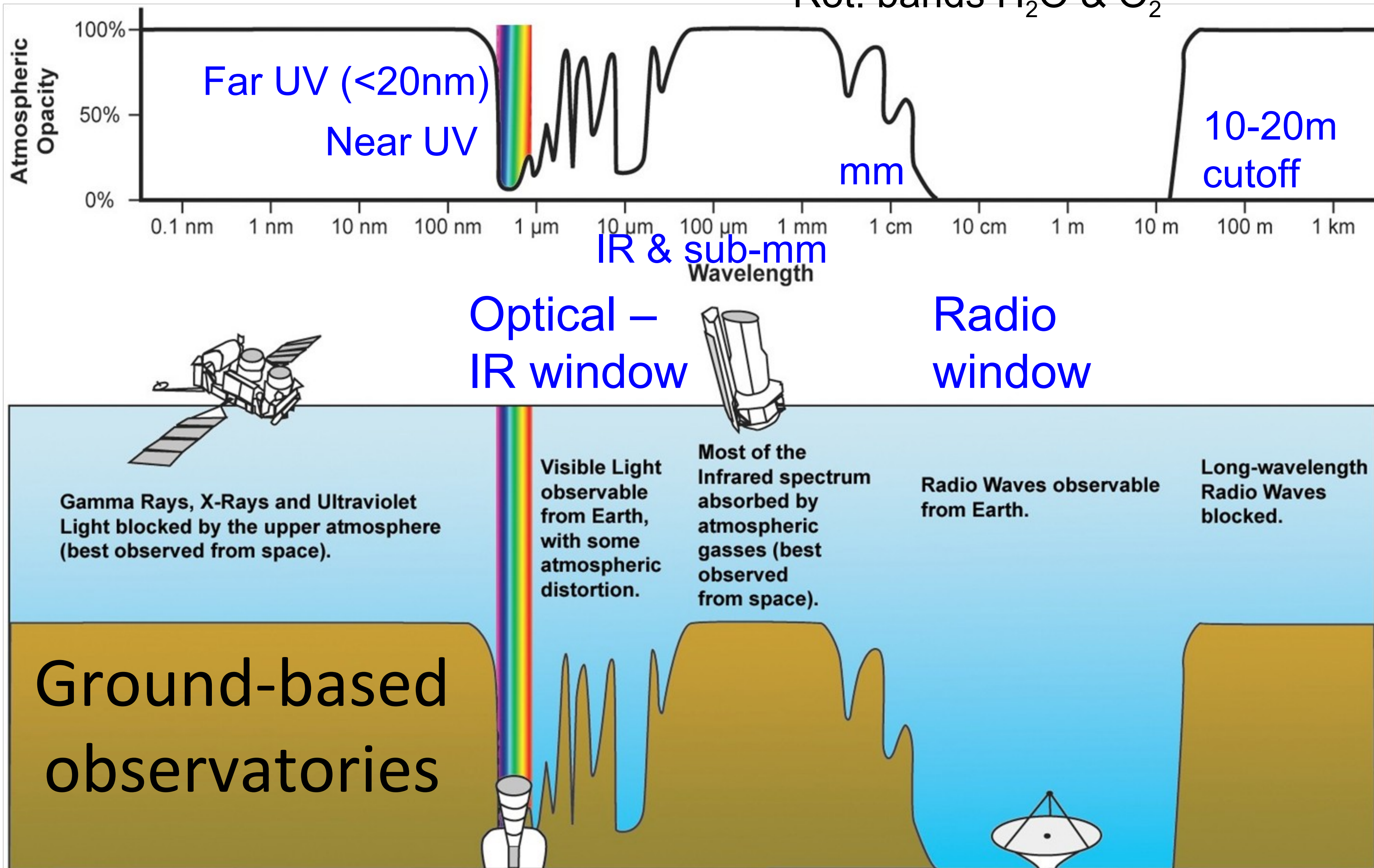

**Fig. 2.4.** Attenuation of electromagnetic radiation by the atmosphere. Curves give the altitude $z_0$ (*right-hand scale*) or the residual fraction of the atmosphere, in mass, above $z_0$ (*left-hand scale*), for three values of the ratio $I(z_0, \lambda, \theta = 0°)/I_0(\infty, \lambda)$. Chacaltaya is a site in the Andes (altitude ~6 000 m)

Continuum $N_2$
Elect bands $O_2$ , $O_3$, cont $O_2$

Bands (rot. & v-r)
$H_2O$ e $CO_2$

Rot. bands $H_2O$ & $O_2$

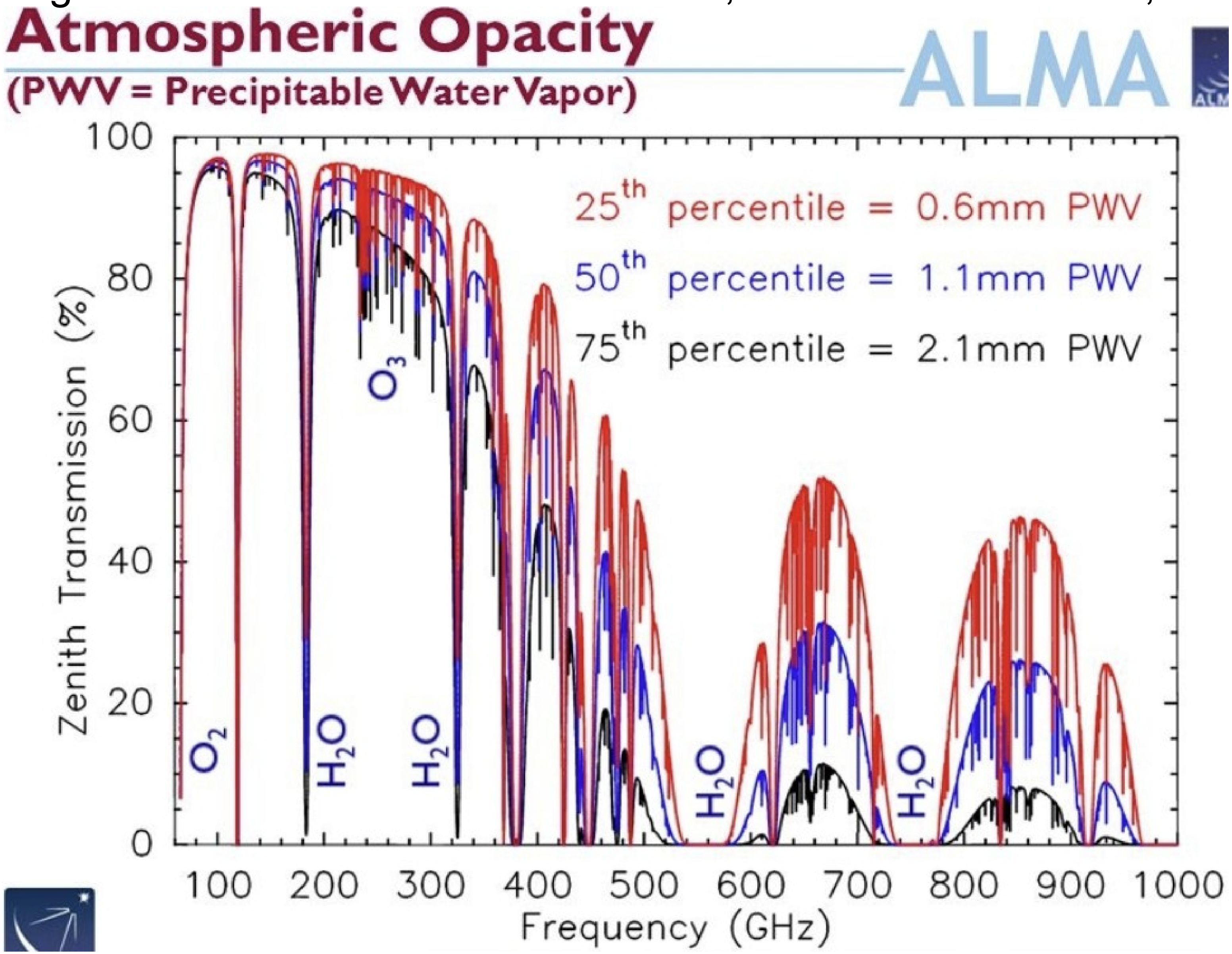
Ionospheric plasma



# ALMA at 5000 m (< 1 mm $H_2O$)

66 antenas working together at mm and submm

Wavelength 3 mm 1 mm 0,5 mm 0,3 mm



# Atmospheric emission

- The atmosphere emits by

florescence (*airglow*) & termically

FLUORESCENCE: recombination of e- & ions from diurnal dissociation; ex.:

$$\boxed{\mathrm{O_2 + h\nu \longrightarrow O_2^+ + e^-}}$$

- Continuum: 1-3 Rayleigh Å$^{-1}$
- Lines: 500 R

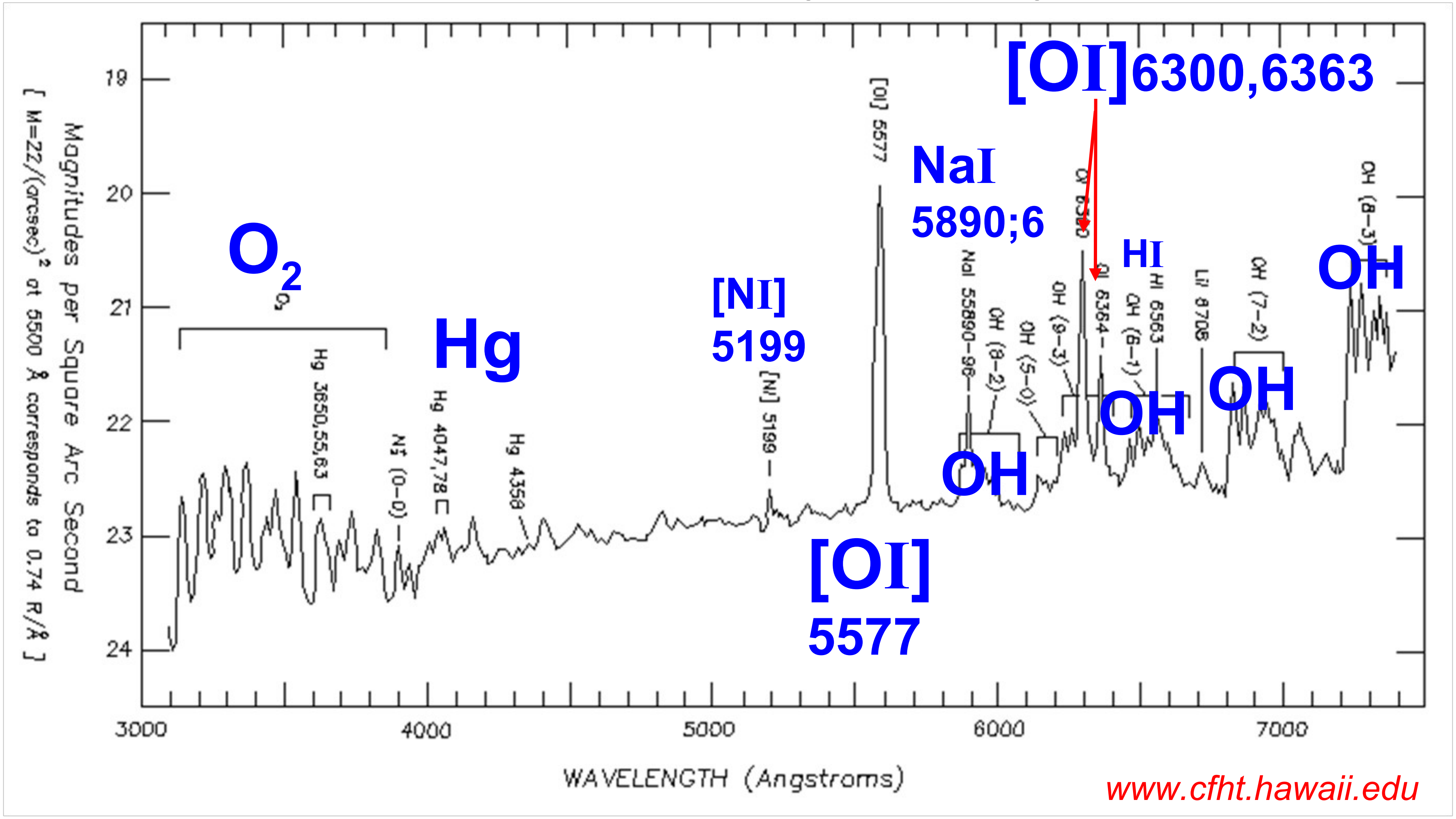
1 Rayleigh (R) = $10^6$ photons cm$^{-2}$ s$^{-1}$ str$^{-1}$

