Interferência da atmosfera terrestre em observações astronômicas

Bibliography: várias fontes (Observational Astrophysics [Lena]; *Meteorology Today [Ahrens])*

Prof. Jorge Meléndez

www.pbase.com/psinclai/la_silla

A grande maioria das observações são sitiadas no solo

Precisamos conhecer a atmosfera terrestre para saber as possibilidades e limitações da observação do solo

O P D - Estação Meteorológica

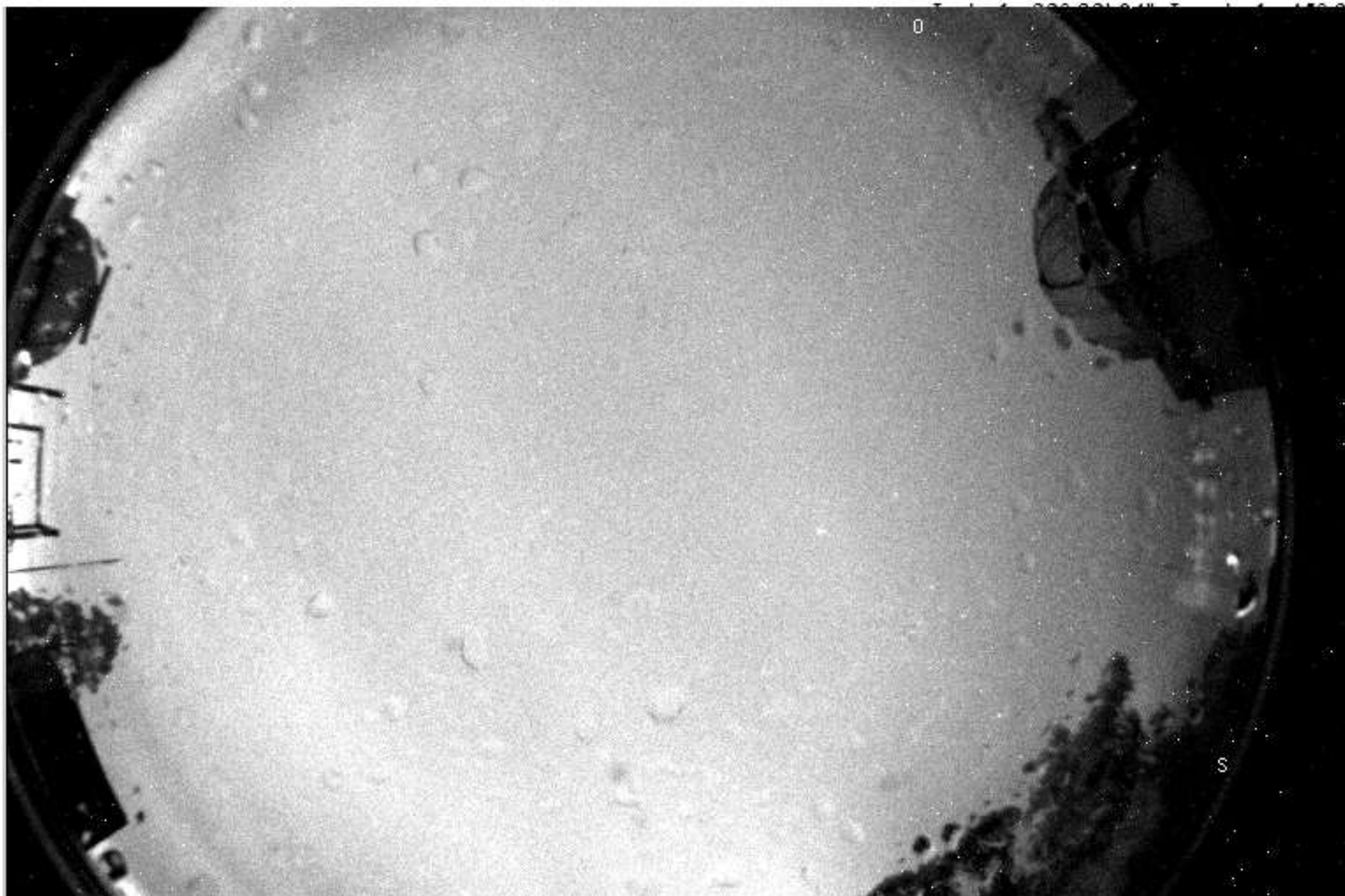

Imagem em 06/March/2014 04:23:18h [765x510] pxs

A atmosfera terrestre

é uma fina camada de gases que rodeia a Terra e que é retida pela sua gravidade

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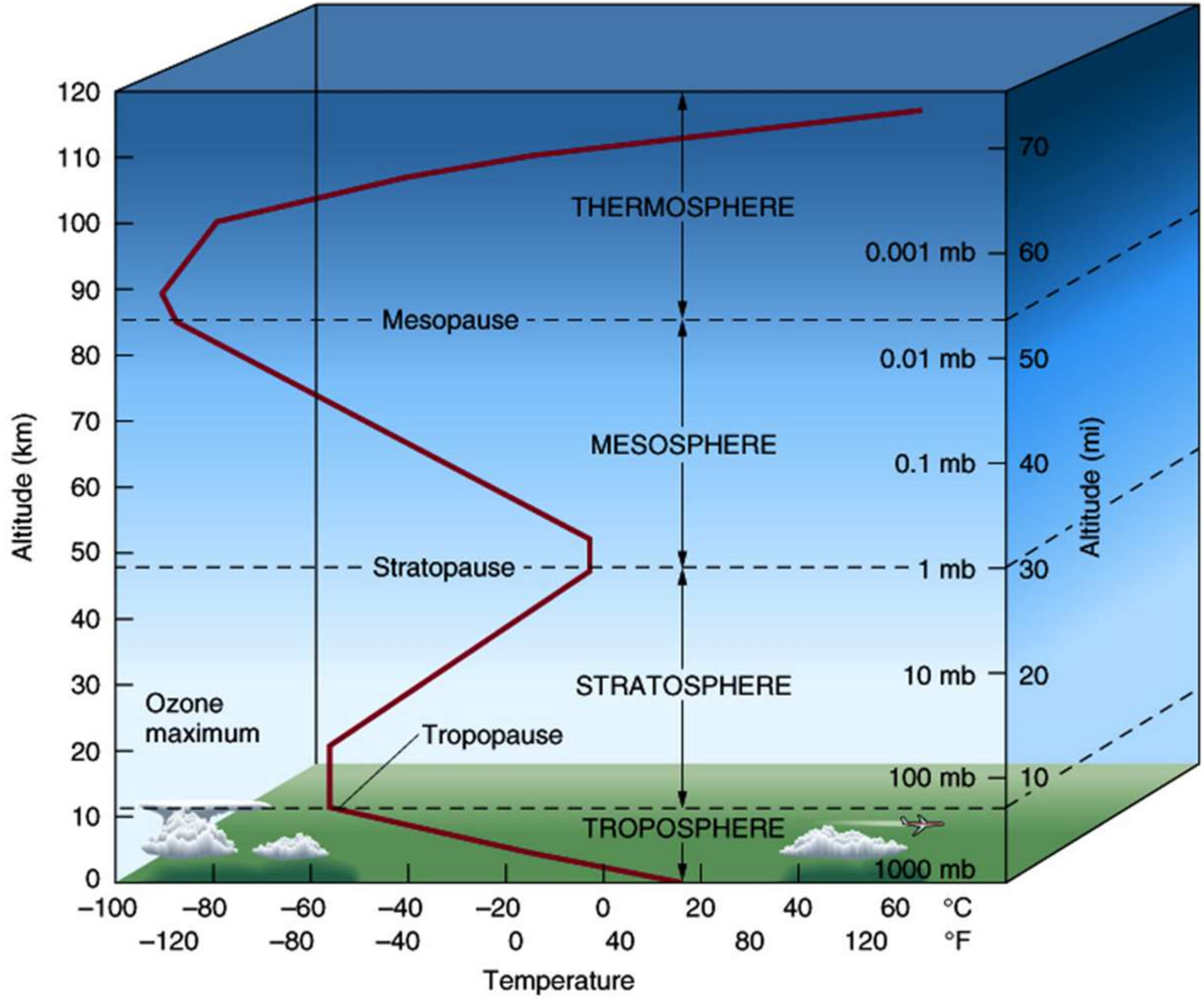
• FIGURE 1.2 The earth's atmosphere as viewed from space. The atmosphere is the thin blue region along the edge of the earth.

Estrutura da atmosfera terrestre



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

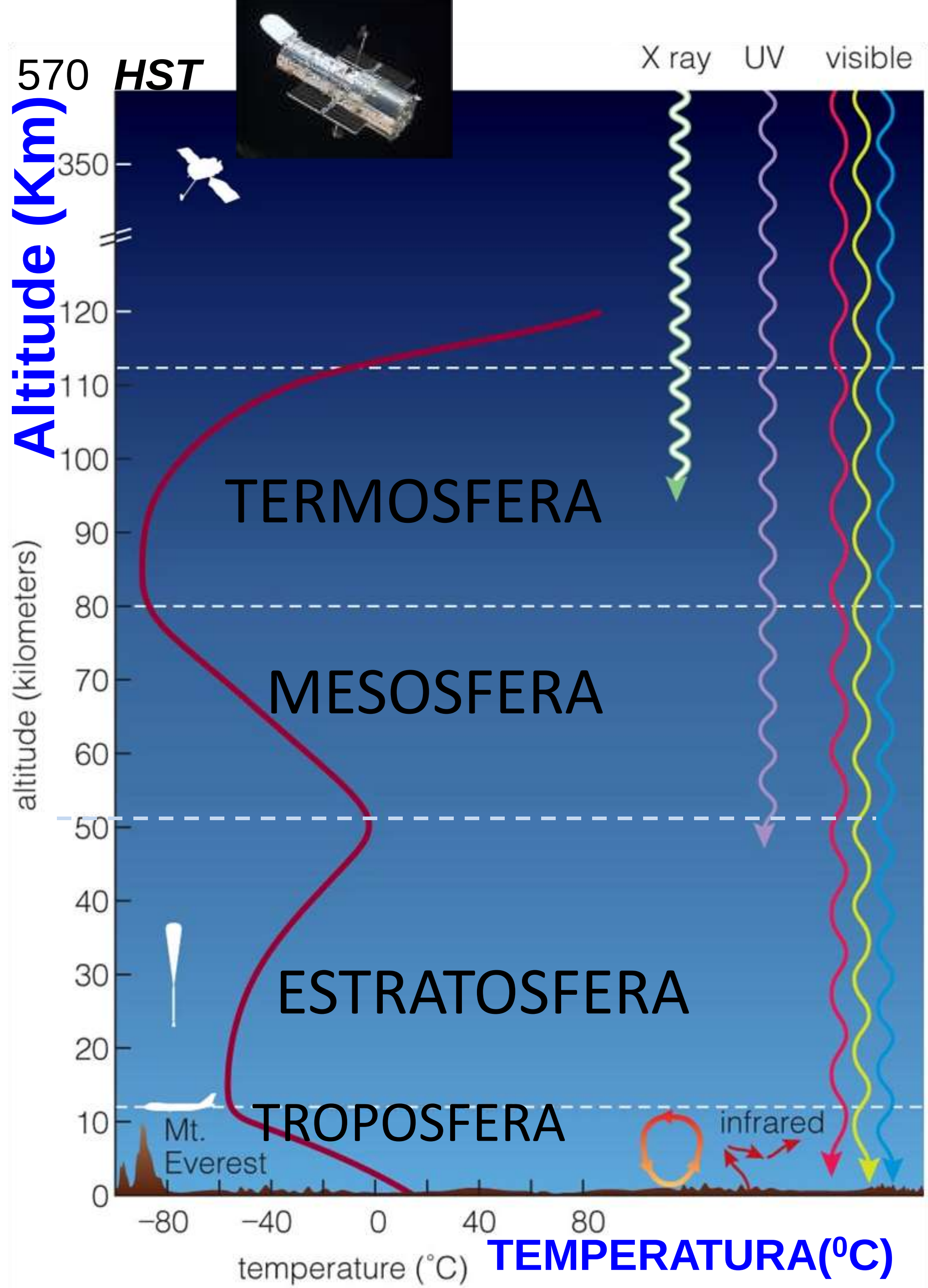
Perfis de temperatura

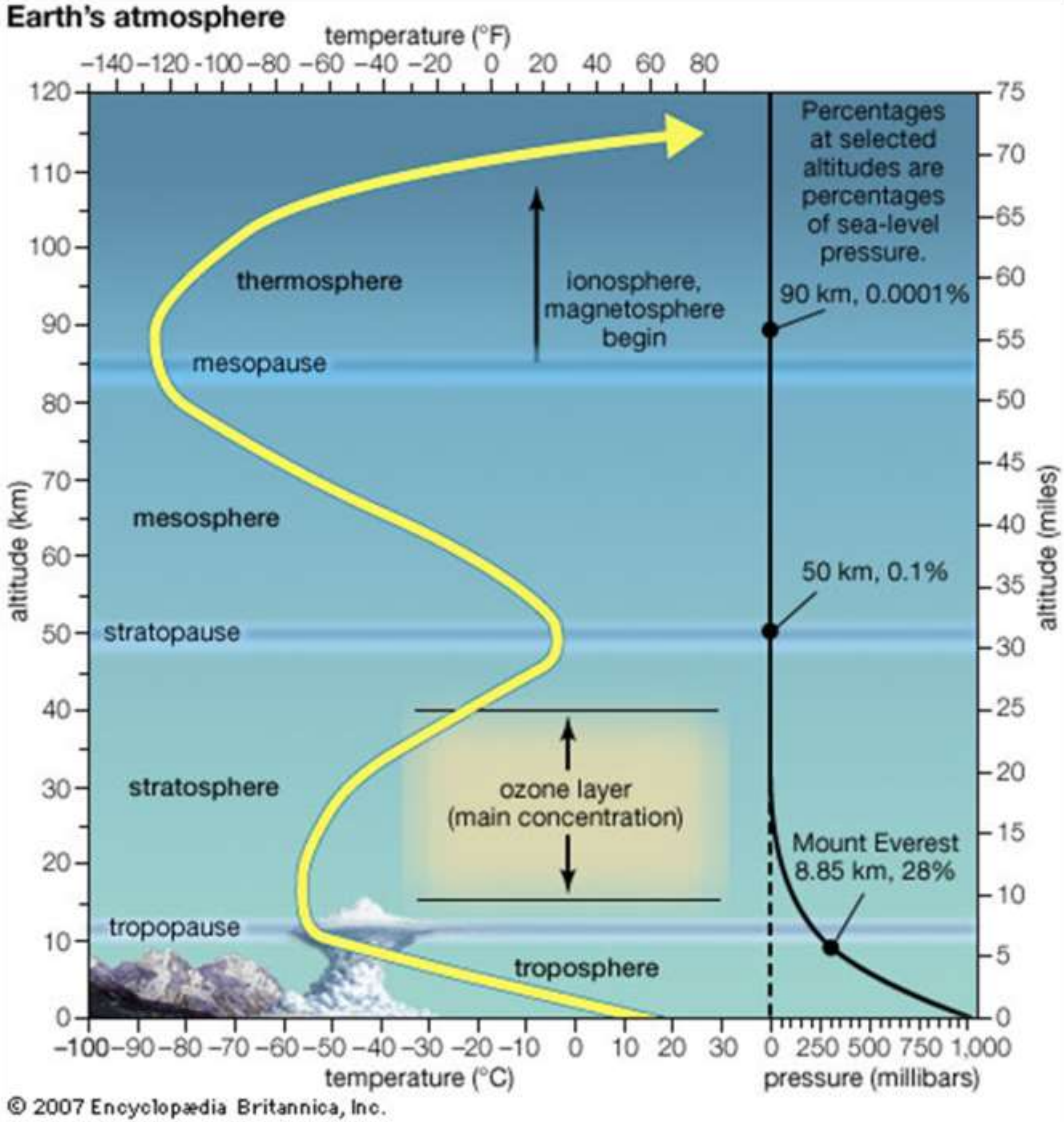
Luz solar UV e raios X aquecem e ionizam gases

Concentração de **ozônio** diminui

Aquecida por absorção de luz UV pelo **ozônio**

Aquecida pela superficie e conveção





Pressão:

decresce exp. com a altura z

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

H: escala de altura ($=RT_m/M_0g$)

Composição química cte até 90 km

$H = RT_m/M_0g$

(escala de altura)

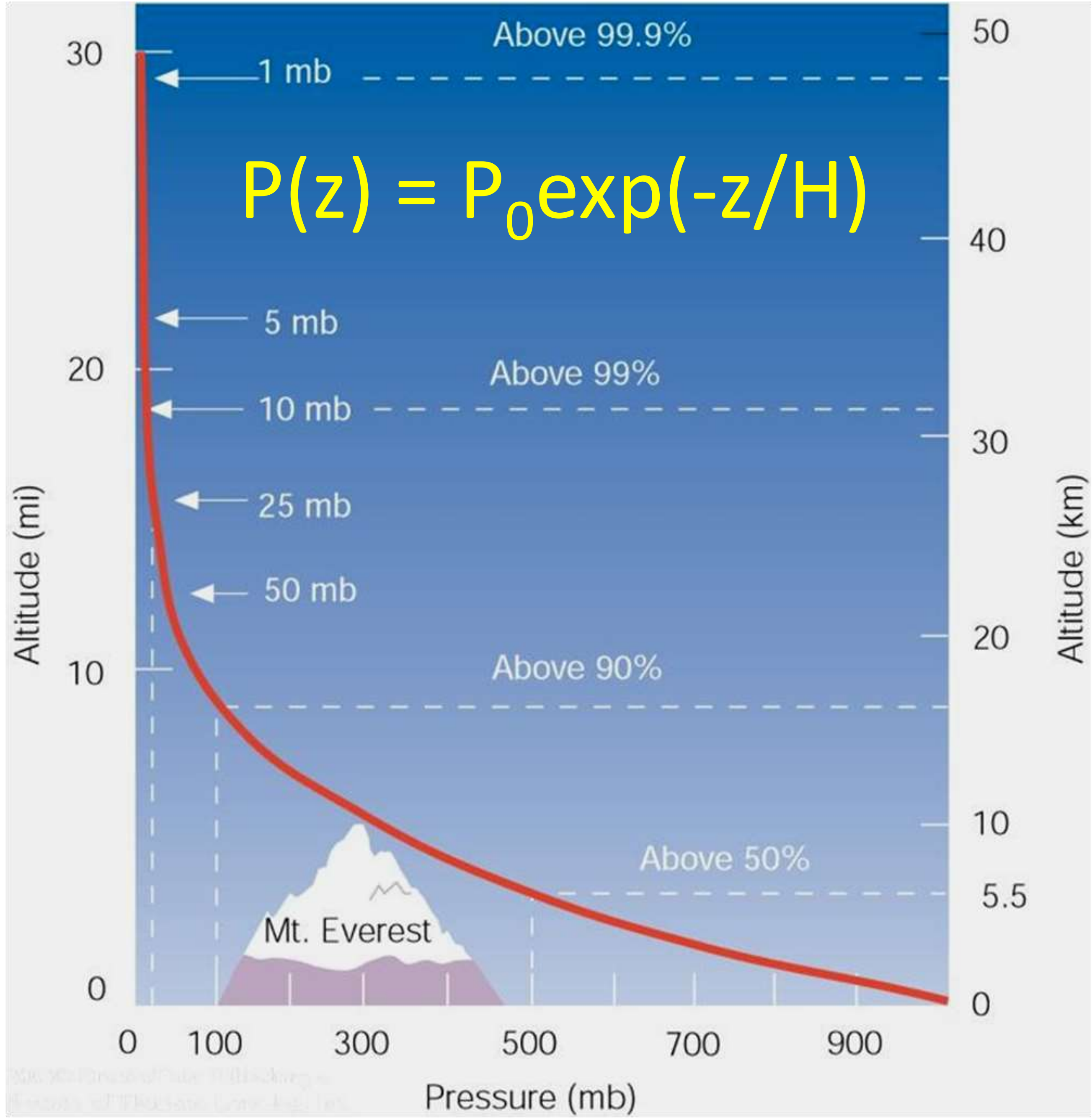
R: cte gases (8.23 J K^{-1} mol^{-1})

T_m: temp. media (0^0 C)

M_0: massa mol. Média (0.029kg)

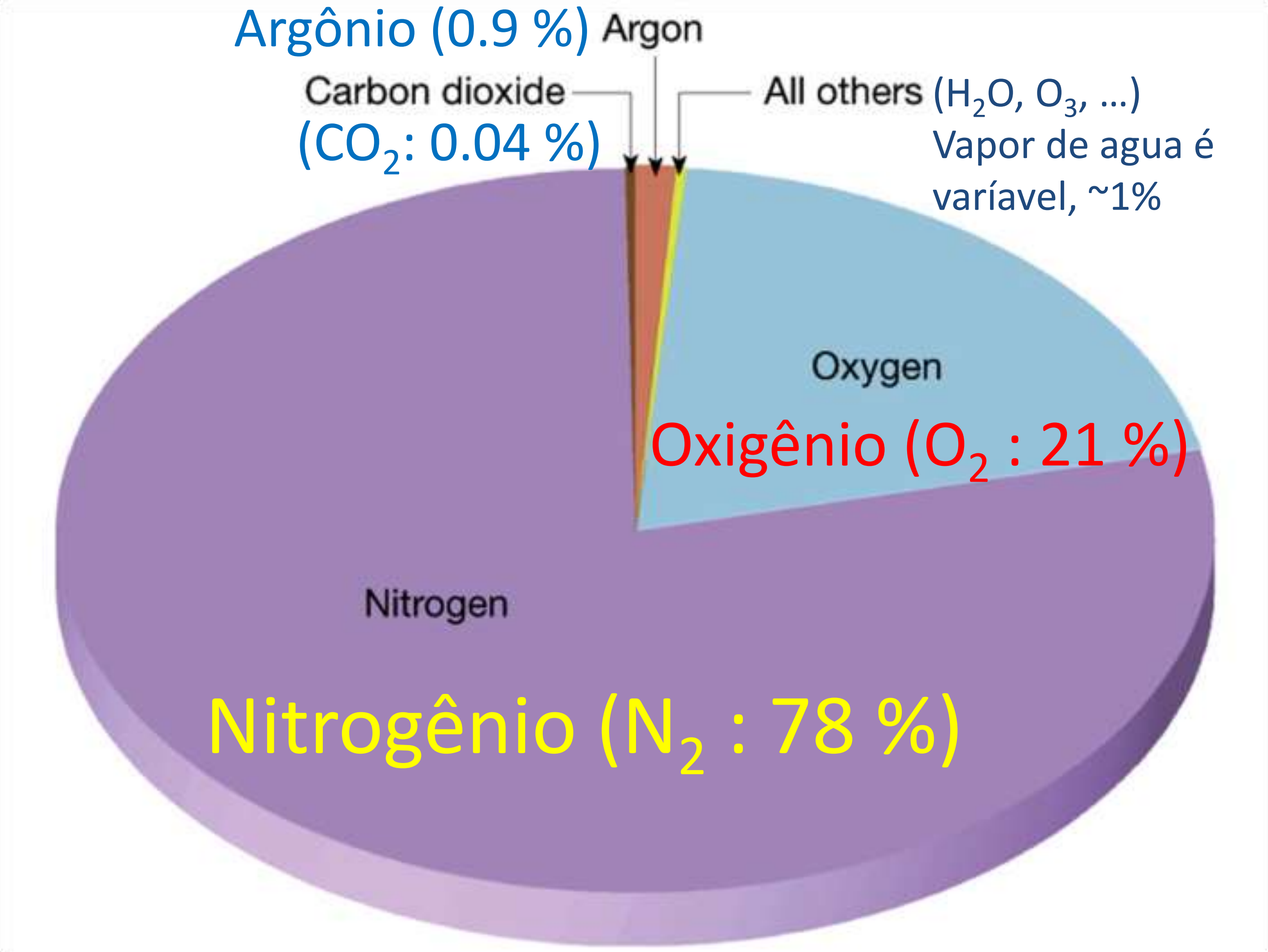
g: acel. grav.

H = 8km



Quais são os maiores constituientes da atmosfera?

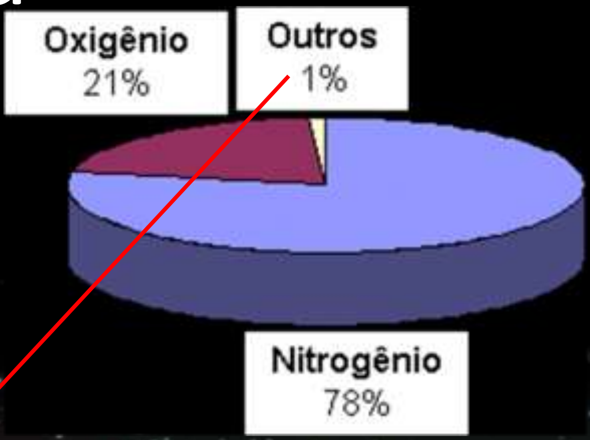
Constituintes da atmosfera

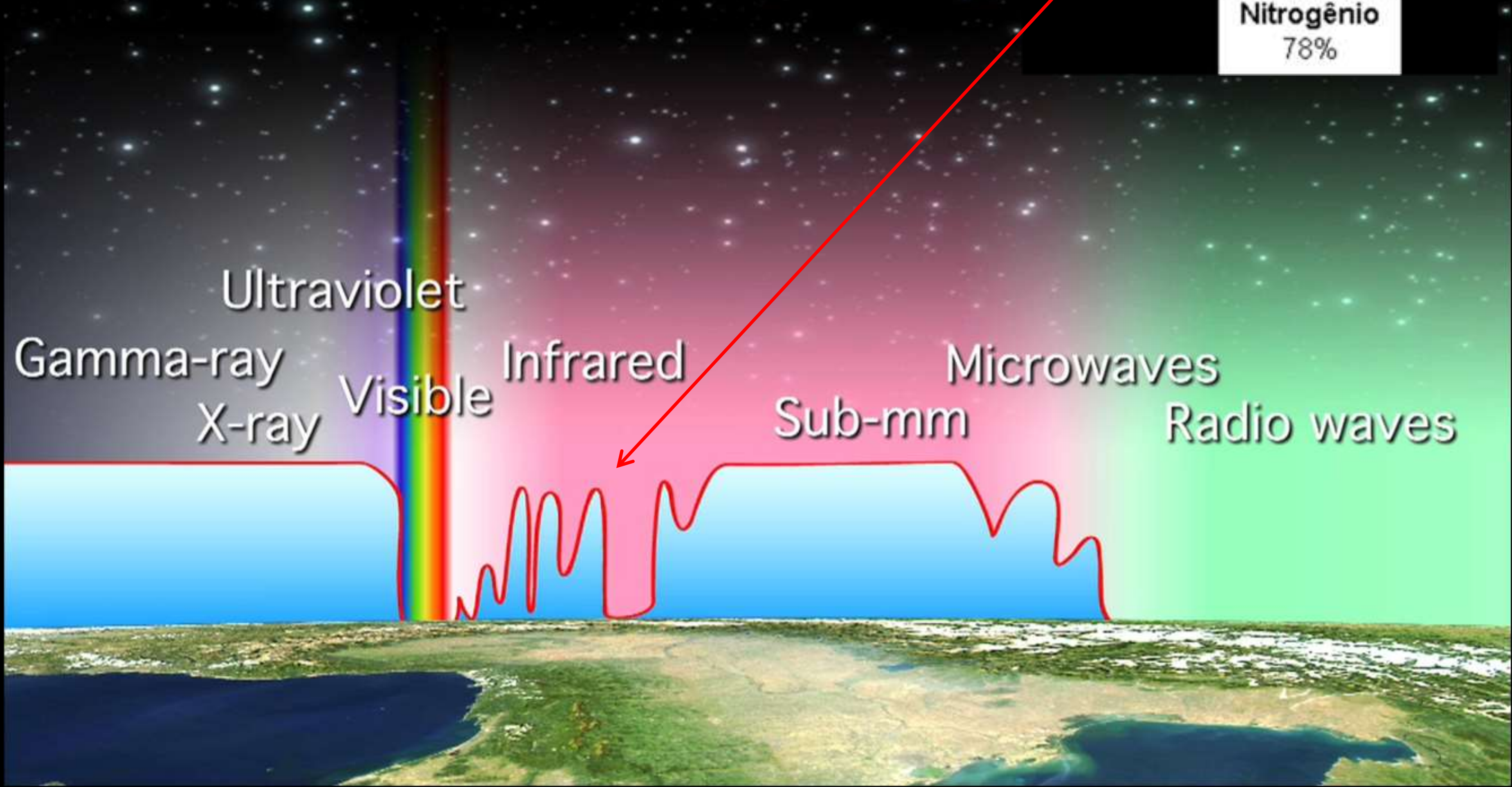


N e O são os principais constituintes e sua proporção relativa é constante entre 0-90 km

Constituintes da atmosfera (CO_2, H_2O, O_3,...)