= $6.8\times10^{-17}$ Wm$^{-2}$um$^{-1}$arcsec$^{-2}$(em =550nm) = 22 mag arcsec$^{-2}$

- Main emitters: OI, NaI, $O_2$, OH, H

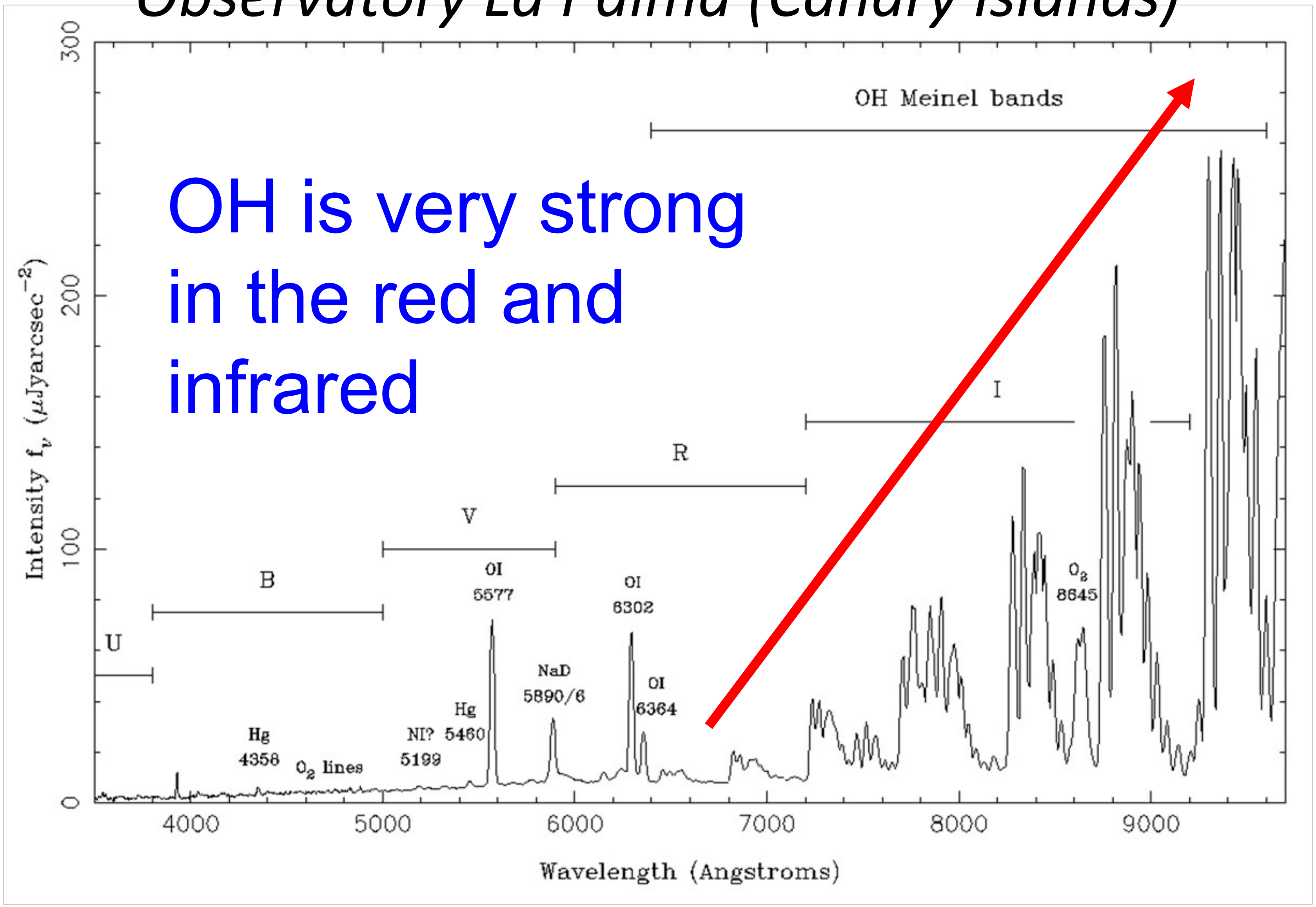
# Spectrum of the night sky (optical)

## Mauna Kea (Hawaii)



# Spectrum of the sky at night (optical & infrared)

*Observatory La Palma (Canary Islands)*



# Sky background for observations on ground and space near Earth

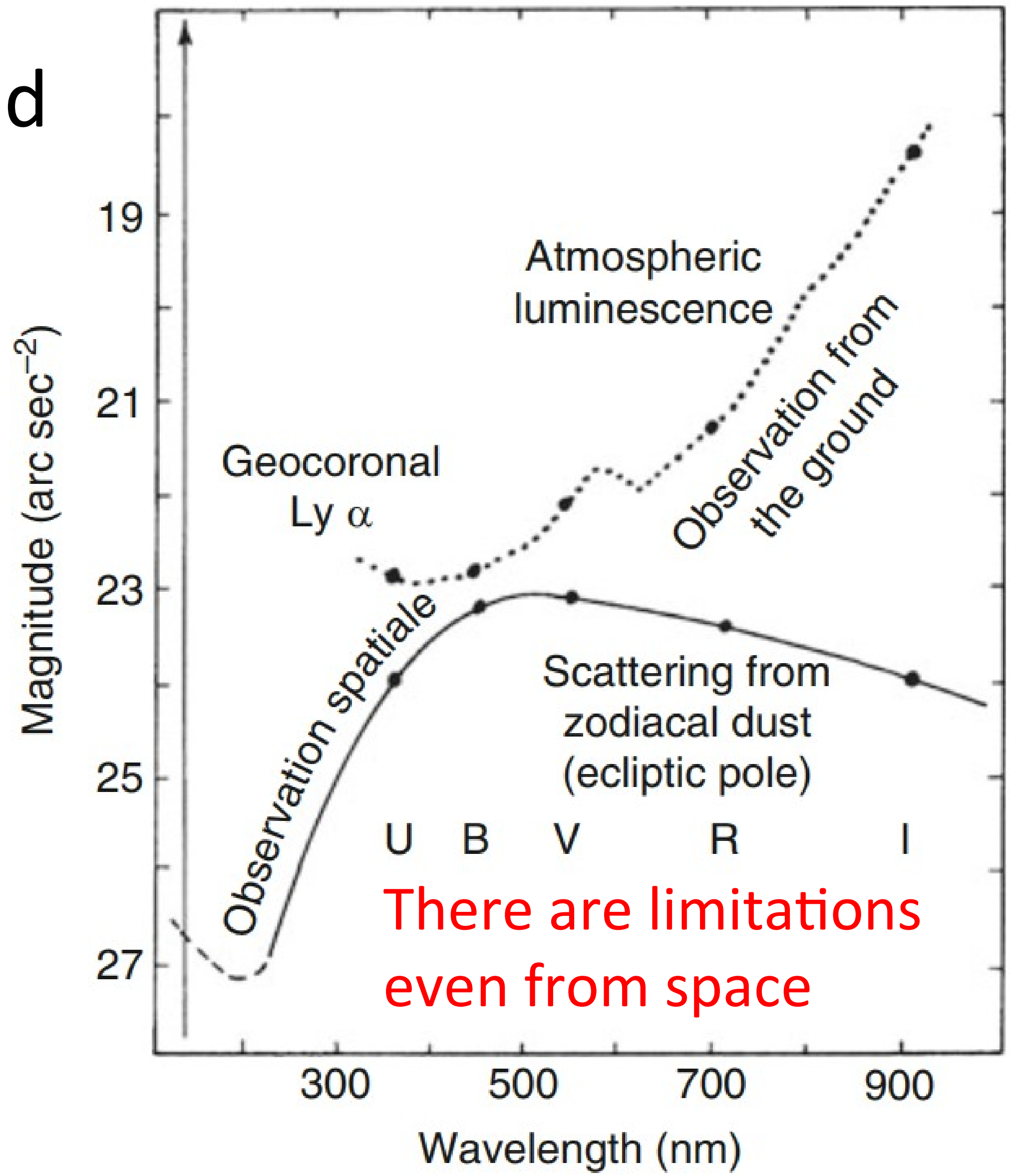
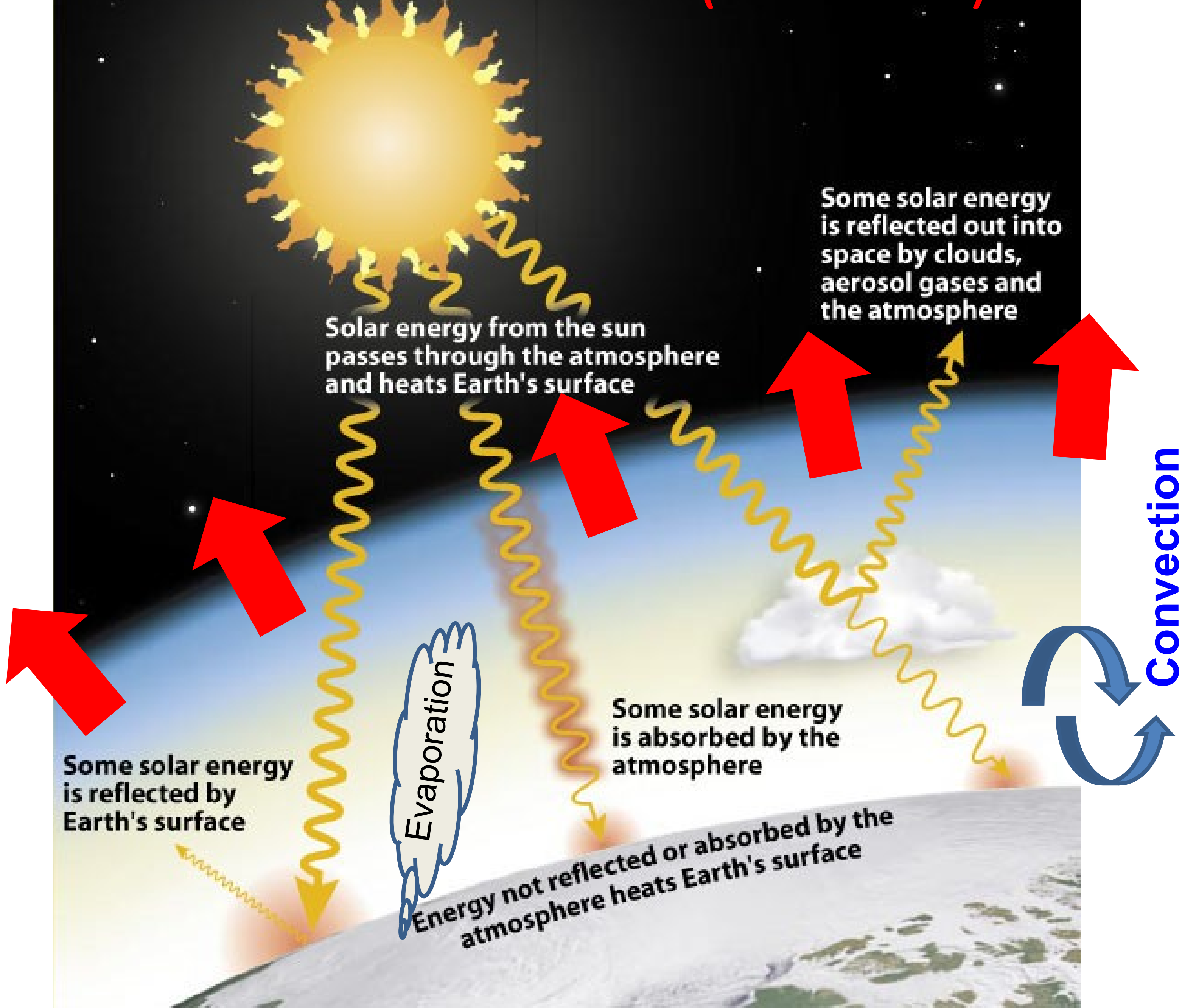