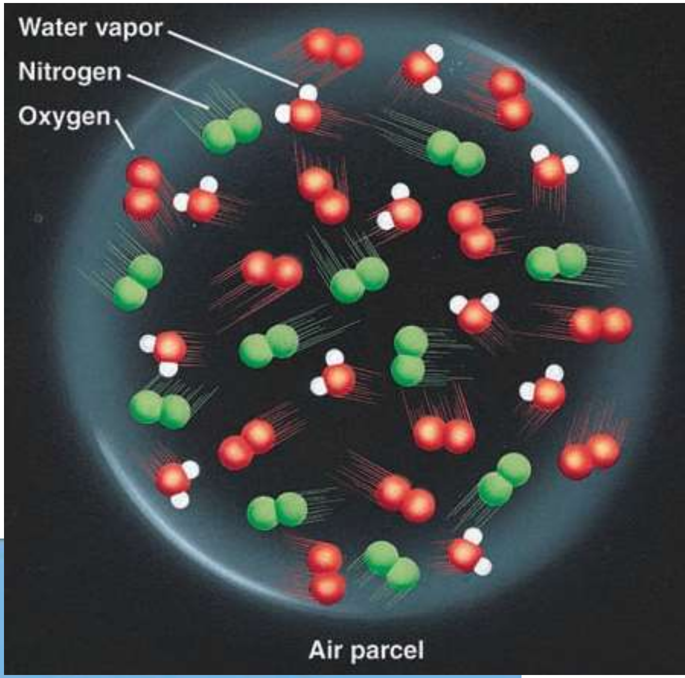
Os constituintes menores (e variaveis) são importantes fontes de opacidade na atmosfera

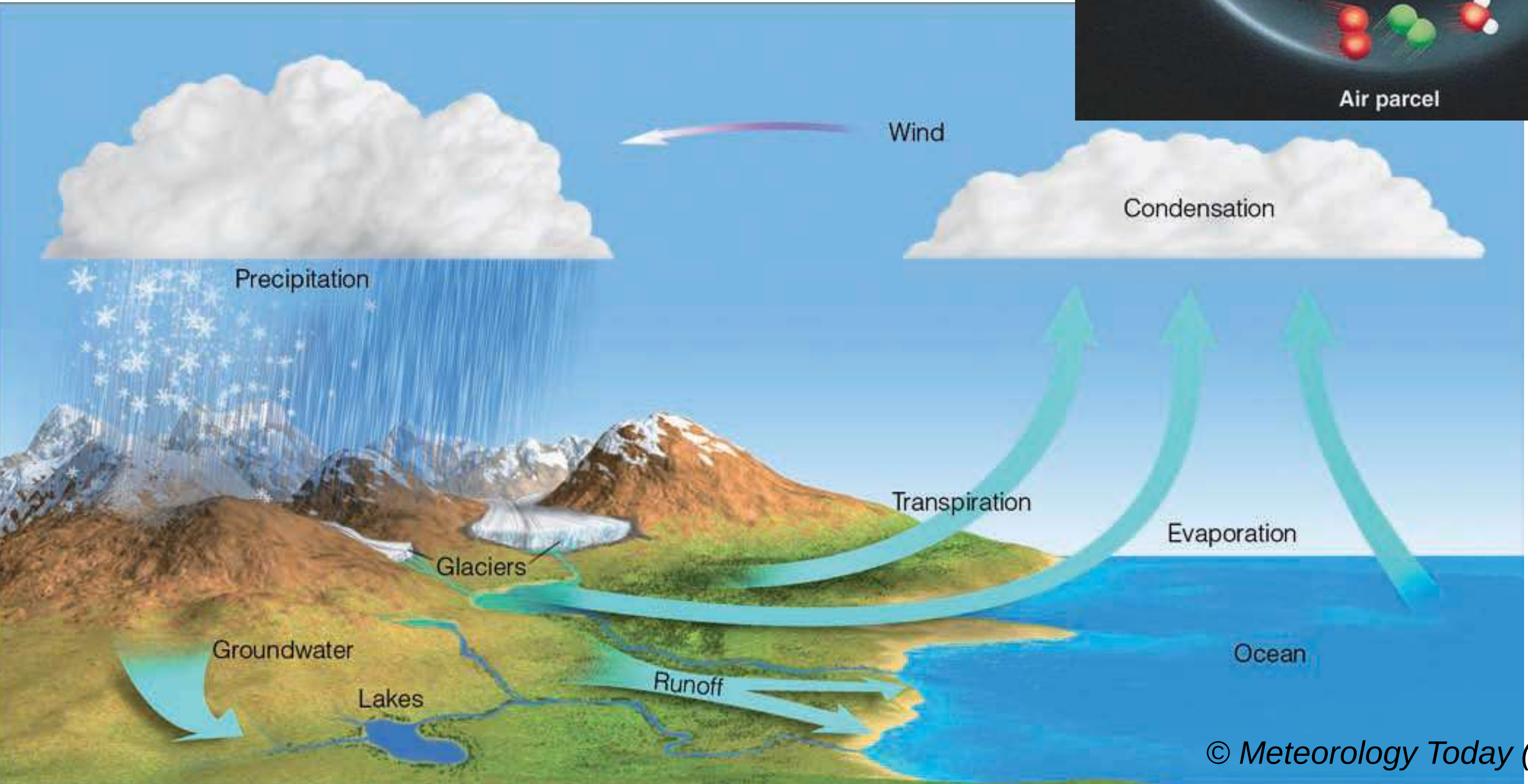




www.cosmicdiary.org

Vapor de água: uma das principais fontes de opacidade na atmosfera





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Medida do conteúdo de Vapor d'água

O conteúdo fracional (*fractional content)*, razão de mistura (*mixing ratio)*, ou humidade específica (*specific humidity*) é:

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

- $0 < r \leq r_s(T)$ (saturação)

$[r]$ = g/Kg

muito sensível à

- Temperatura
- z (altitude)
- Latitude
- tempo

Mixing ratio em função da latitude

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

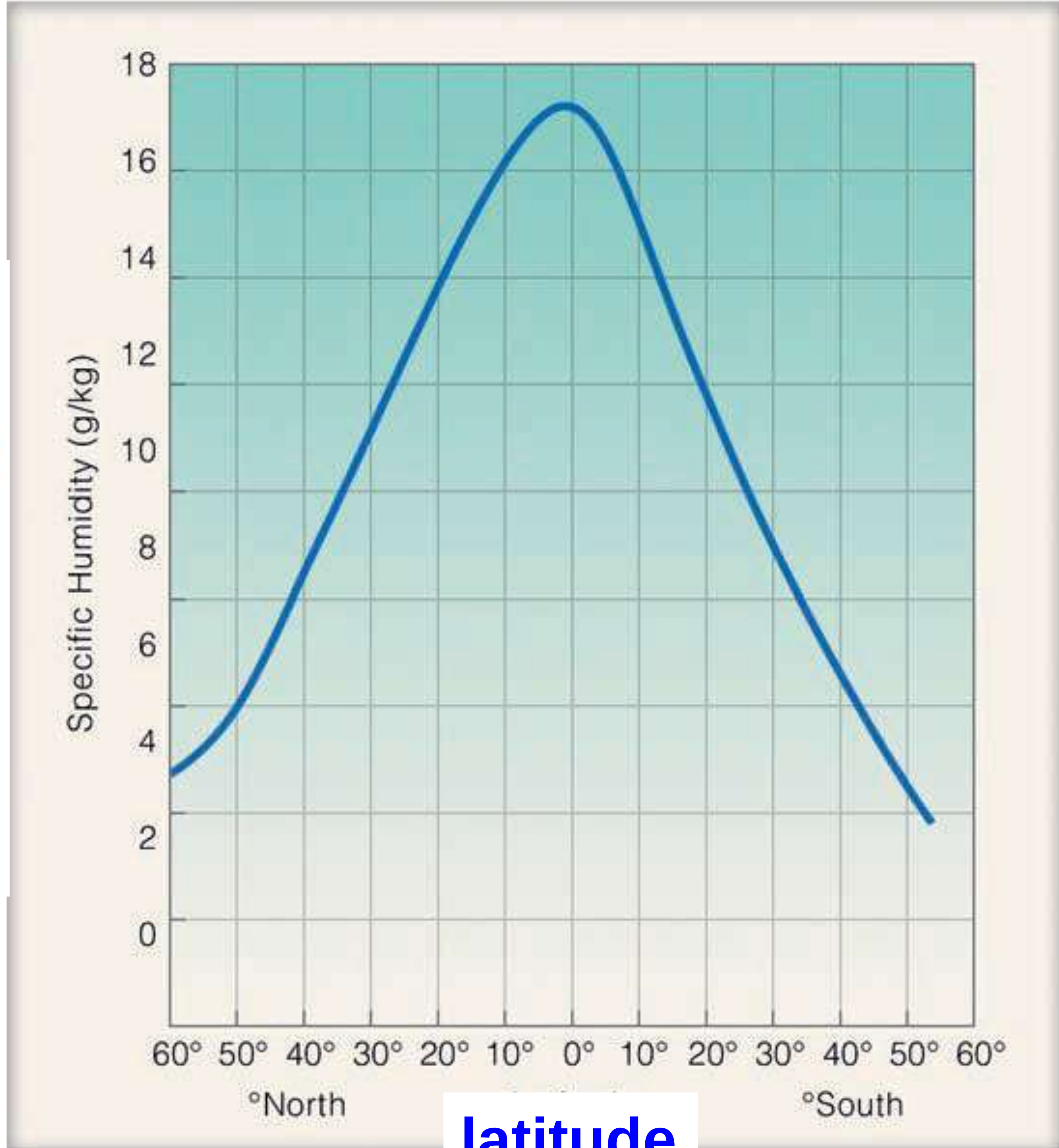
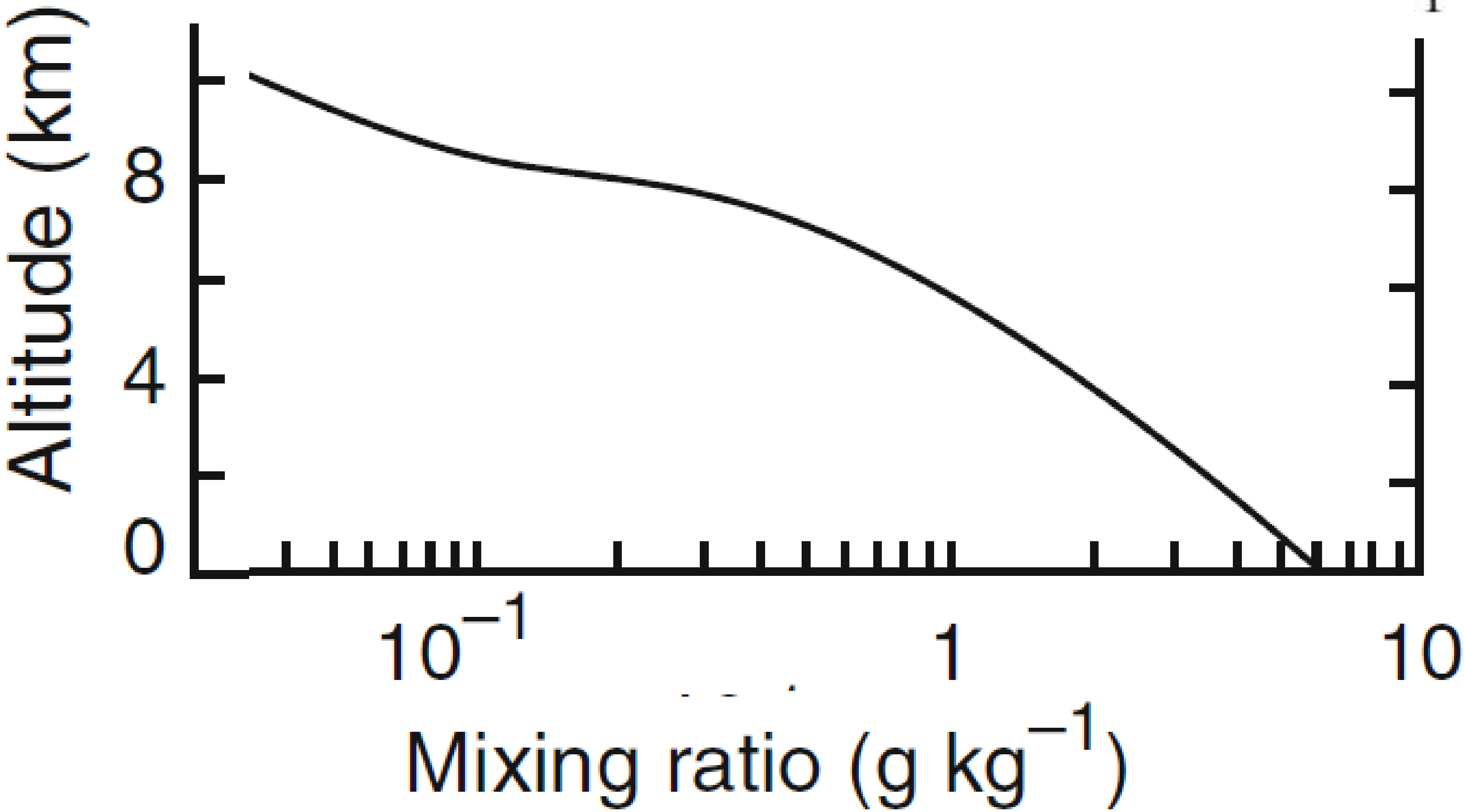


FIGURE 4.9 The average specific humidity for each latitude.

Concentração de vapor de H_2O em função da altitude

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

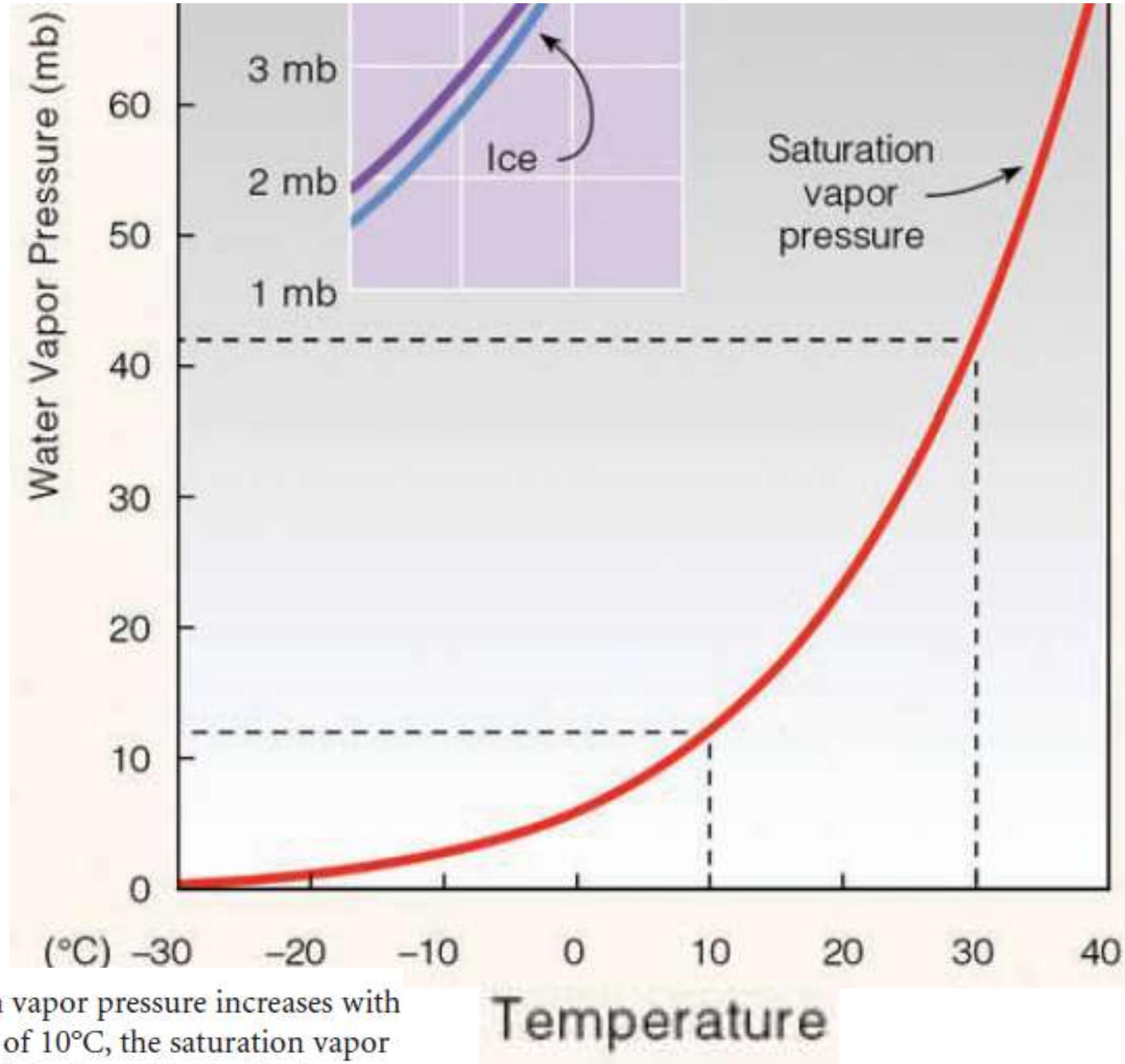


Umidade relativa
(Relative humidity: RH)

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

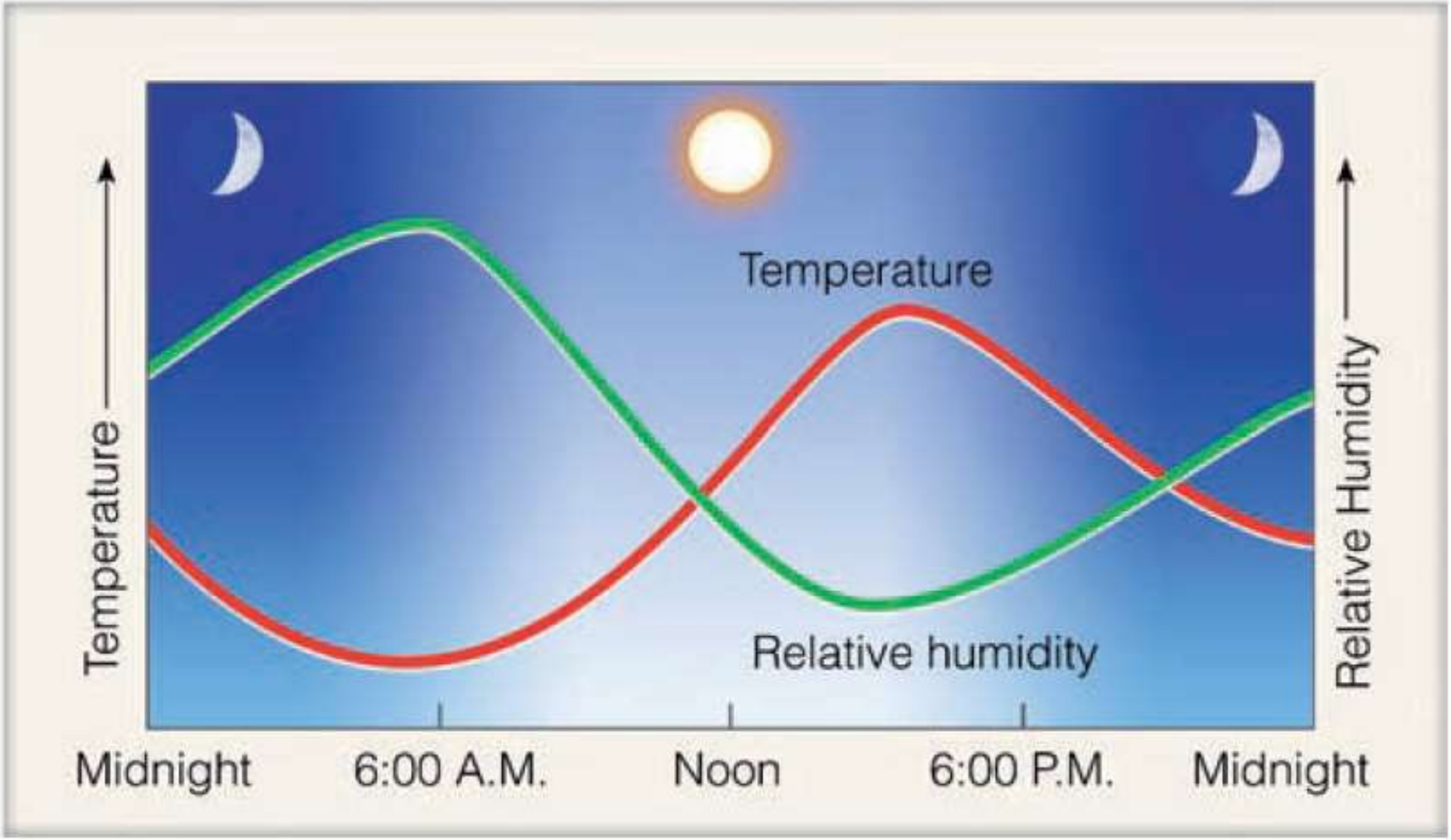
$$\textbf{RH} = \frac{\text{conteúdo de vapor de } H_2O}{\text{máximo conteúdo de vapor de } H_2O \text{ para saturação a uma determinada T}}$$

$$RH = \frac{\text{conteúdo de vapor de } H_2O}{\text{máx conteúdo de vapor de } H_2O \text{ para saturação}}$$



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

Mudança da RH ao longo do dia

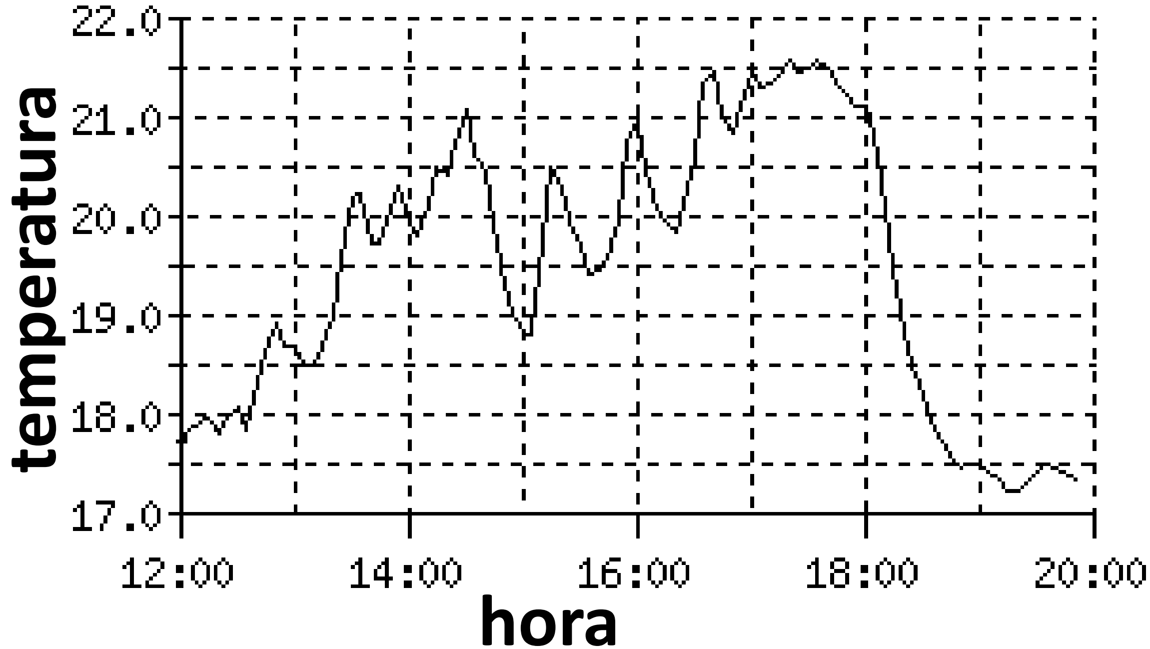


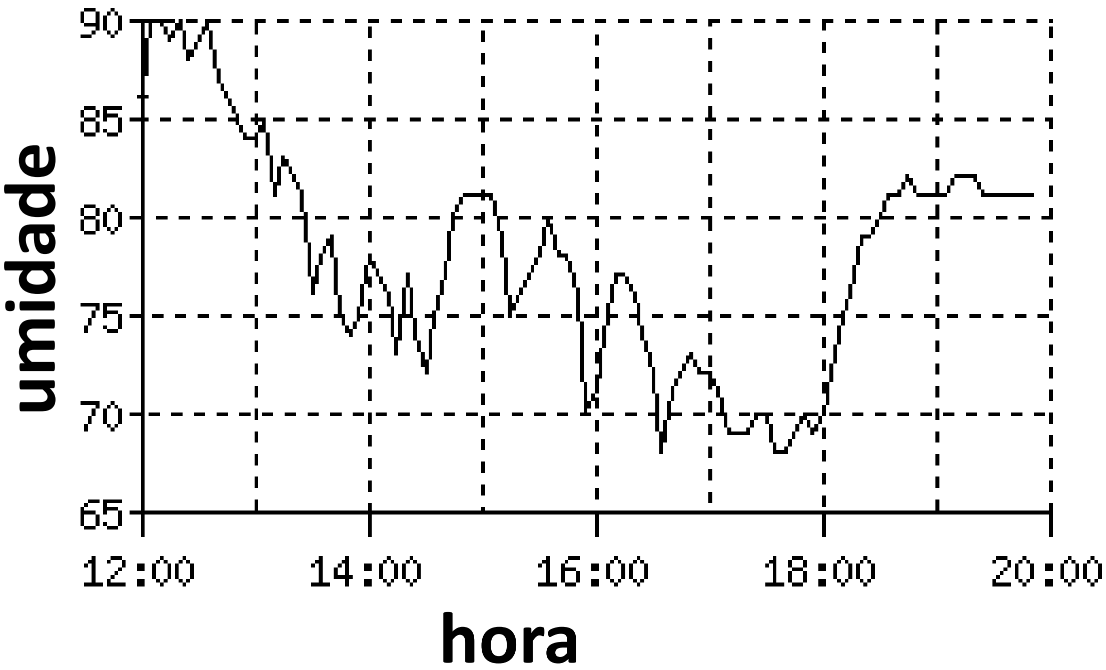
• FIGURE 4.12 When the air is cool (morning), the relative humidity is high. When the air is warm (afternoon), the relative humidity is low. These conditions exist in clear weather when the air is calm or of constant wind speed.