**Fig. 2.9** Visible and ultraviolet magnitudes of the sky background per square arc second, for observations from the ground and from space near the Earth. Letters denote the spectral bands of the photometric system (see Sect. 3.3), corresponding to the points (•). (After Courtès G., personal communication; Smith H.E., Burbridge E.M., Ap. J. **210**, 629, 1979; Leinert C., Sp. Sci. Rev. **18**, 281, 1975; Machetto F. et al, ESA-SP **1028**, 1980, European Space Agency)

# Thermal emission (infrared)



# Thermal emission

- Atmosphere could be considered a gas in LTE until 40-60km
- For $\tau << 1$ (shallow optical depth), the intensity of radiation at altitude z and zenithal distance θ, is:

$$I_\lambda(z) \approx \tau_\lambda B_\lambda(\bar{T}) \frac{1}{\cos\theta}$$

$B_\lambda$ : Planck function at mean temperature $\bar{T}$ of the atmosphere

$\tau << 1$ and $B_\lambda$ non-negligible, satisfied for:
Infrared (1 - 20 μm) & milimeter (0.5 – 2 mm) windows

# Thermal emission

$$I_\lambda(z) \approx \tau_\lambda B_\lambda(\bar{T}) \frac{1}{\cos\theta}$$

Using a mean temperature 250K:

**Table 2.3**
Mean thermal emission of the atmosphere. 1 jansky = $10^{-26}$ W m$^{-2}$ Hz$^{-1}$

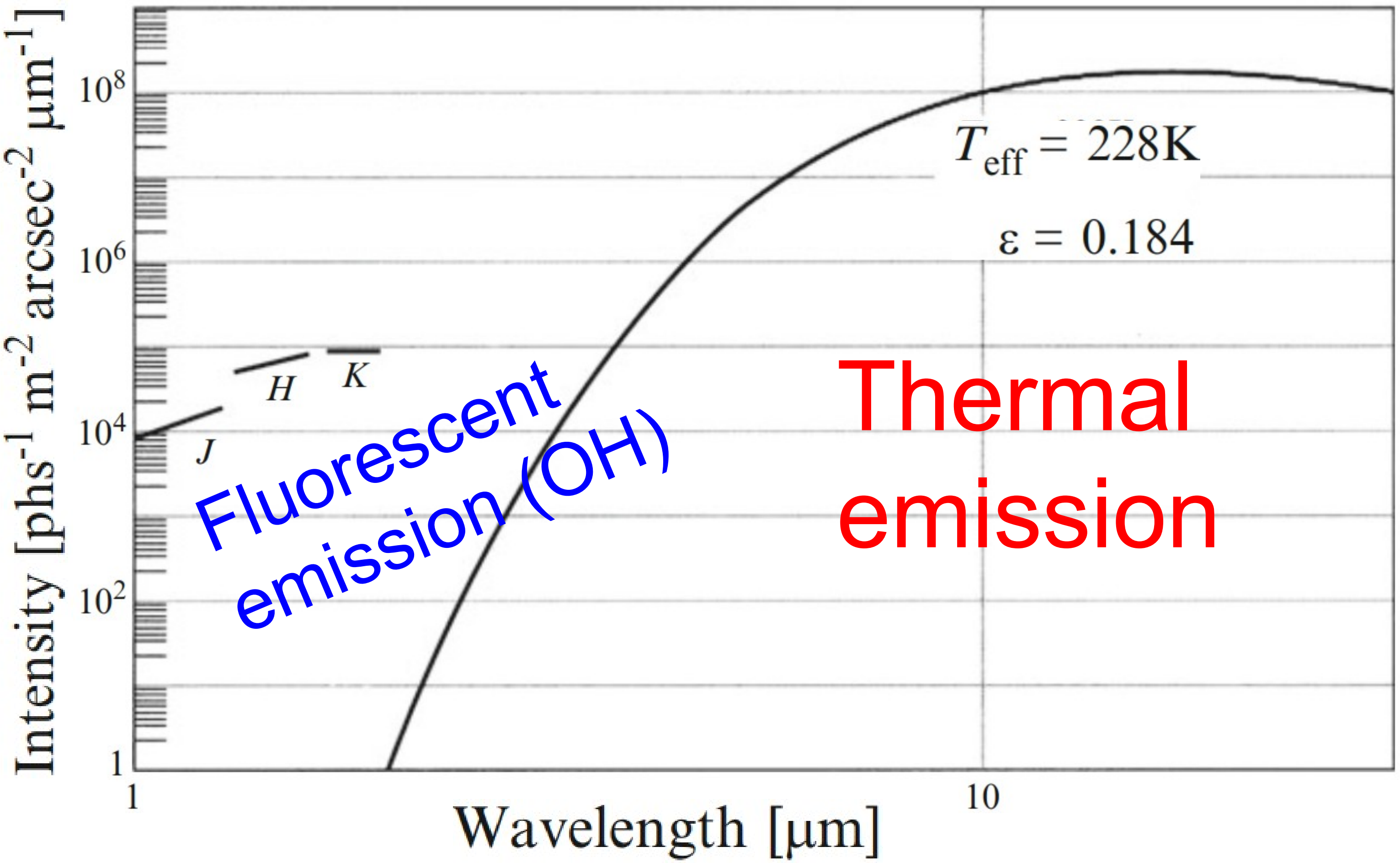
| Spectral band (see Sect. 3.3) | *L* | *M* | *N* | *Q* |
|---|---|---|---|---|
| Mean wavelength [μm] | 3.4 | 5.0 | 10.2 | 21.0 |
| Mean optical depth $\tau$ | 0.15 | 0.3 | 0.08 | 0.3 |
| Magnitude [arcsec$^{-2}$] | 8.1 | 2.0 | −2.1 | −5.8 |
| Monochromatic intensity [Jy arcsec$^{-2}$] | 0.16 | 22.5 | 250 | 2 100 |

Astronomical sources could be several orders of magnitude weaker than sky thermal emission (also could be problematic for sky fluorescent emission).

Léna, Lebrun & Mignard 1998
Observational astrophysics, 2nd Ed

# Sky background in the infrared: thermal emission vs. OH

Sky background emission in the infrared at the altitude of Mauna Kea (4200 m).



# Scattering of radiation: Rayleigh & Mie

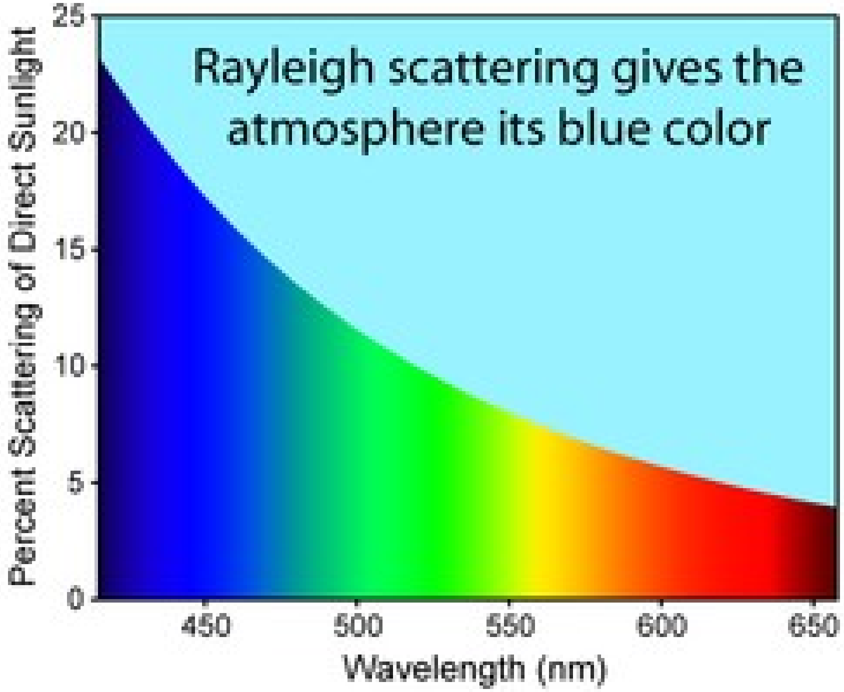
- Caused by molecules and aerosols in suspension
- Influence of ar molecules depends on altitude, *but aerosols depend on winds, weather, season, volcanic activity, industrial pollution*

# *Rayleigh scattering*

- For particles smaller than the light wavelength $\lambda$:

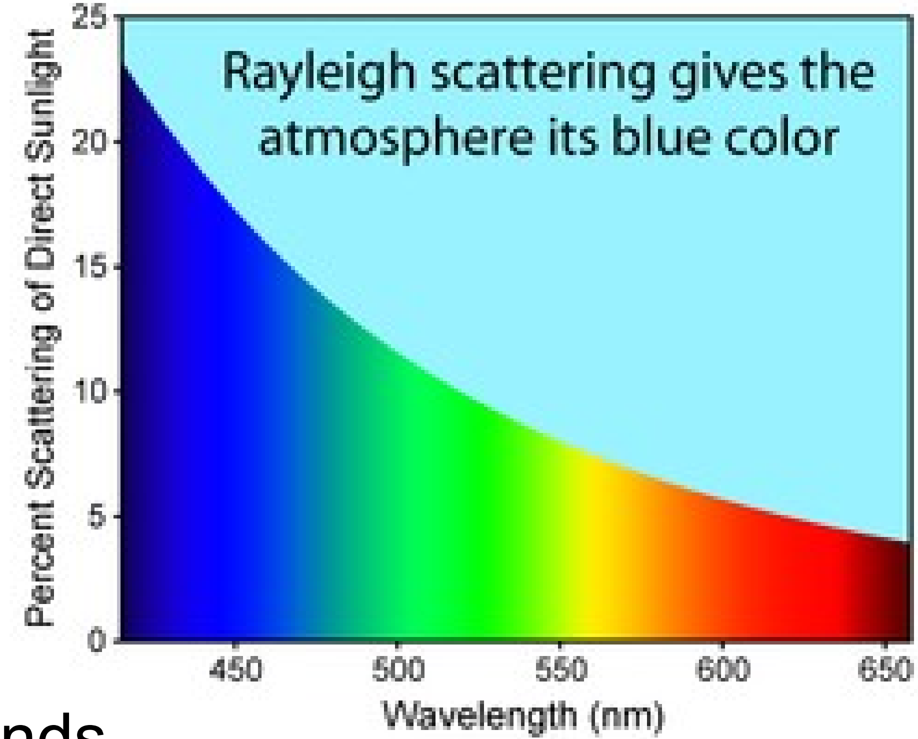
$$\sigma_R(\lambda) = \frac{8\pi^3}{3}\frac{(n^2-1)^2}{N^2\lambda^4}$$

- n: refraction index;
- N: density of molecules



# This is why the sky is blue

$$\sigma_R(\lambda) = \frac{8\pi^3}{3}\frac{(n^2-1)^2}{N^2\lambda^4}$$



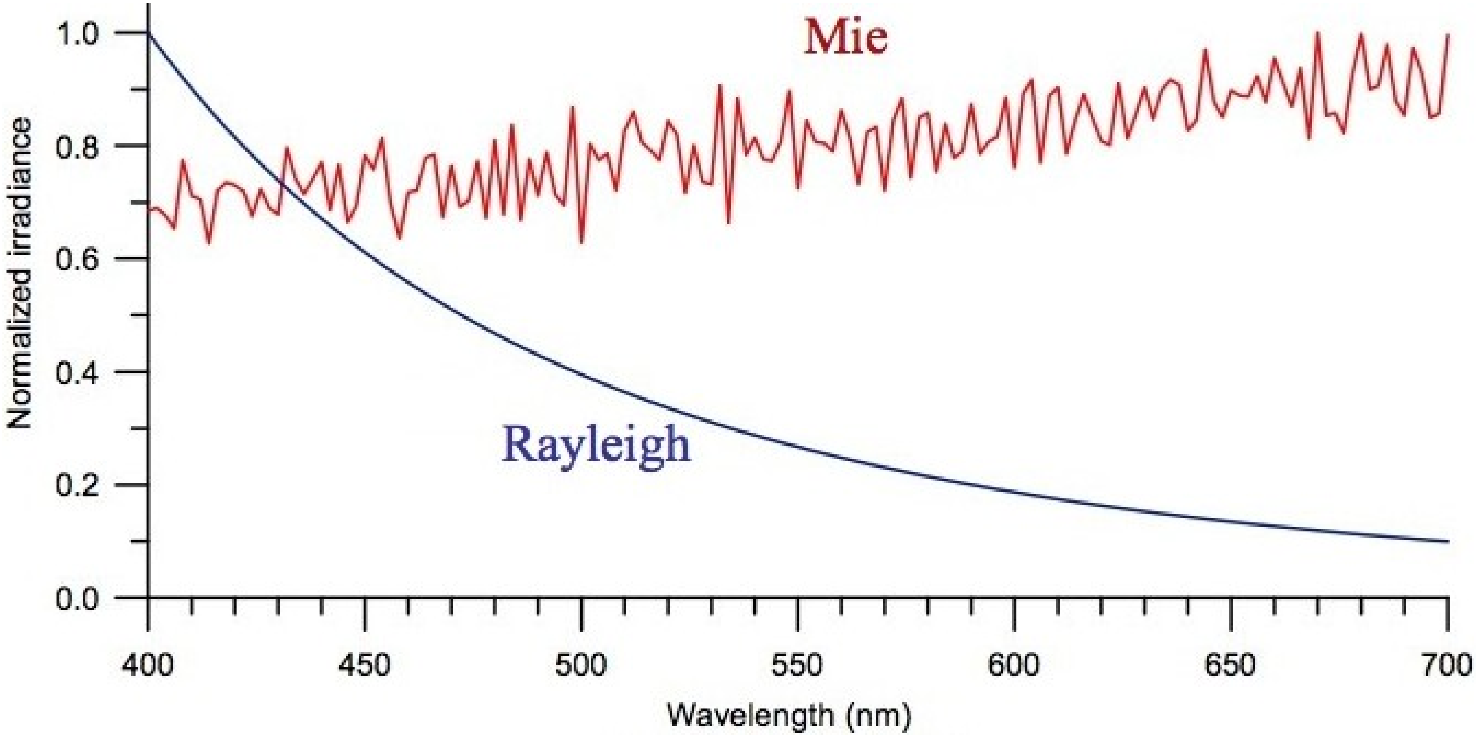

Rayleigh scattering also depends on the incident angle θ:

$$j = \sigma_R \frac{3}{4}(1+\cos^2\theta)\frac{d\omega}{4\pi} I$$

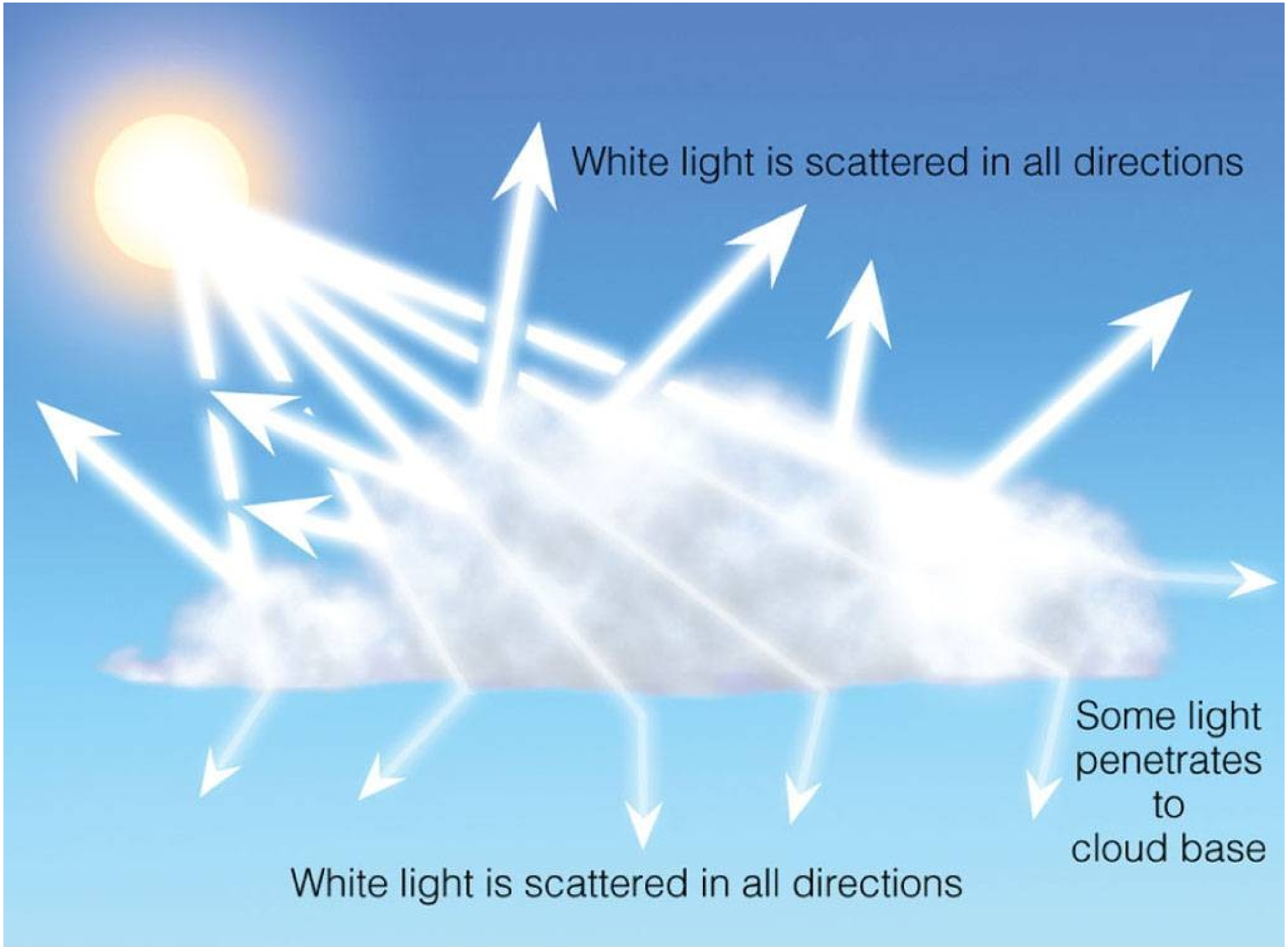
At z=2km: at $90^0$ from the Sun, λ=7000A, sky brightness is $10^{-7}$ of the Sun's disk

# Mie scattering

- Scattering by particles larger than $\lambda$ of light
- Does not depend much on wavelength



# Mie scattering



# Sky brightness during the day in the optical & IR

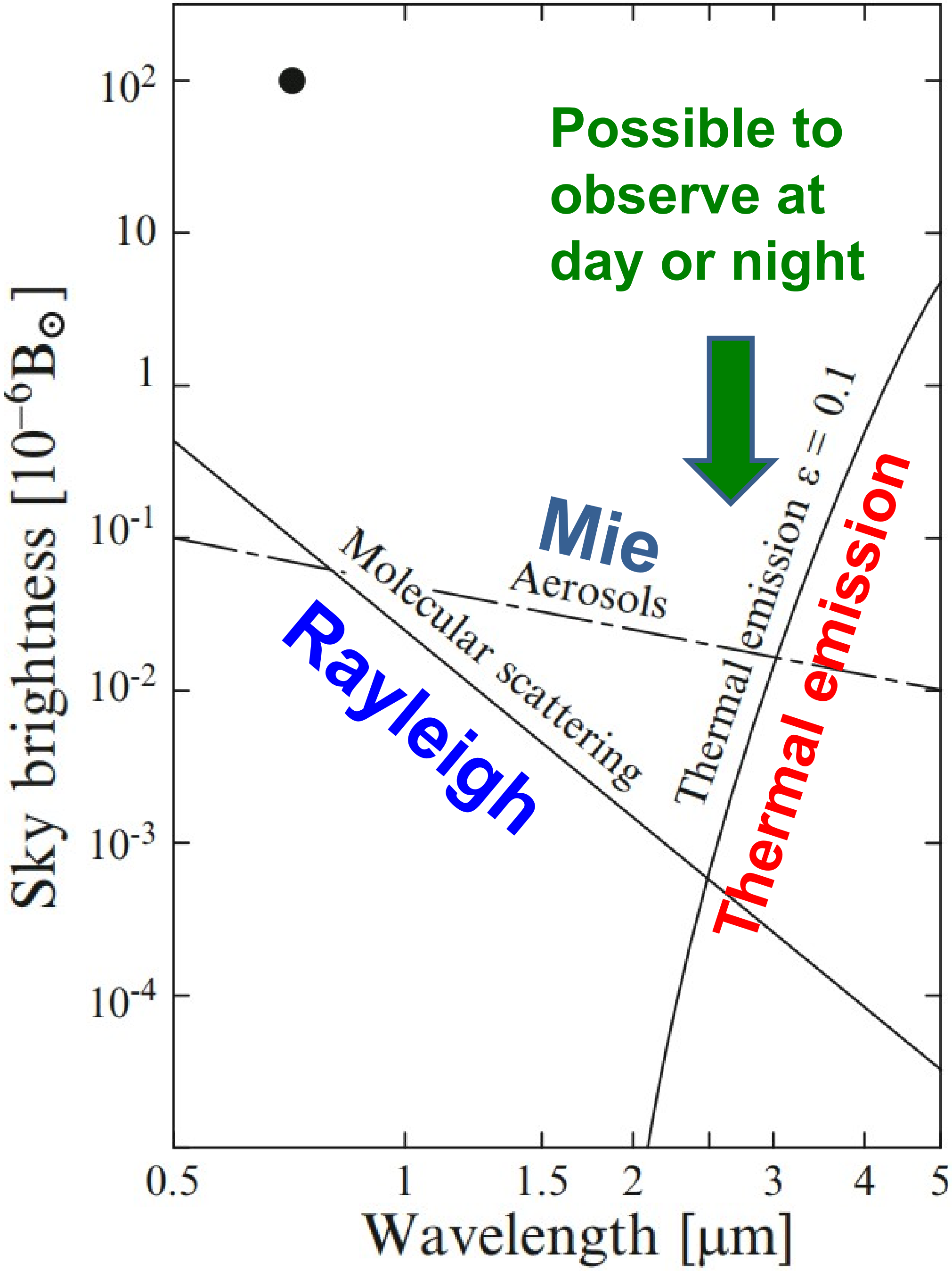



*Fig. 2.11 (Lena, Observational Astrophysics). Molecular scattering is given for the altitude z = 2000m, at $90^0$ from the Sun. The wavelength dependence is $\lambda^{-4}$. Thermal emission is also shown, assuming uniform mean emissivity of 0.1.*

*The dashed line shows the possible additional contribution due to aerosols, varying as $\lambda^{-1}$. For comparison, (•) marks the sky brightness measured at 0.5 arcmin from the Sun's limb at Kitt Peak (Arizona)*