Mudança da RH no dia 5/mar/2014 no OPD

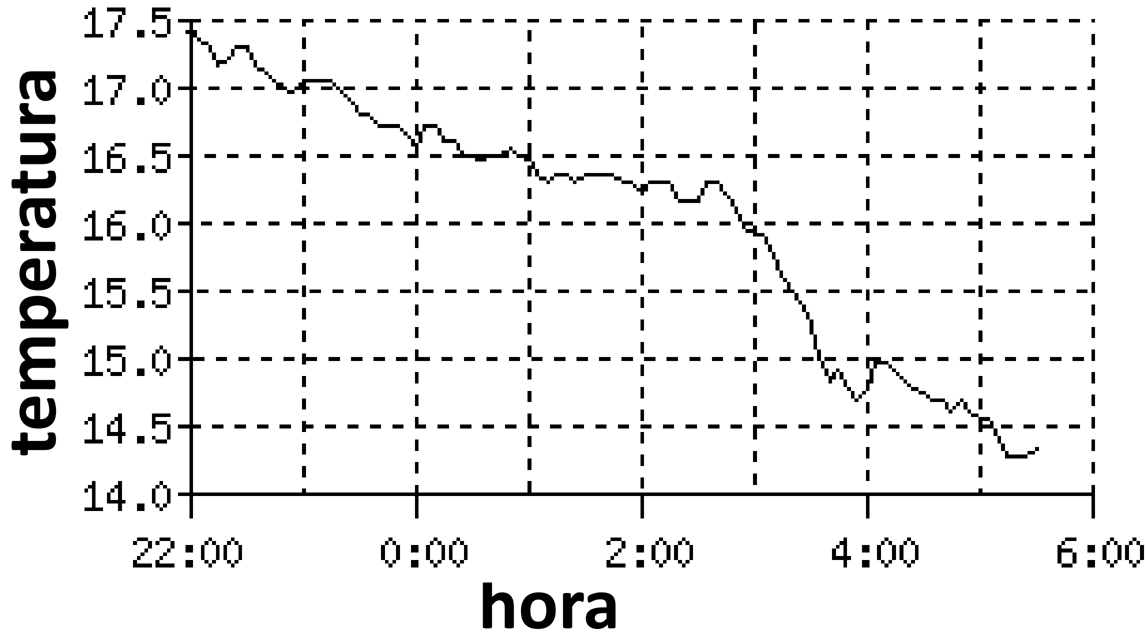
18h: 70%
20h: 80%
22h: 90%
0h: 100%

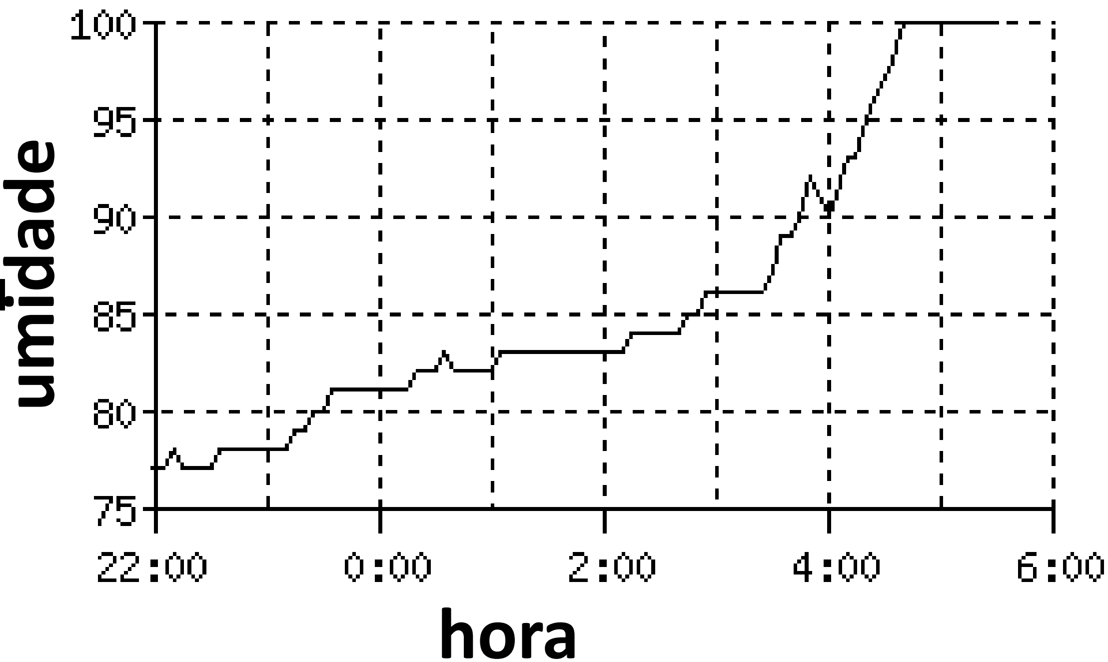
Mudança da temperatura e umidade no 9/3/2014

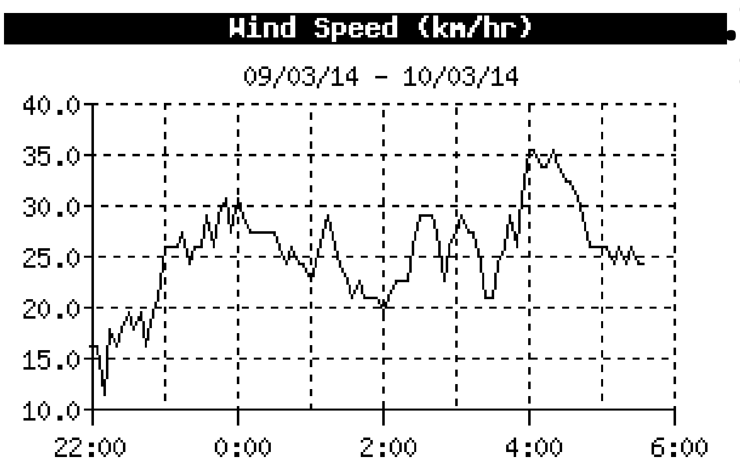




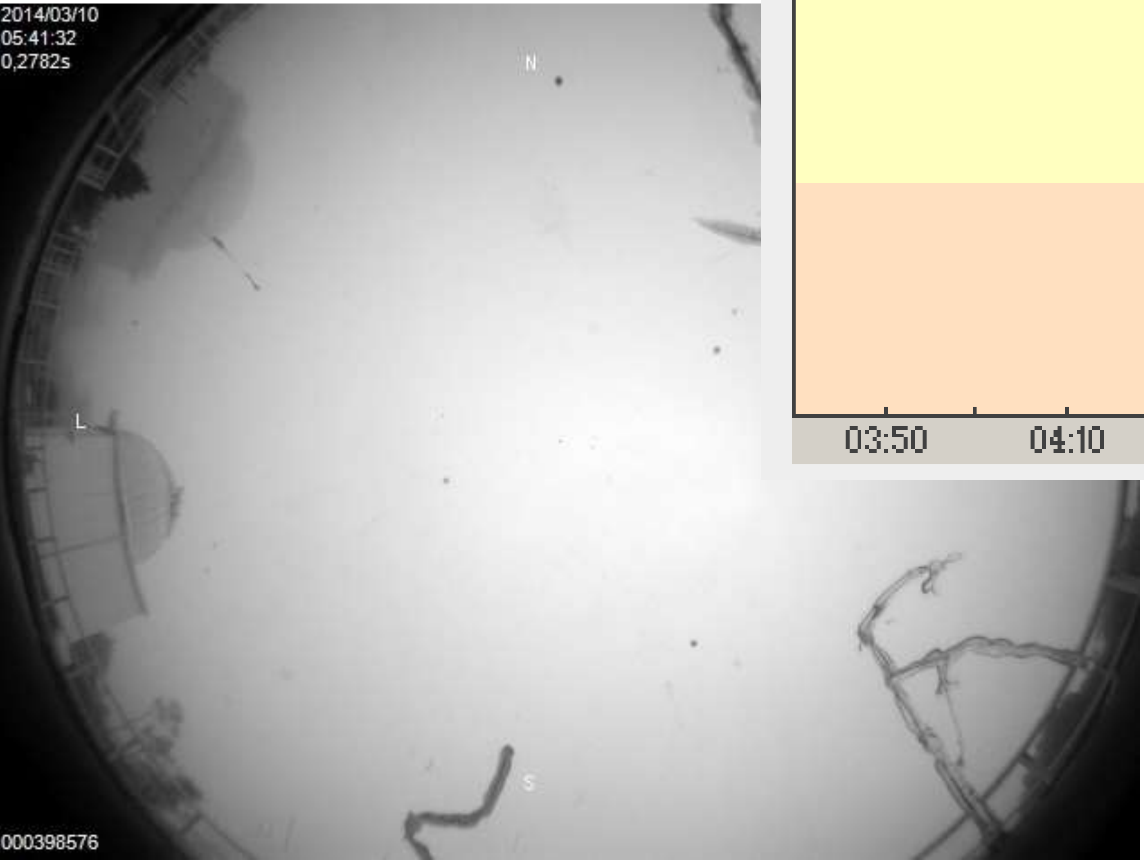
Mudança da temperatura e umidade no 9/3/2014