# Other atmospheric factors: Atmospheric turbulence

Vincent *van Gogh*

# Sources of turbulence by different obstacles

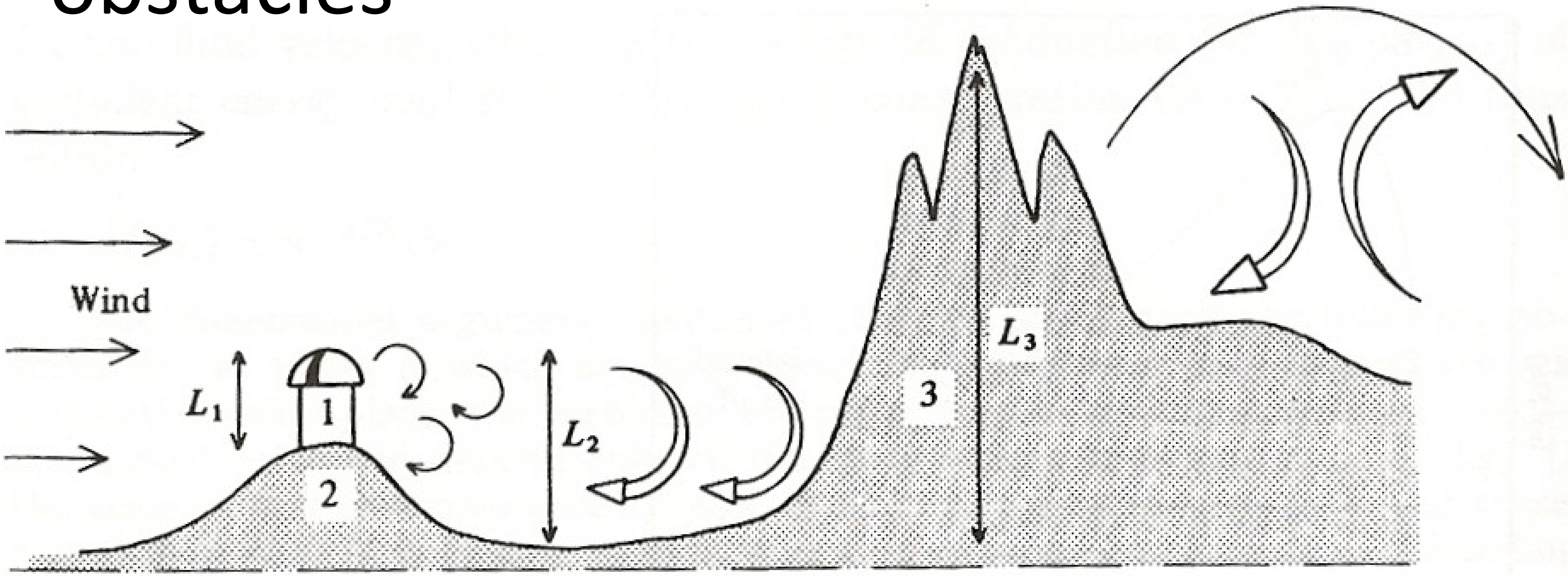
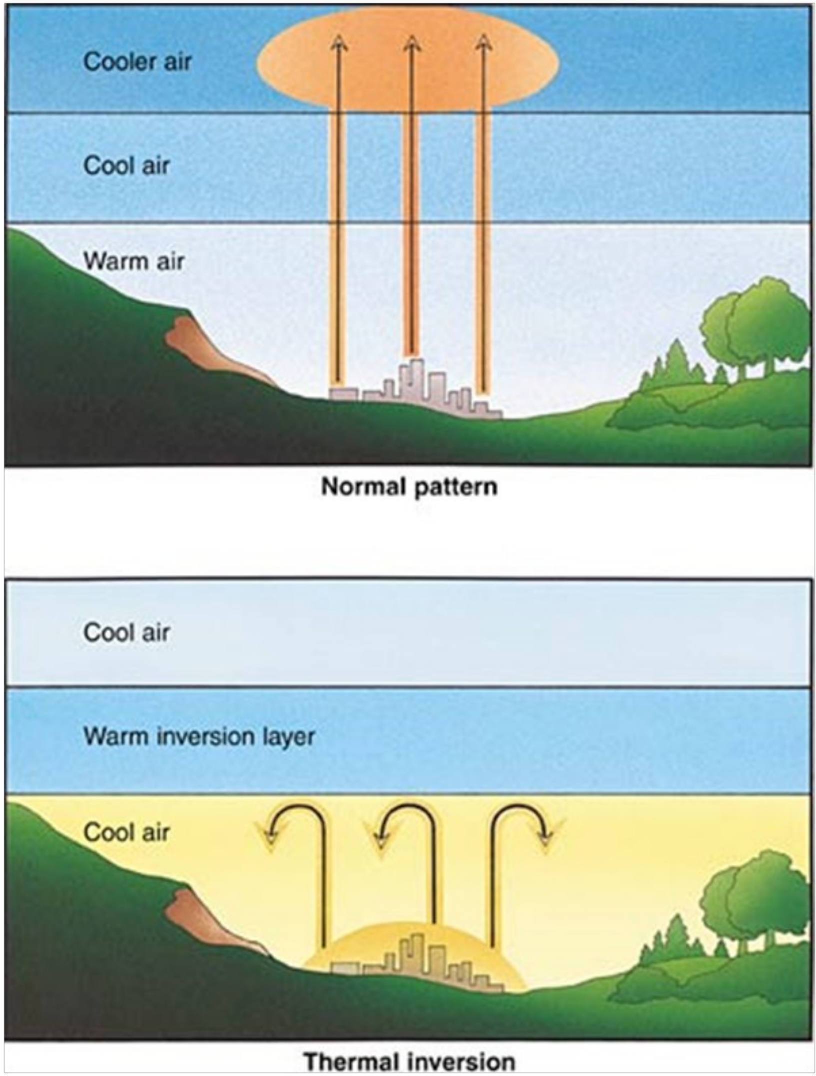



**Fig. 2.13.** Schematic representation of the generation of turbulence in the atmosphere by different obstacles. The amplitude of the temperature fluctuations depends on the amplitude of the turbulence and on the deviation of the actual temperature gradient from the adiabatic gradient. The scales $L_1$, $L_2$, $L_3$ are characteristic of the external scales of turbulence caused by wind around the obstacles 1, 2 and 3

# Other atmospheric factors: **inversion layer**

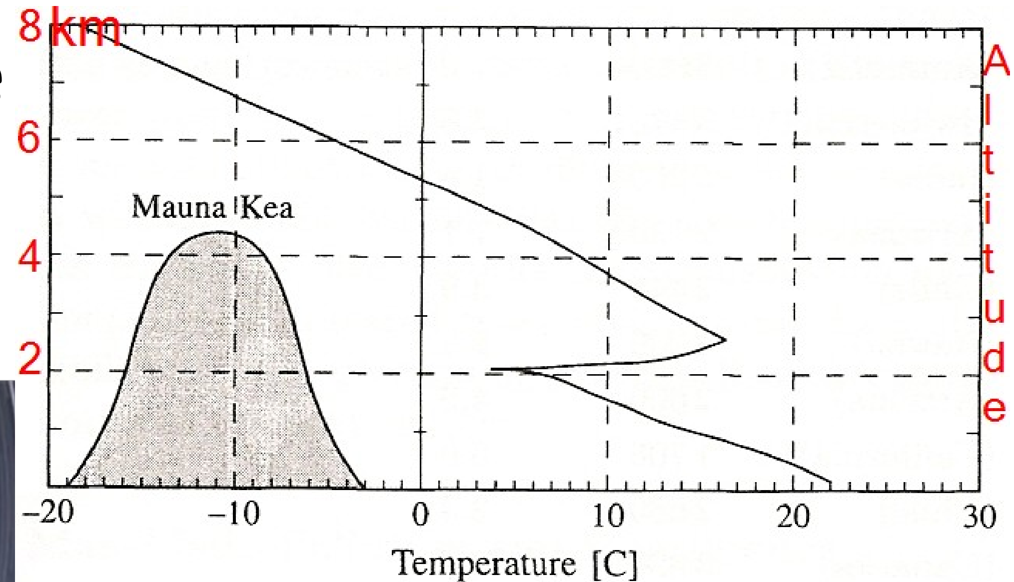
- Important factor to choose an astronomical site
- Inversion layer ~ 2km, but could occur at lower *z*



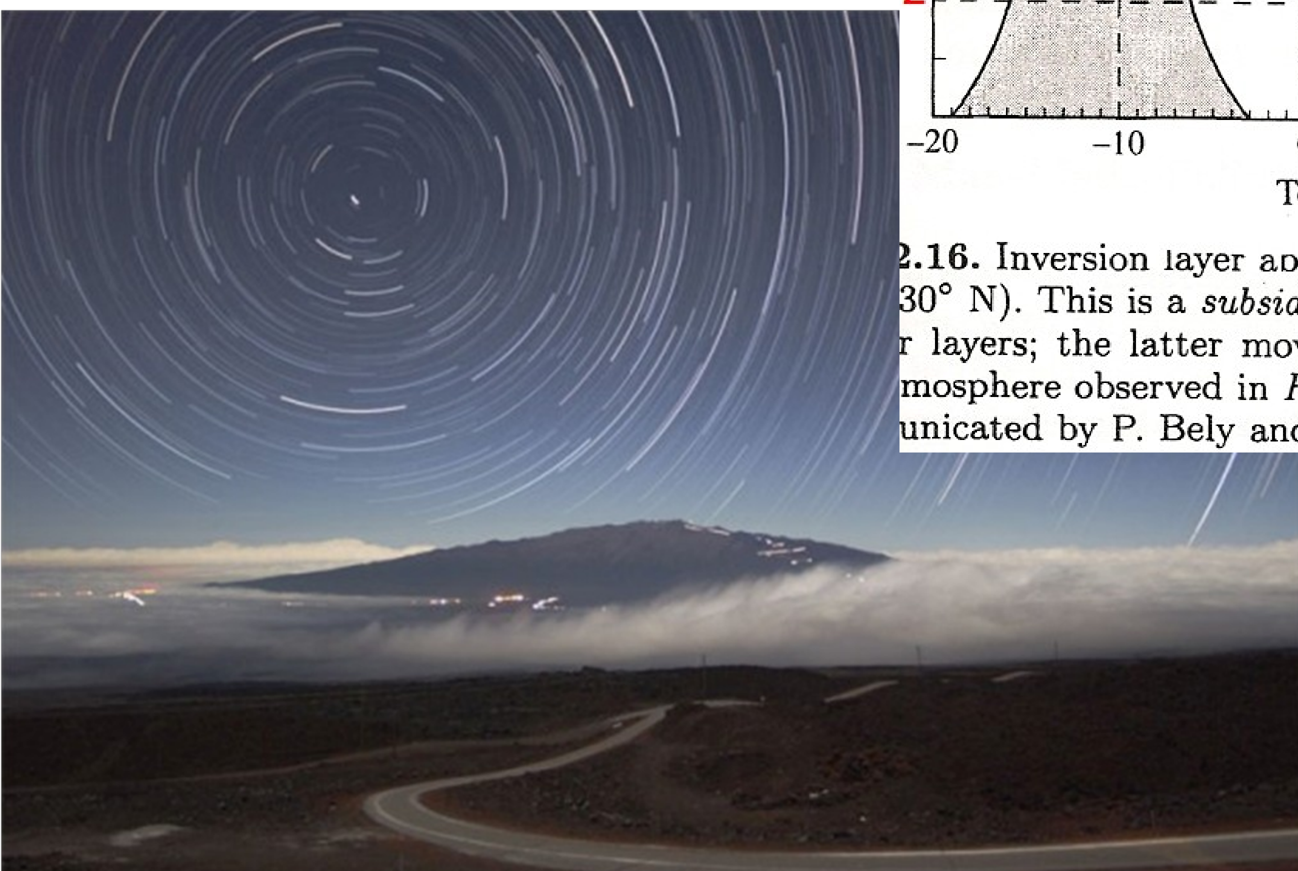

São Paulo, 6af, 23 maio 2008, 08h30m *www.estadao.com.br*

# Inversion layer

Inversion layer above the pacific ocean around the Big Island of Hawaii




2.16. Inversion layer above the Pacific Ocean, near the isl
30° N). This is a *subsidence inversion*, caused by reheatin
r layers; the latter movement itself is caused by the gen
mosphere observed in *Hadley cells*. (Sounding balloon mea
unicated by P. Bely and the Hilo Weather Bureau, Hawaii



www.gemini.edu

# High altitude → less clouds

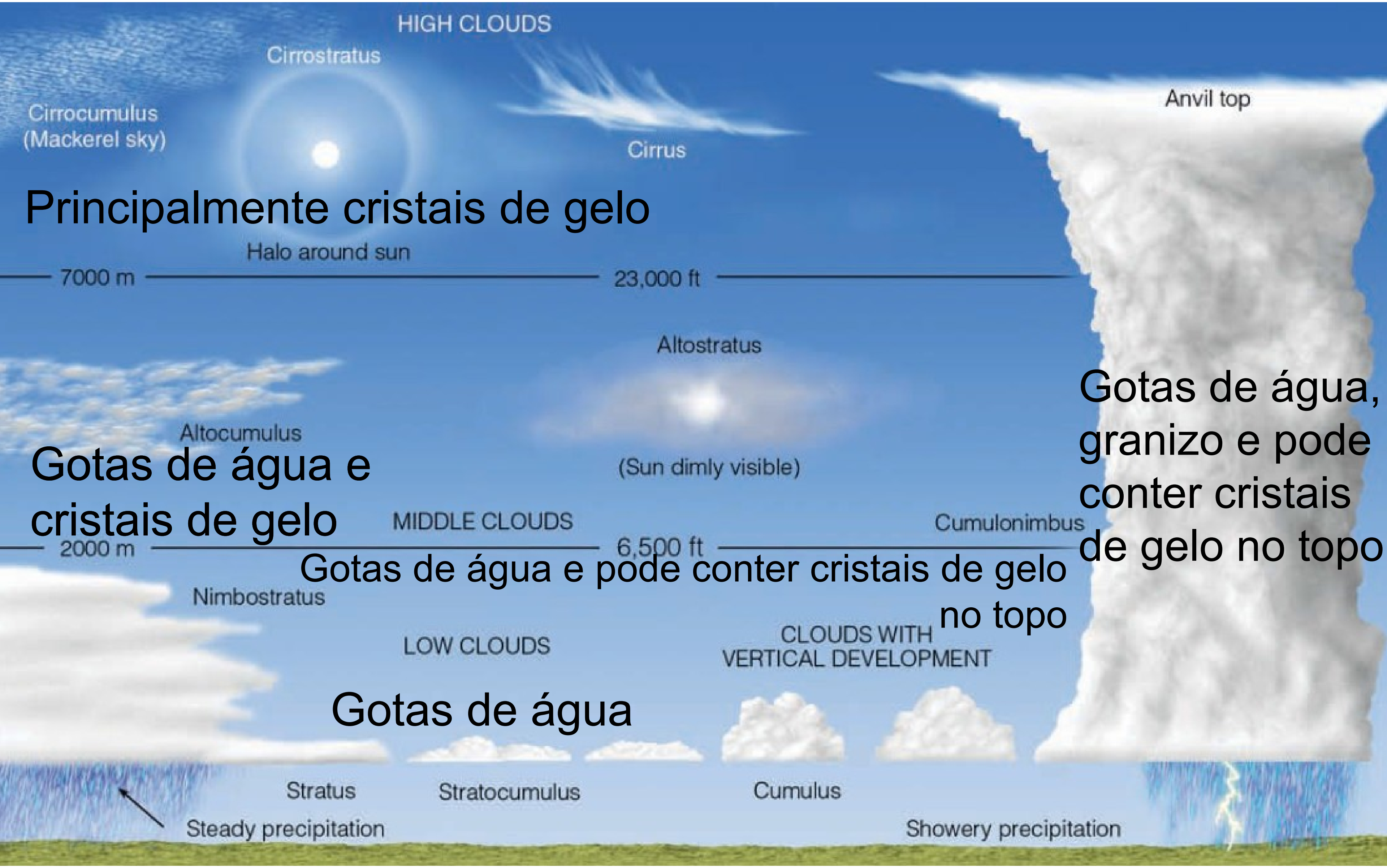



FIGURE 5.24 A generalized illustration of basic cloud types based on height above the surface and vertical development

# ESO / La Silla Observatory, 1/10/2013

## La Silla - MeteoMonitor

| | Current | | Average | |
|---|---|---|---|---|
| Humidity: | 50.0 | | 50.0 | % |
| Temperature: | 4.0 | | 4.0 | °C |
| Dew Point | -6.0 | | -6.0 | °C |
| Wind Speed: | 11.0 | | 11.0 | m/s |
| Atm. Pressure: | 766.4 | | 766.4 | hPa |
| Sun Altitude: | 6. | | | ° |
| DIMM Seeing: | 1.08 | arcsec | | |