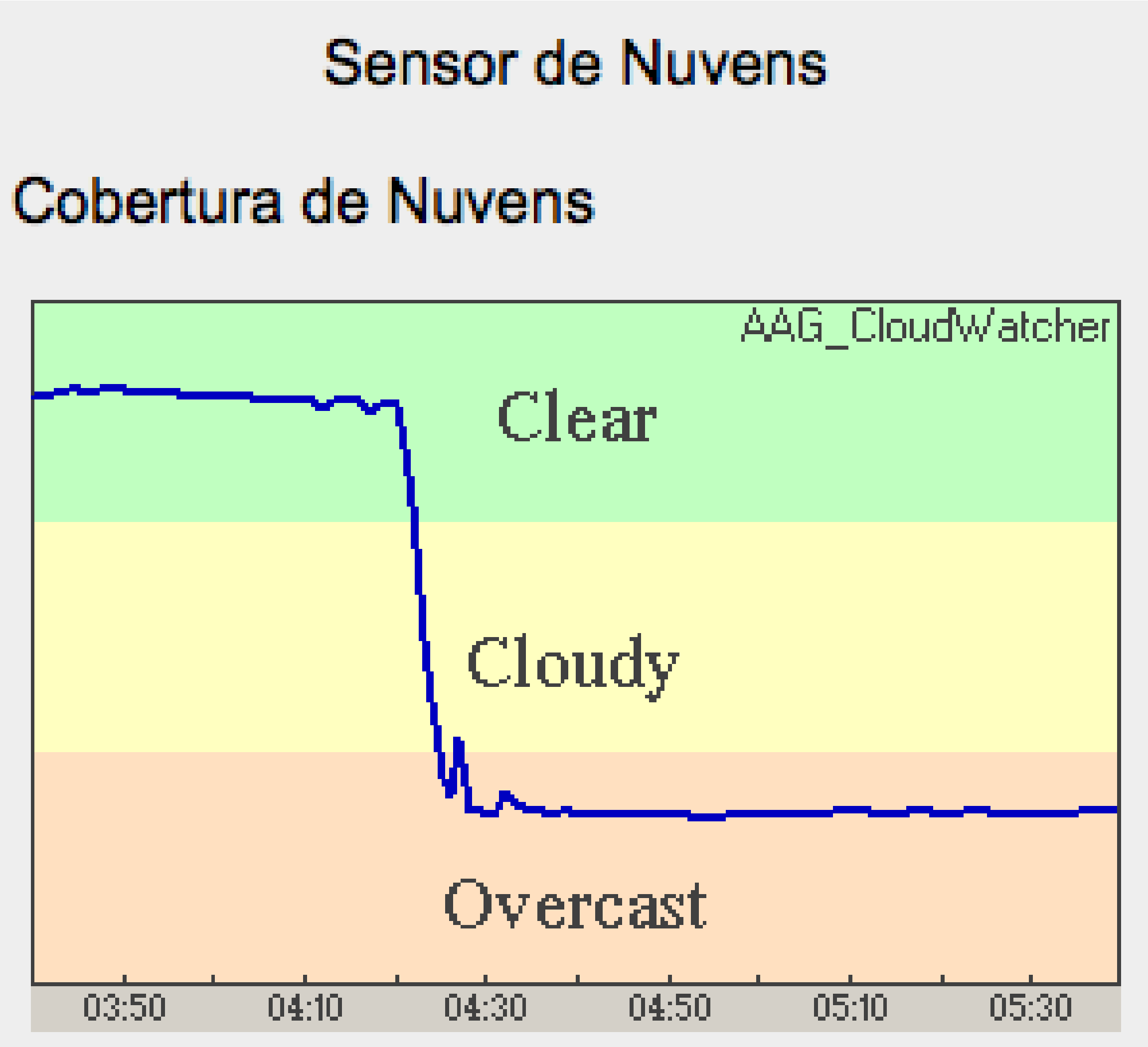






Cobertura de nuvens no 9-10/3/2014

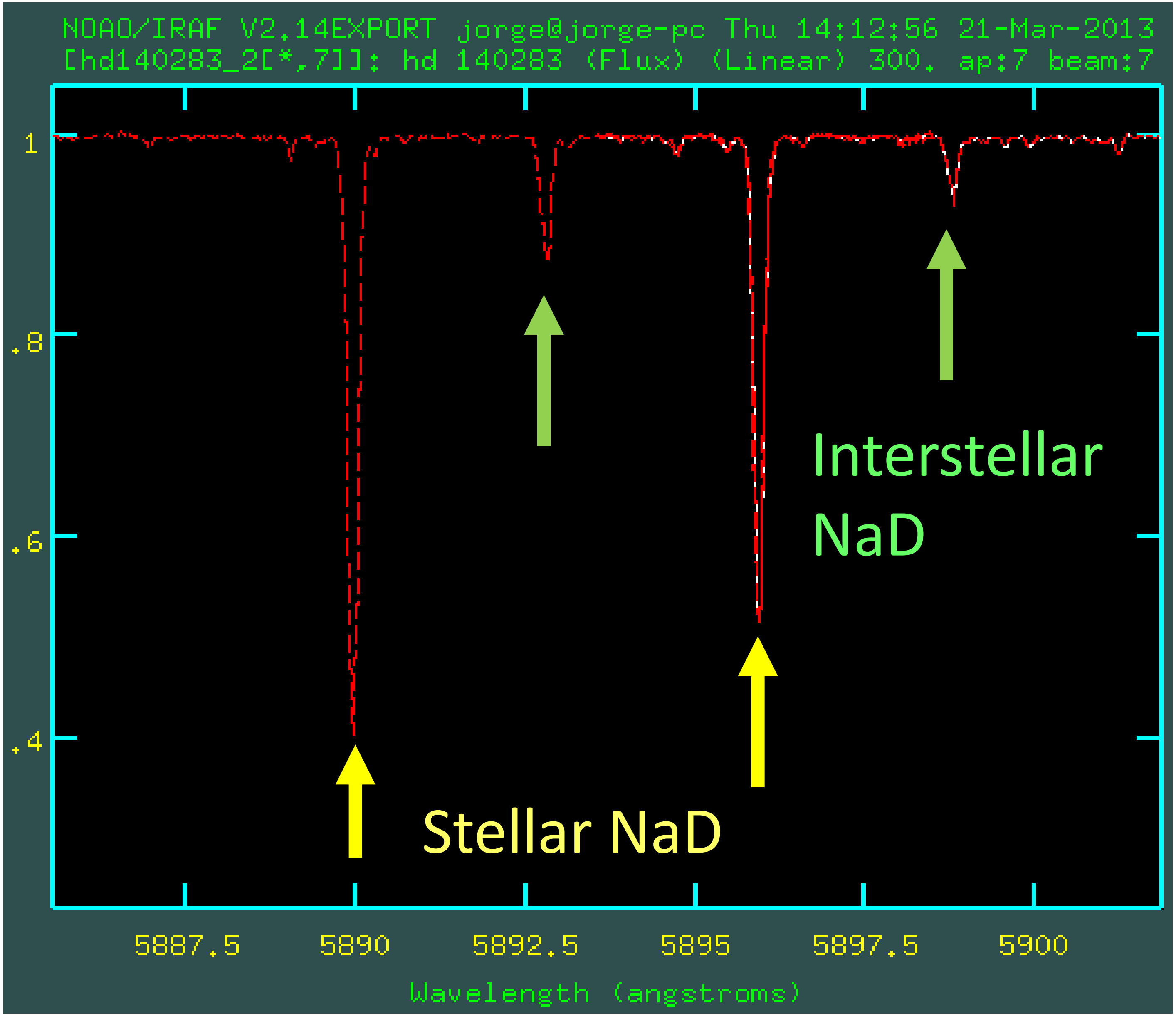




hora

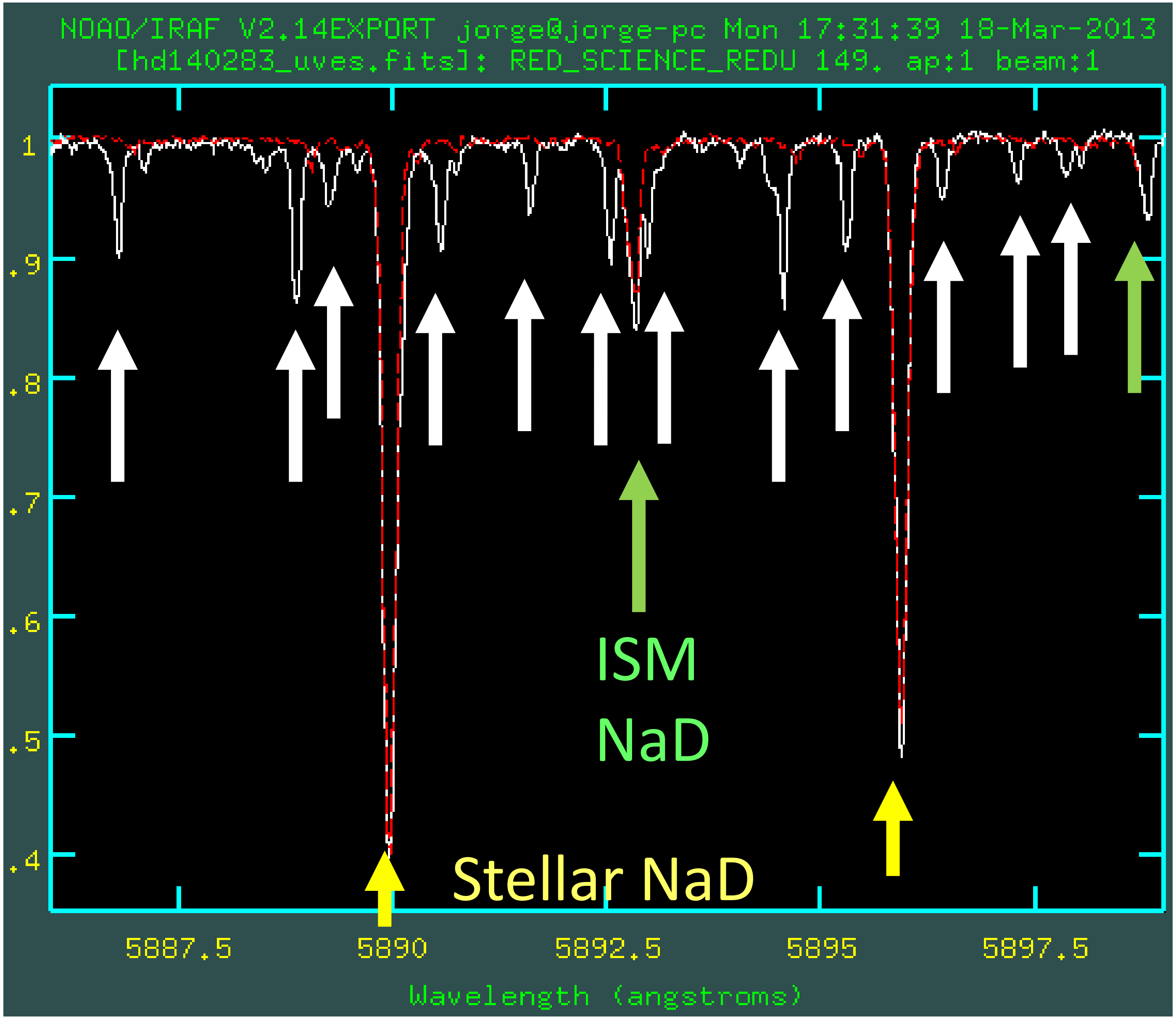
Comparação do conteúdo de vapor de H_2O em dois diferentes observatórios

Keck (4.2km) spectrum of HD140283

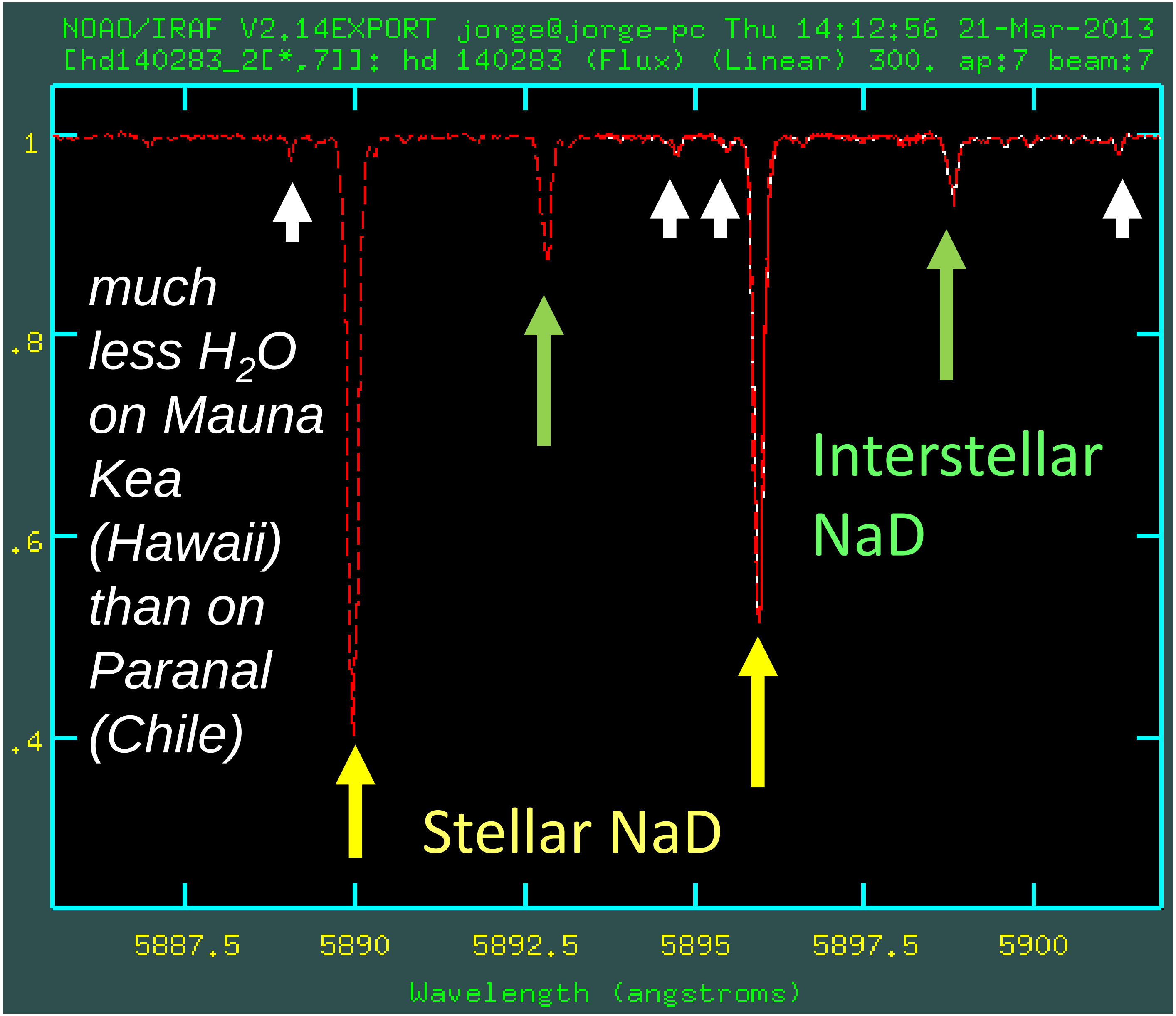


Keck (4.2km) vs. VLT (2.7km)

Water vapor clearly present on Paranal (VLT)

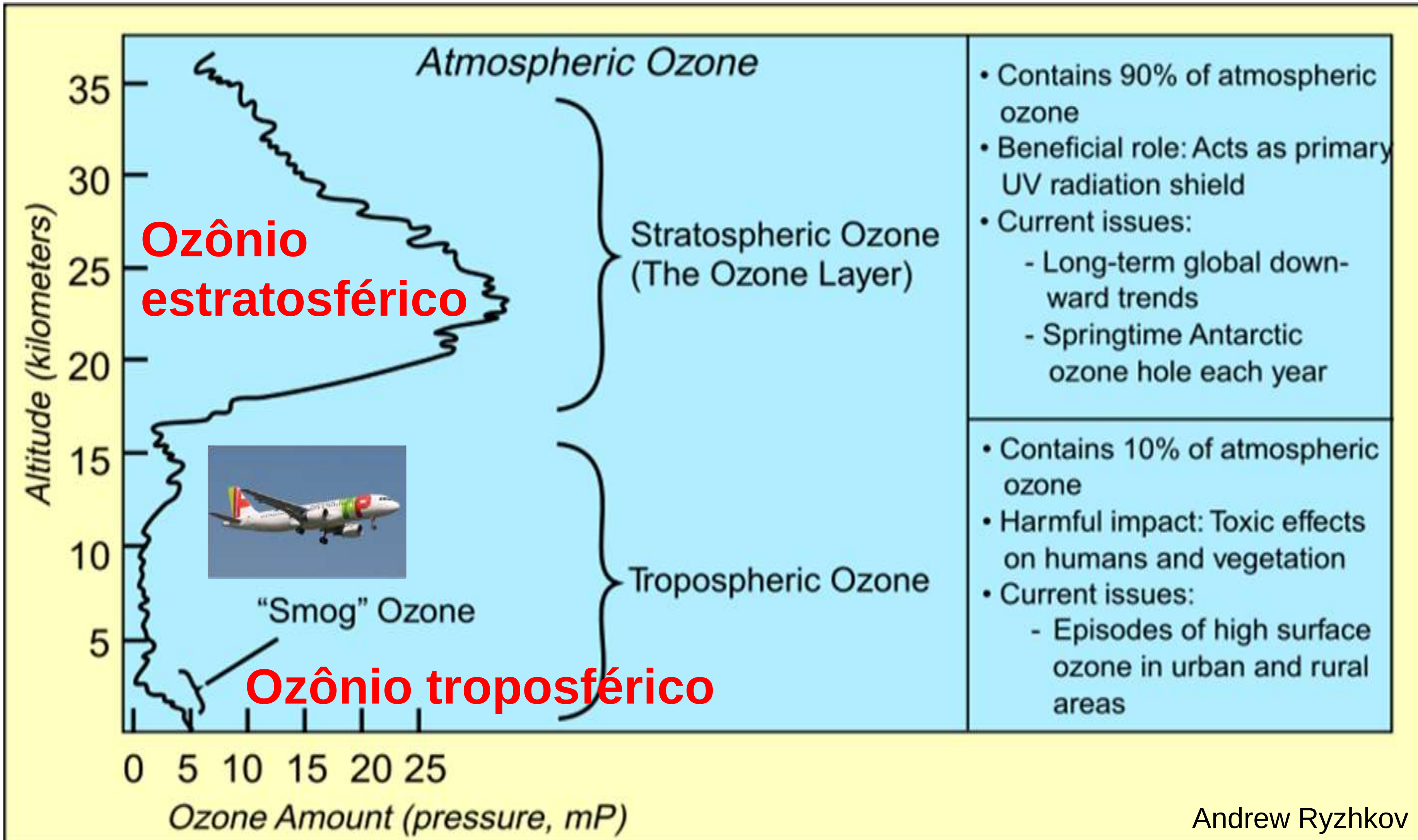


Keck (4.2km) spectrum of HD140283



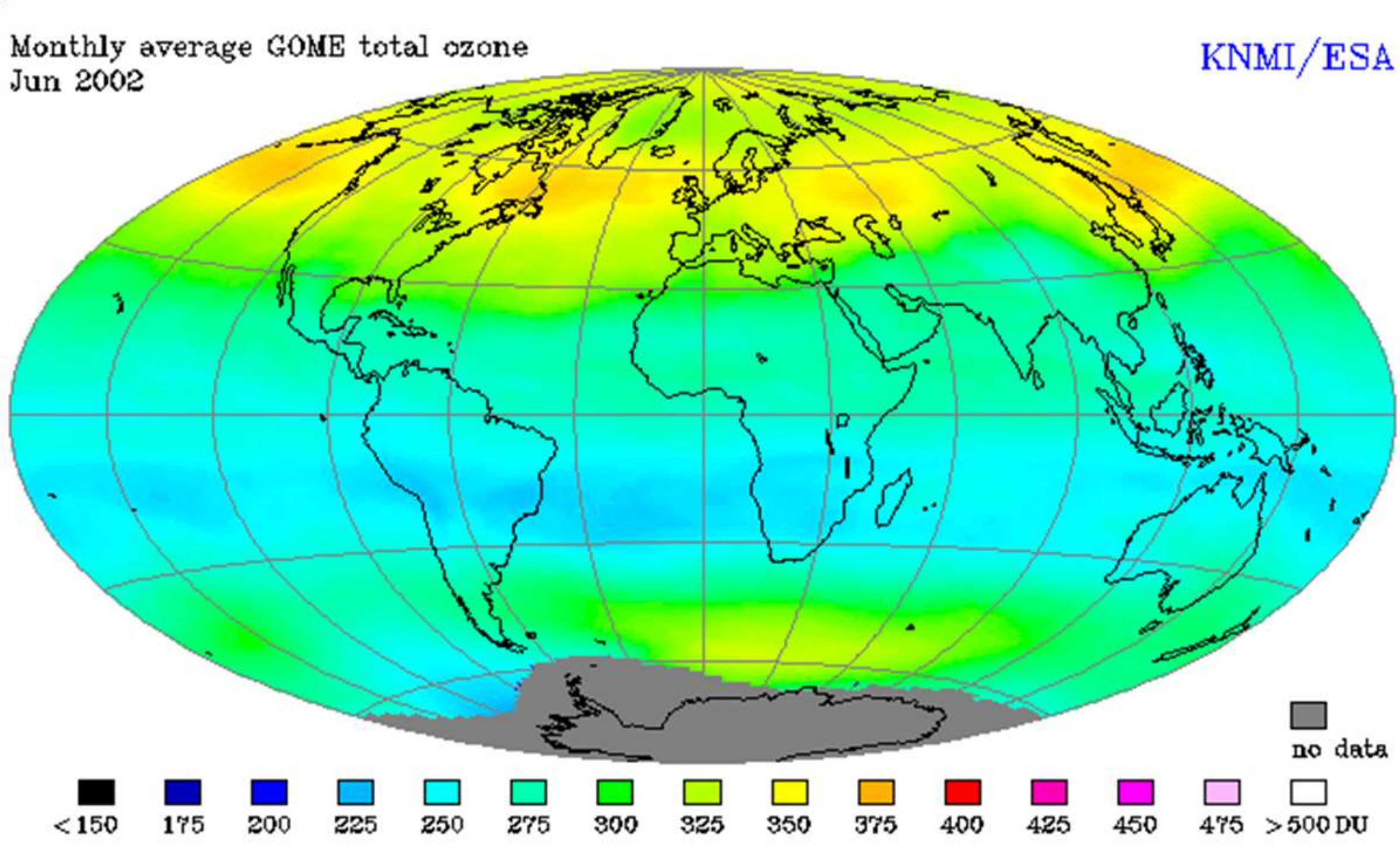
Ozônio (O_3)