**Last Update**

UT: 2013-10-02 10:50

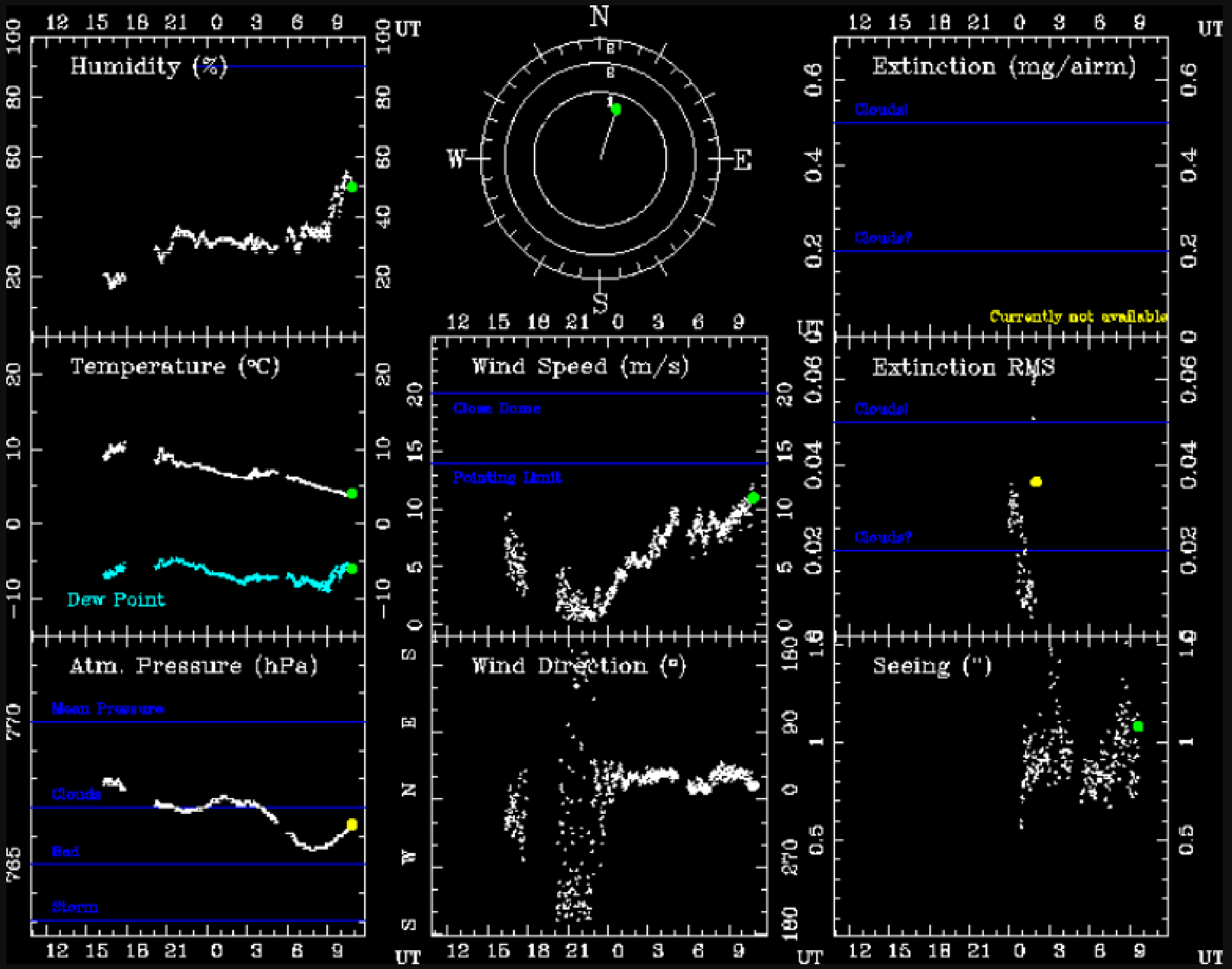
JD: 2456567.951

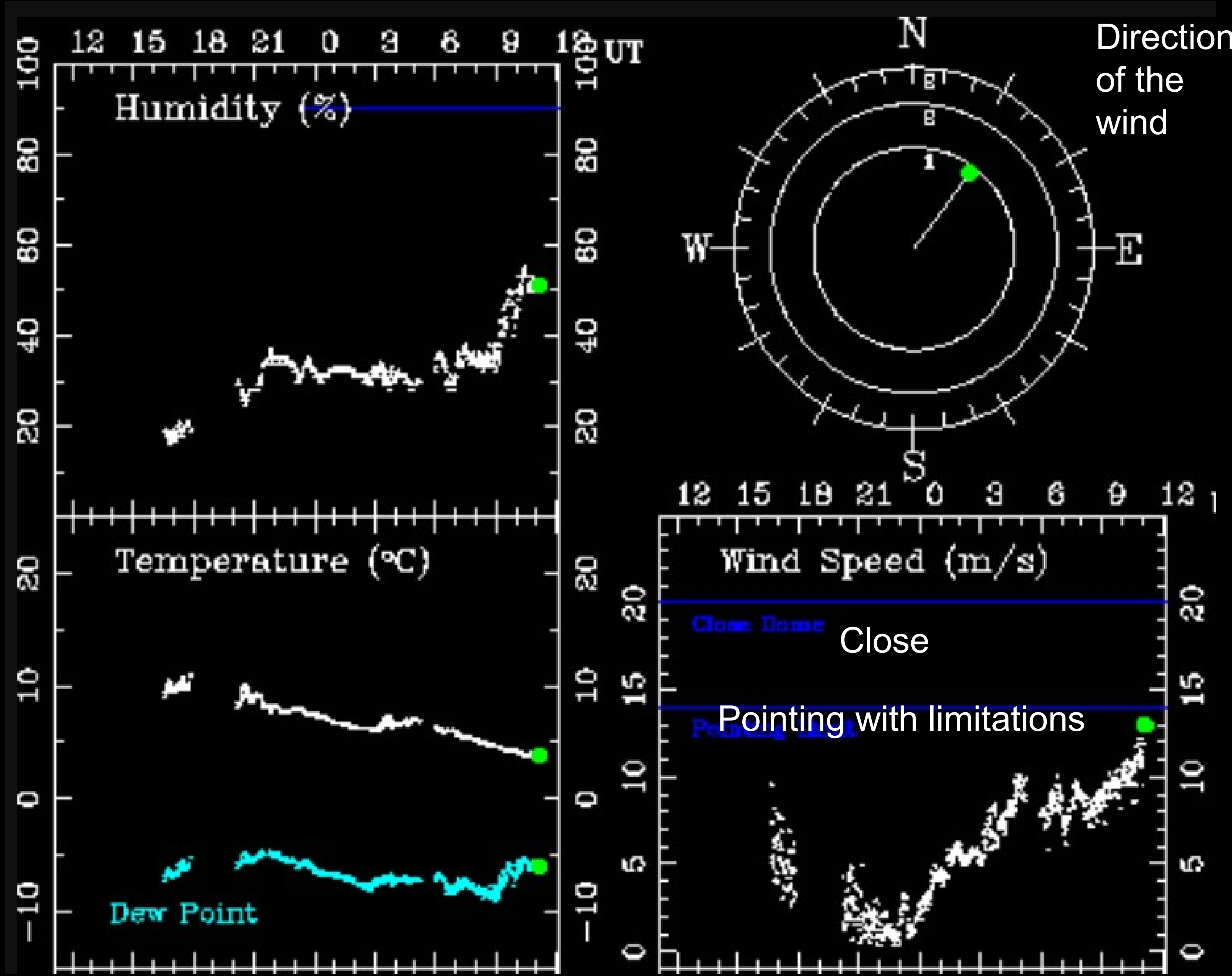
ST: 06:52

Update | PRINT GRAPH

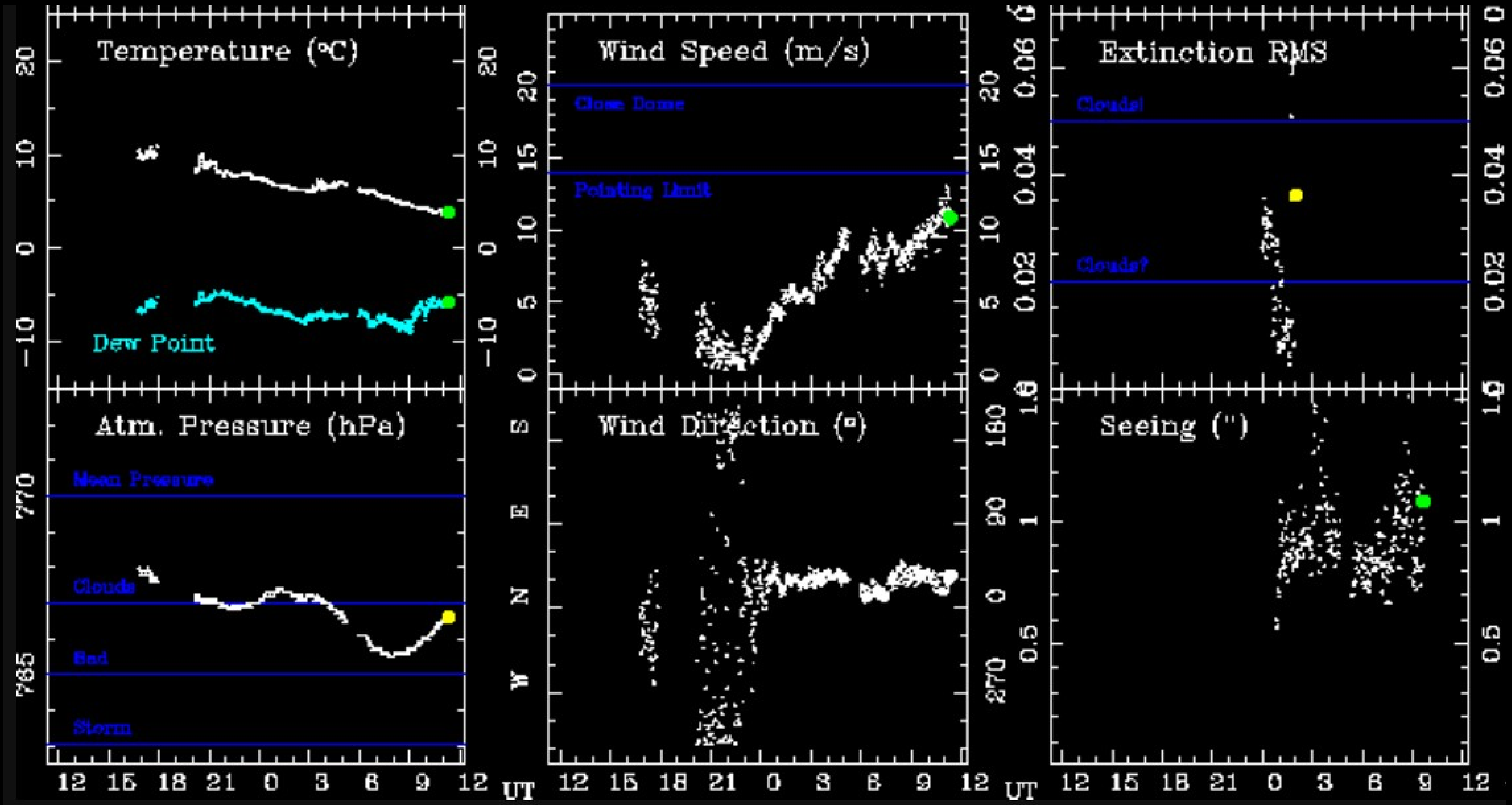
Help/Info | Zoom graph

Satellite Pics | Plot Archive



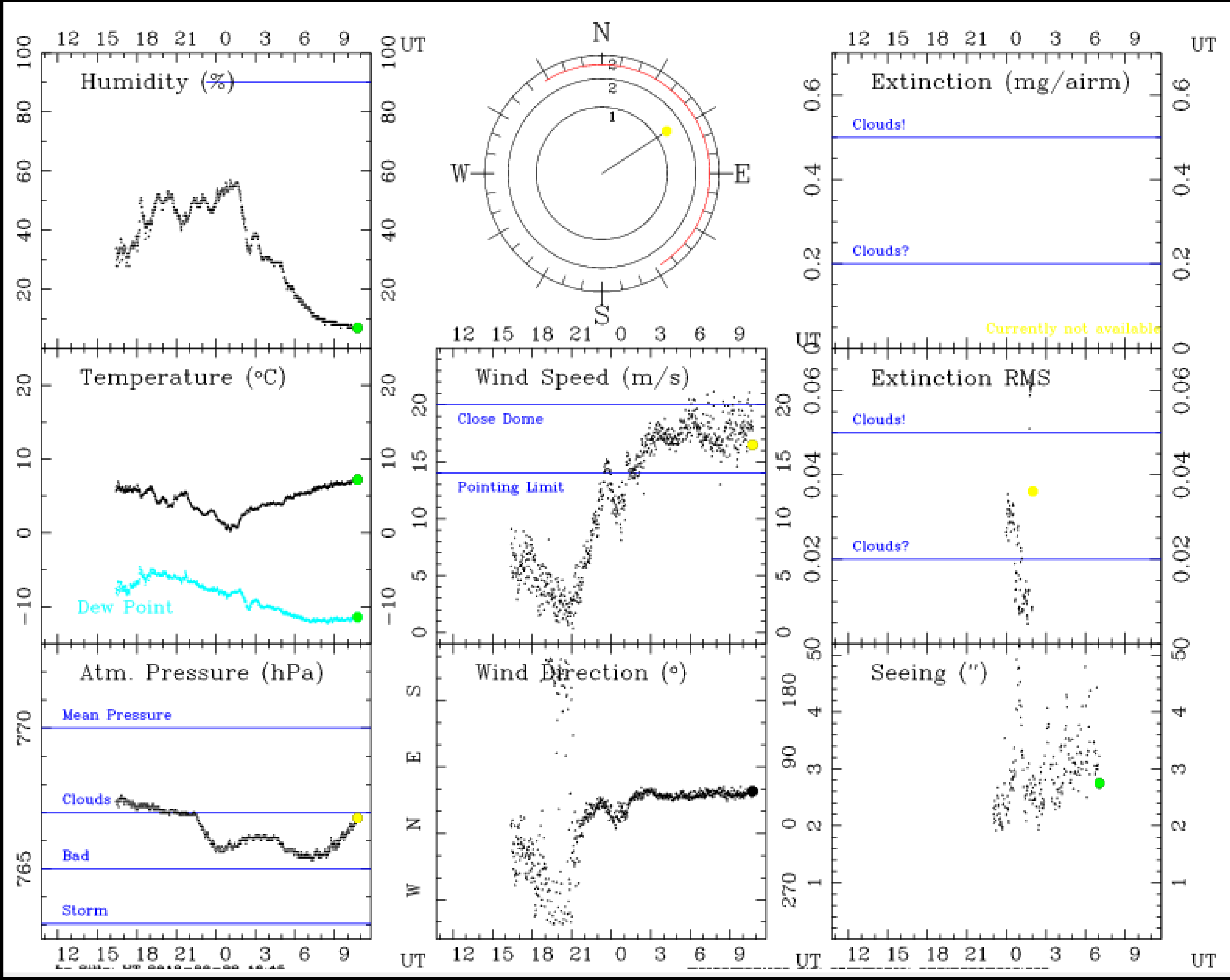


Direction of the wind
Humidity (%)
Temperature (°C)
Dew Point
UT
N
E
S
W
Wind Speed (m/s)
Close Dome
Close
Pointing with limitations



Temperature (°C)
Dew Point
Wind Speed (m/s)
Close Dome
Pointing Limit
Extinction RMS
Clouds!
Clouds?
Atm. Pressure (hPa)
Mean Pressure
Clouds
Bad
Storm
Wind Direction (°)
Seeing (")
UT
UT

ESO La Silla, 22/9/2013



# Dome-Closing Conditions at ESO LaSilla

**Wind Speed Monitor Light Codes**

| Lights | Speed (m/sec) | Action By Observer |
|---|---|---|
| Green | < 14 m/s | |
| Yellow | < 14-20 m/s | Don't observe into the wind |
| Red | > 20 m/s (18 m/s for 3,6m) | DOME: Don'wait to be told! |

**Humidity**. General humidity sensors are installed on the weather tower; their readings are relayed on the MeteoMonitor . Domes have to be closed when the relative humidity exceeds 80% (was 90%), and can be re-opened when it remains below 70% for 30min. Similarly, the domes must be closed when the temperature difference between the coldest part of the telescope and the dew point drops below 2 degrees.

https://www.eso.org/sci/facilities/lasilla/sciops/At_Telescope.html

# Hawaii

Hawaii, 18/8/2013

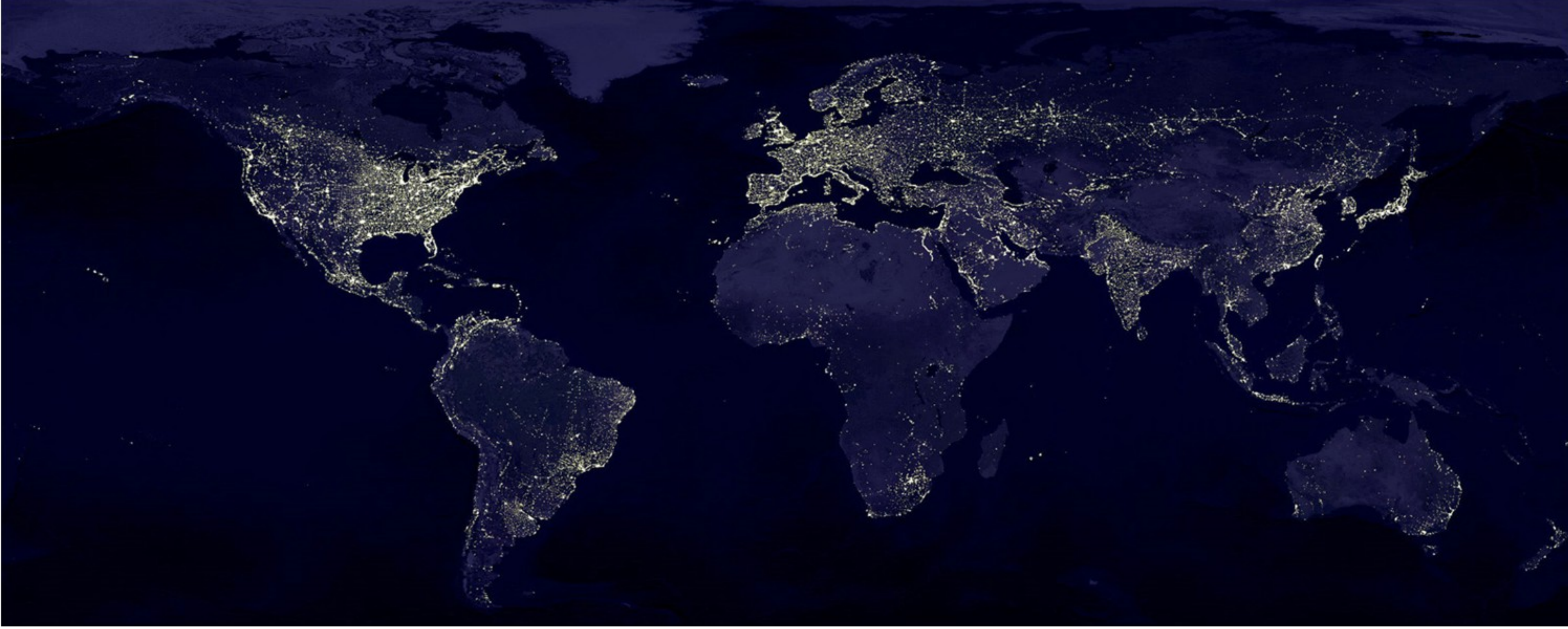
# Mauna Kea (Hawaii) weather conditions

**Current Conditions**

| | |
|---|---|
| Temp | 1.9 C |
| RH | 60 % |
| Wind | W 7 mph |
| Road | Open |