A estrutura vertical do O_3 varia muito (latitude, estação do ano), mas tem um máximo ~20km



Ozônio (O_3)

O hemisferio norte tem uma maior concentração de ozônio que o hemisferio Sul



Ozônio (O_3)

A quantidade total de O_3 tem um ciclo annual

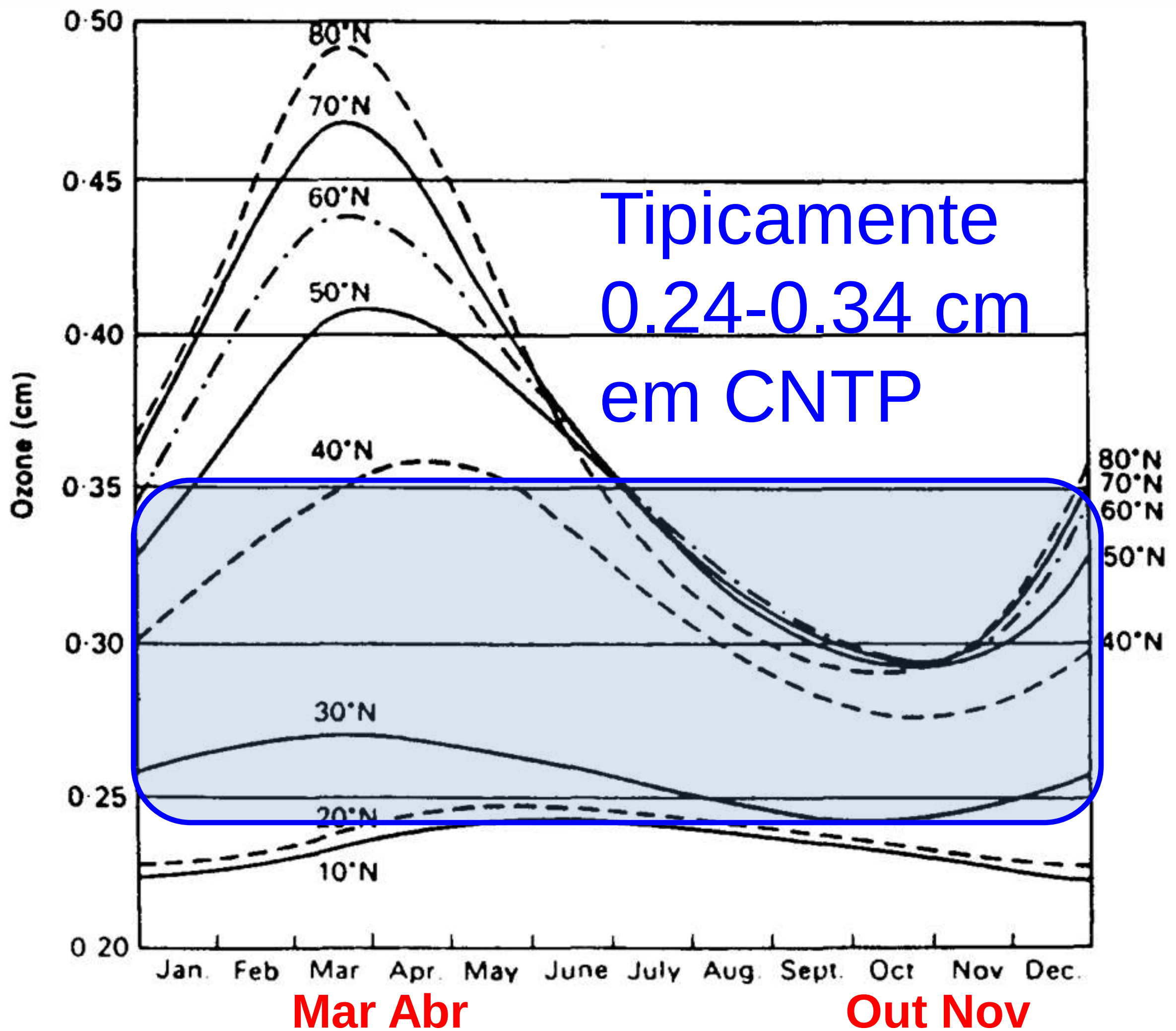
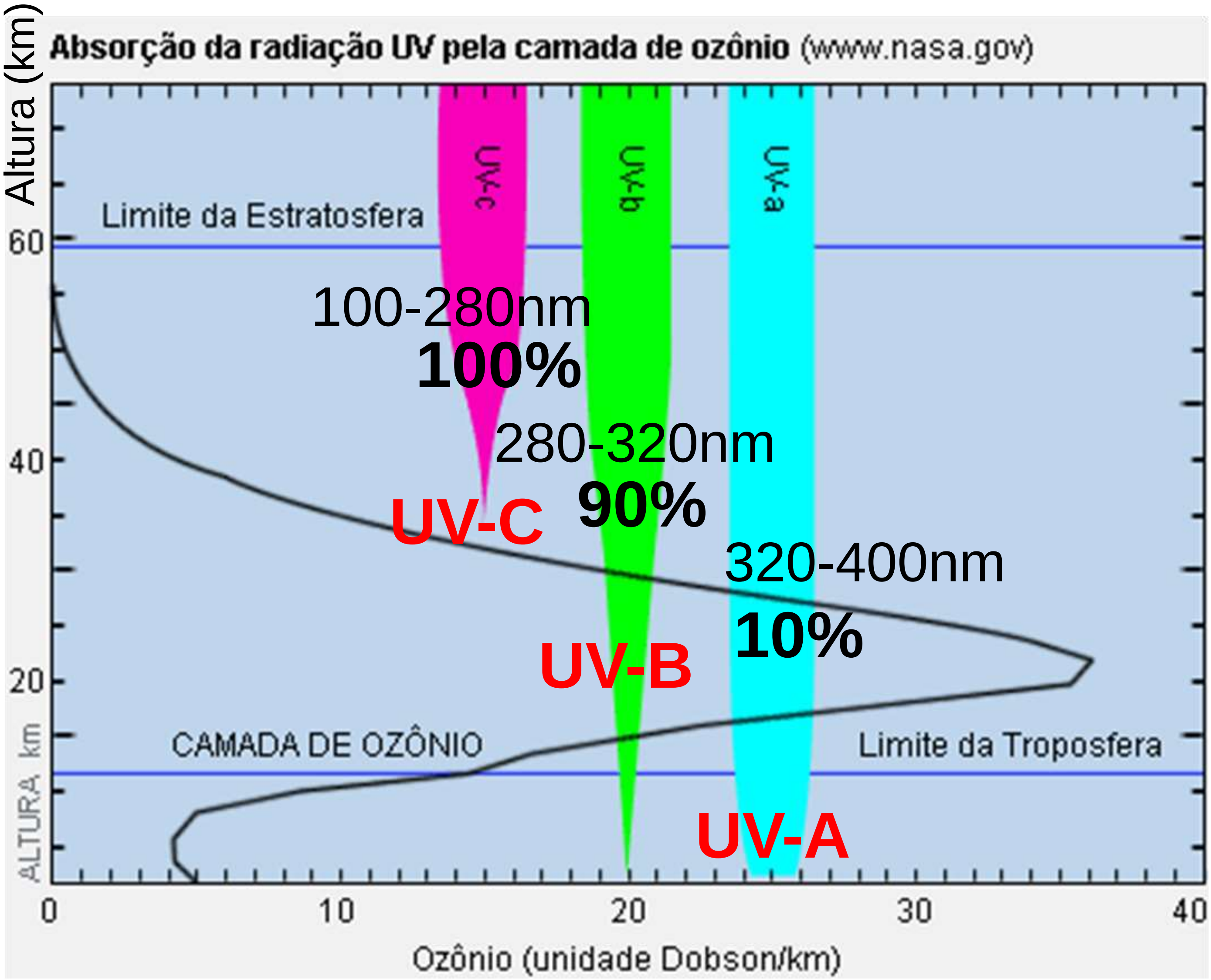
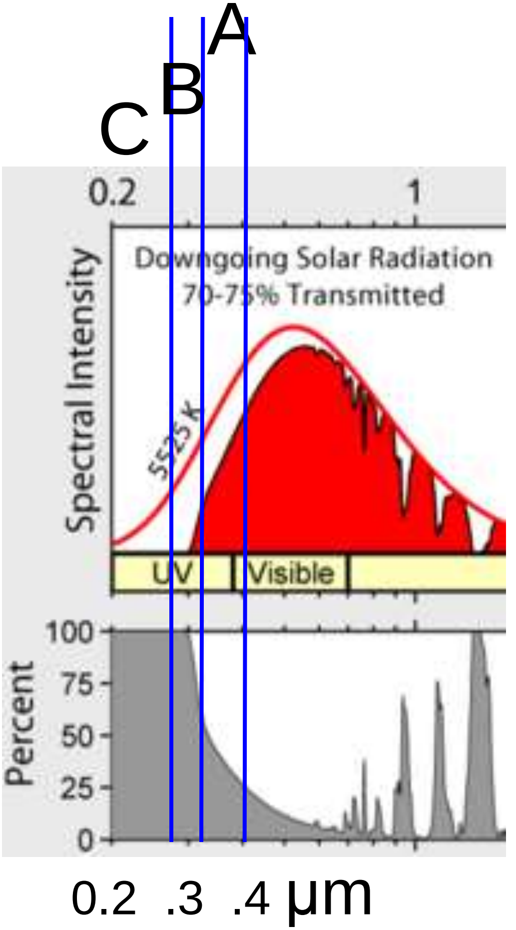


Figure 1. Annual Variation of Total Ozone for Each 10° of N Latitude

Variação annual do ozônio a cada 10 graus de latitude no hem. Norte

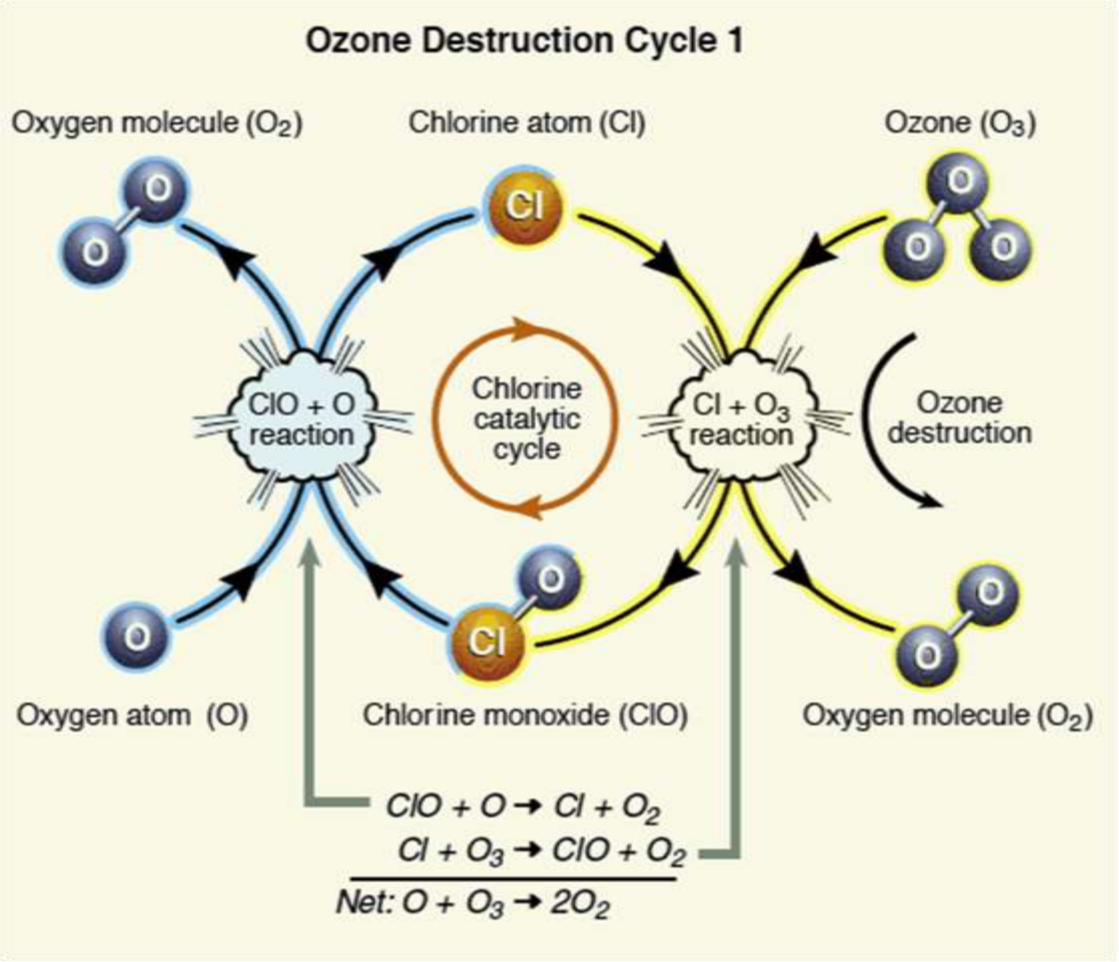
Ozônio: principal proteção contra a radiação UV solar