## Observations

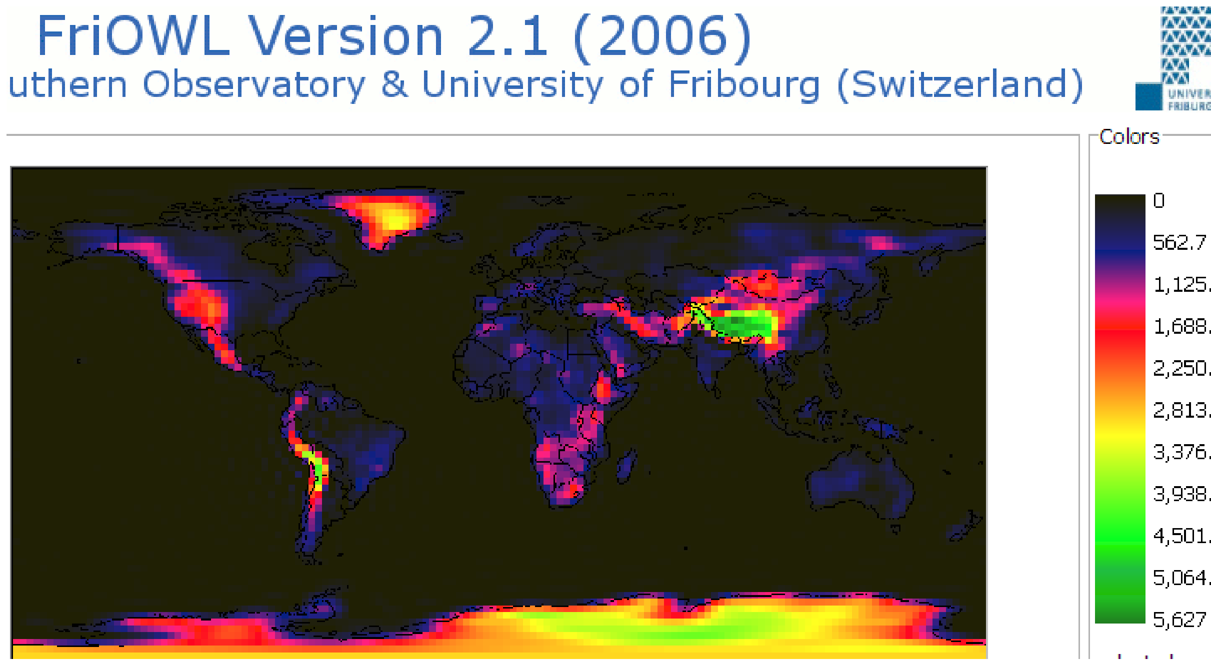
| STN | DATE HST | TIME HST | TEMP °C | DPNT °C | RH % | WSPD mph | PK WSPD mph | WDIR dir | PRES mb | RAIN mm | PW mm | Seeing arcsec | Trends |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CFHT/GEM | 10/02/13 | 01:31 | 1.9 | -5.1 | 60 | 7 | 11 | W | 617 | 0.00 | | 0.50 | Meteogram |
| UKIRT | 10/02/13 | 01:27 | 1.9 | -5.8 | 57 | 5 | | NW | 615 | | | | Meteogram |
| IRTF | 10/02/13 | 01:28 | 0.0 | -5.4 | 57 | 6 | 7 | NW | | | | | Meteogram |
| SUBARU | 10/02/13 | 01:28 | 0.8 | -4.9 | 66 | 2 | 4 | WNW | 621 | 0 | | | Meteogram |
| KECK | 10/02/13 | 01:30 | 2.1 | -5.9 | 56 | | | | 620 | | | | |
| JCMT | 10/02/13 | 01:26 | 2.5 | -5.5 | 56 | 4 | | N | 625 | | 3.16 | | Meteogram |
| CSO | 10/02/13 | 01:30 | 9.3 | -3.6 | 40 | 0 | 0 | N | 626 | | 3.45 | | Tau |
| SMA | 10/02/13 | 01:17 | 3.4 | -3.6 | 60 | 3 | | ENE | 624 | 0.0 | | | Trend |
| VLBA | 10/02/13 | 01:26 | 5.2 | -8.9 | 36 | 4 | 7 | NNW | 654 | 0 | | | Meteogram |
| HP | 10/02/13 | 01:30 | 9.3 | 1.3 | 57 | 7 | 8 | WNW | 727 | 0 | | | Meteogram |
| UNITS | UTC \| HST | | °C \| K \| F | | % | mph \| Kts \| mps | | dir | mb | mm | Tau \| mm | arcsec | |



# Choosing an astronomical site

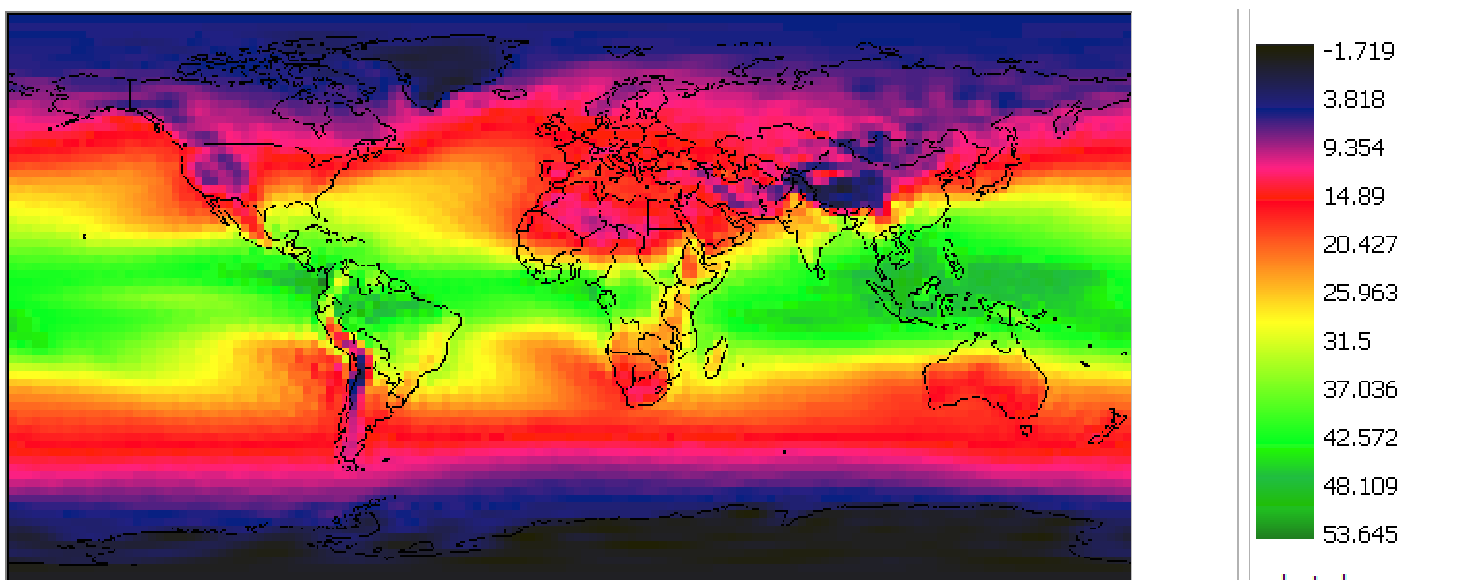
- No clouds (related to inversion layer)
- Photometric quality (atmospheric transparence)
- Transparence in the infrared & mm (atmospheric $H_2O$)
- Image quality (related to variations in temperature and the air refraction index)

# Choosing an astronomical site



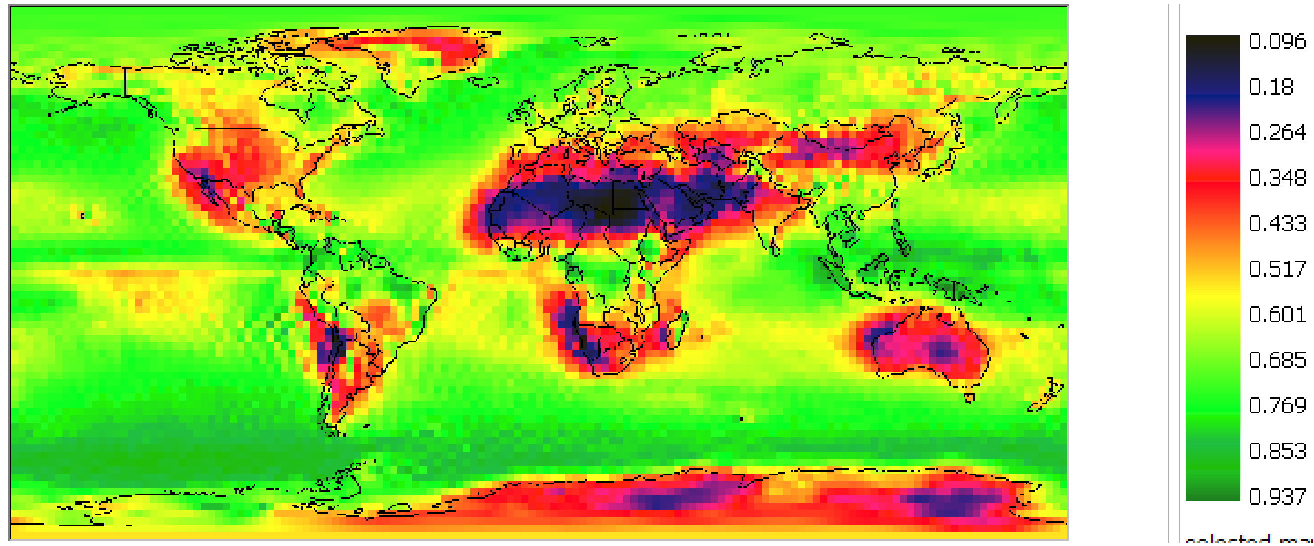

Altitude

precipitable $H_2O$



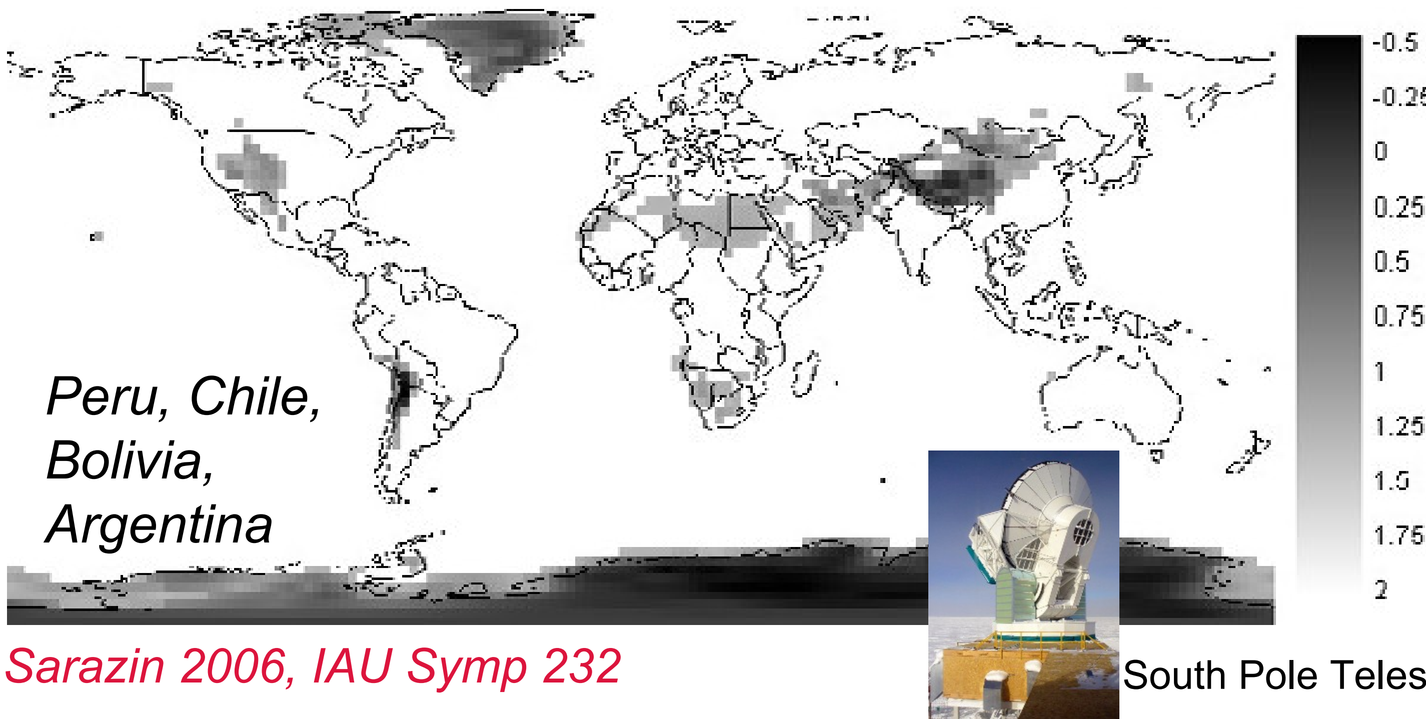
# Choosing an astronomical site

Cloud coverage




**BEST SITES**

High summits + low cloudiness + low precipitable water vapor




*Peru, Chile, Bolivia, Argentina*

*Sarazin 2006, IAU Symp 232*

South Pole Telescope