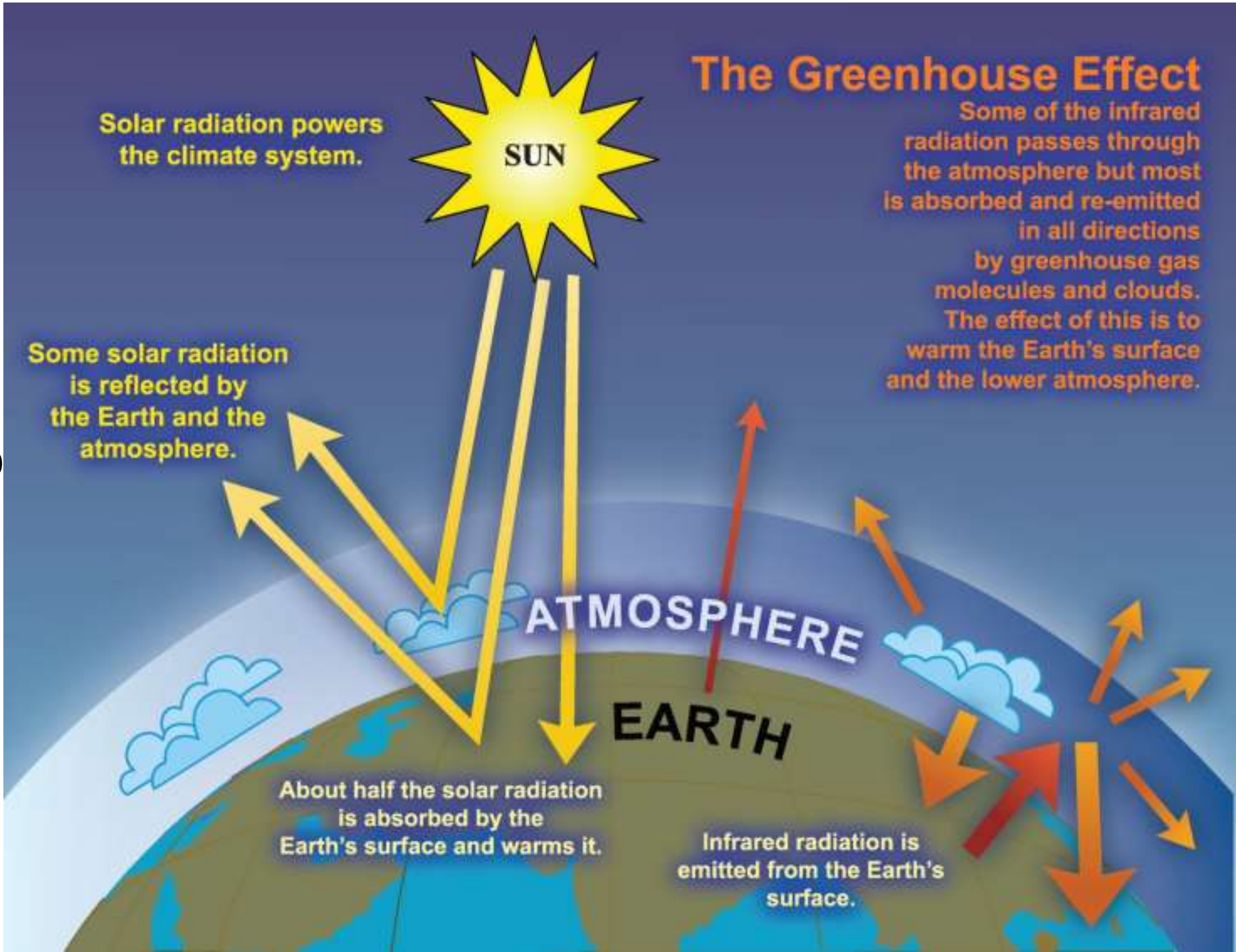
Destruição do Ozônio

- Constituintes menores (Cl, NO) destroem o O_3
- Os cloroflour-carbonetos, CFCs, podem alcançar a estratosfera e destroir ozônio



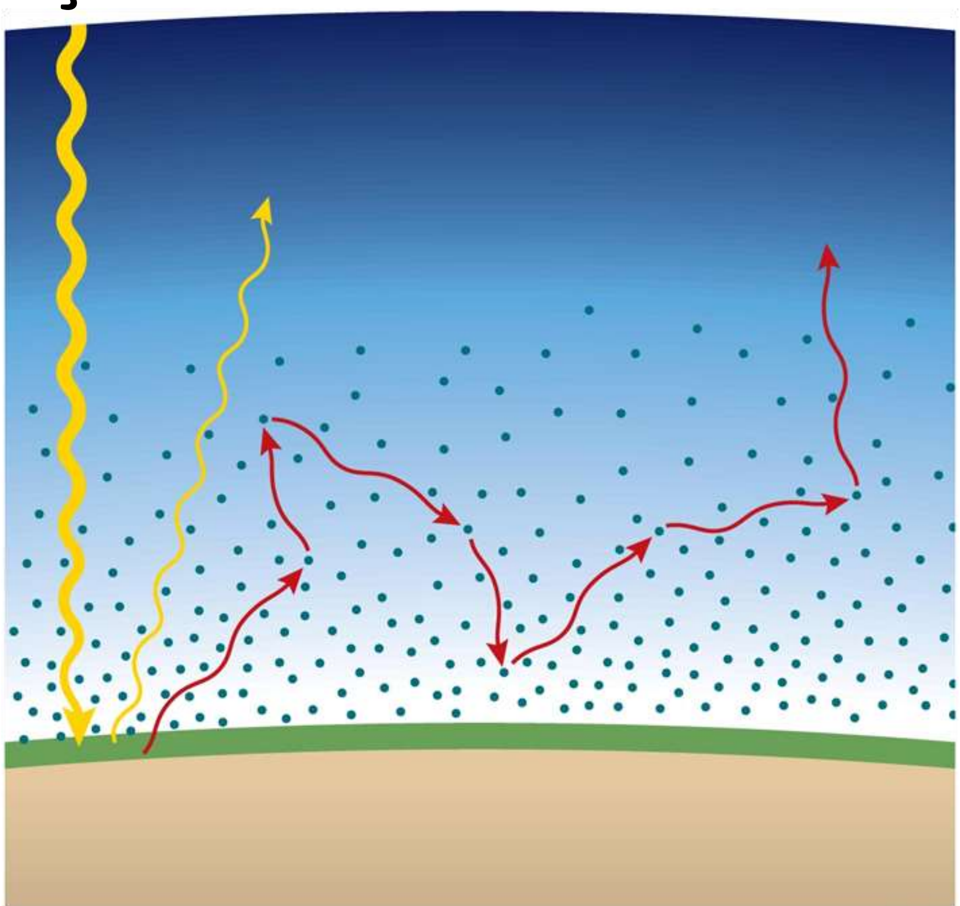
Dióxido de carbono CO_2

- Importante fonte de absorção no infravermelho
- Tem distribuição similar ao O_2 e N_2
- Razão de mistura não depende da altura



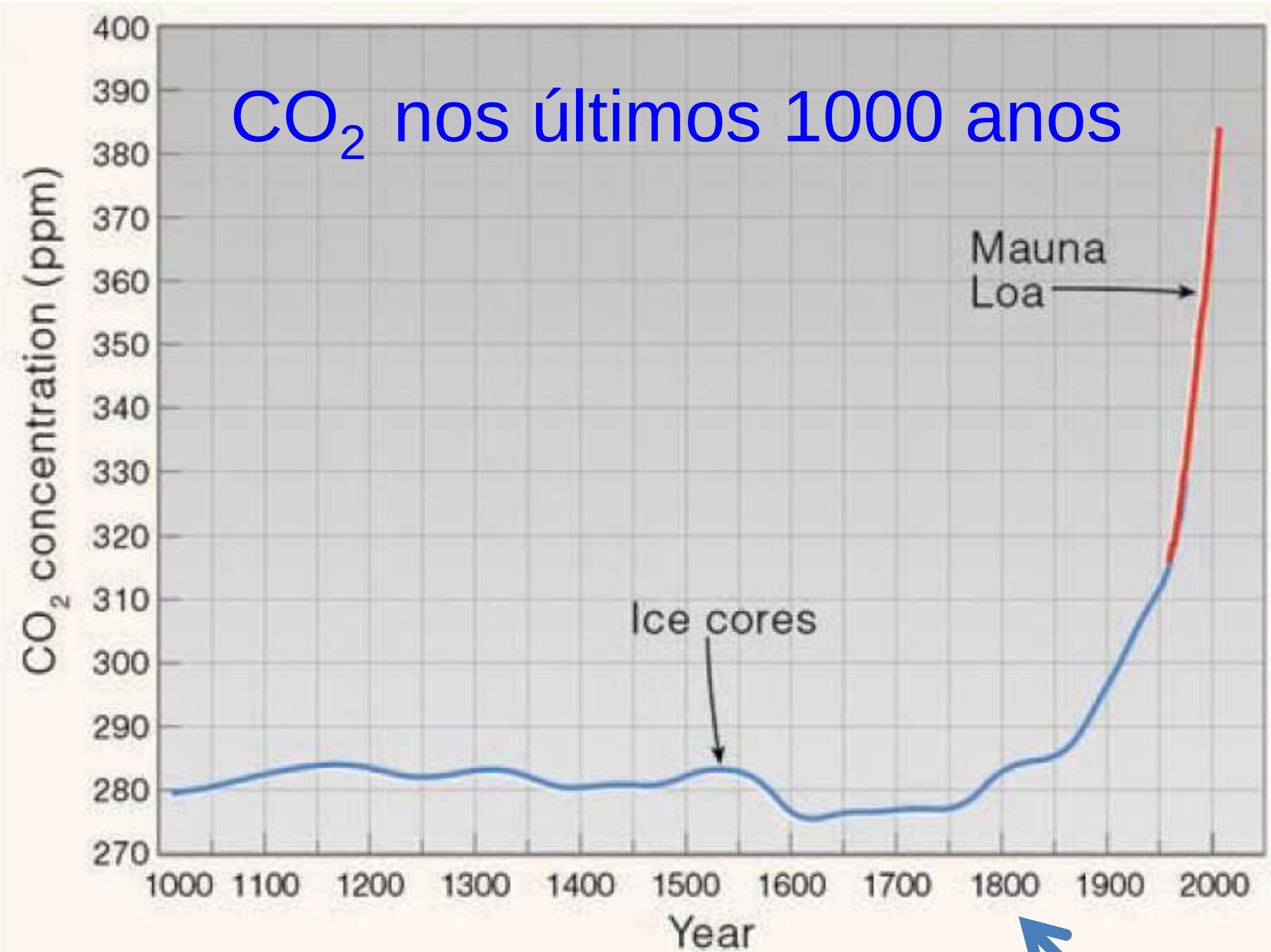
CO_2 e aquecimento global

Luz visível atravessa a atmos e esquenta a superficie. Os gases (CO_2, H_2O & CH_4) na atmos absorvem a luz IR refletida, re-emitindo-a em direções aleatorias.

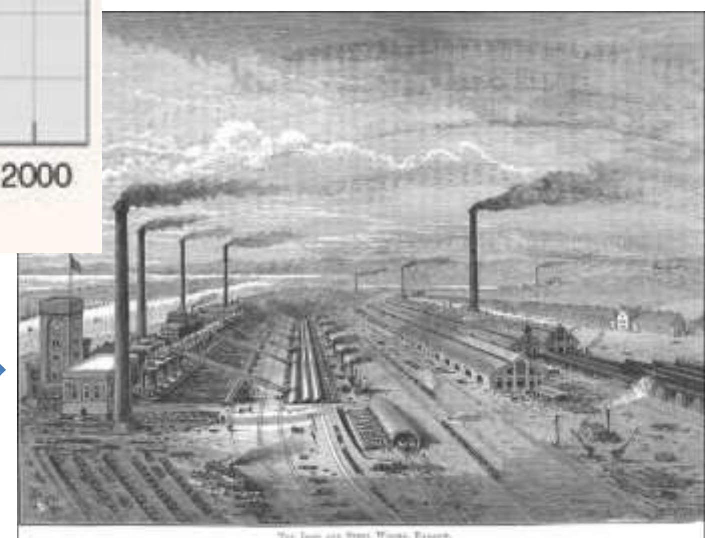


- CO_2 é a segunda fonte (após H_2O) do aquecimento global

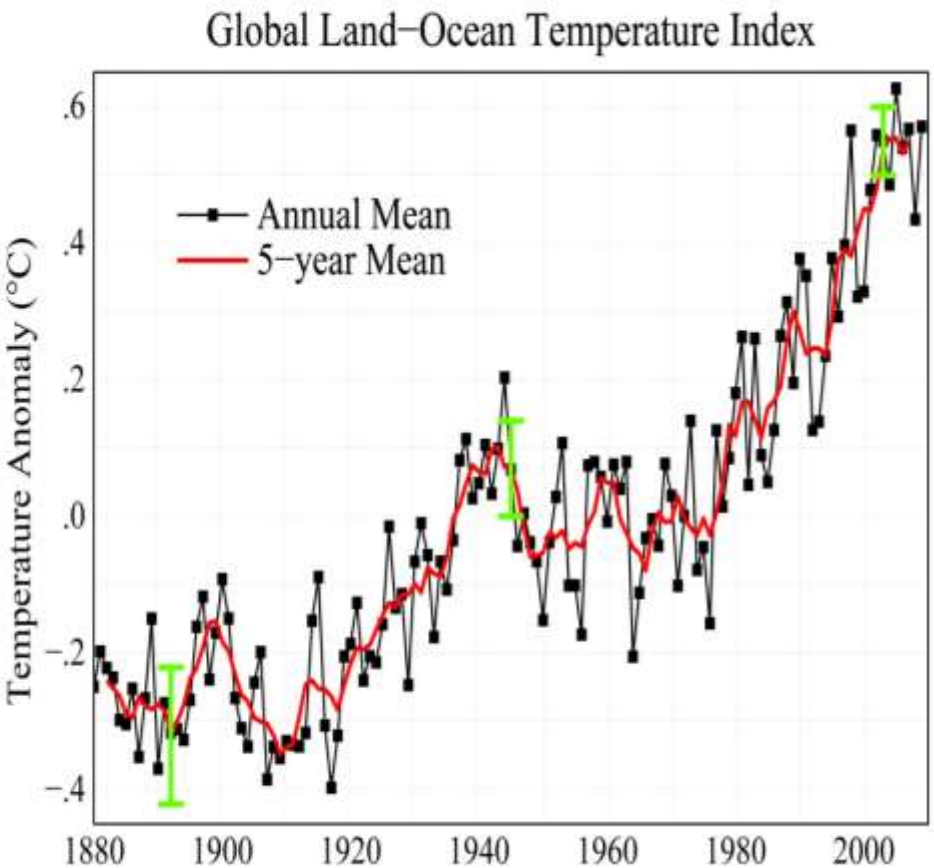
CO_2 e aquecimento global

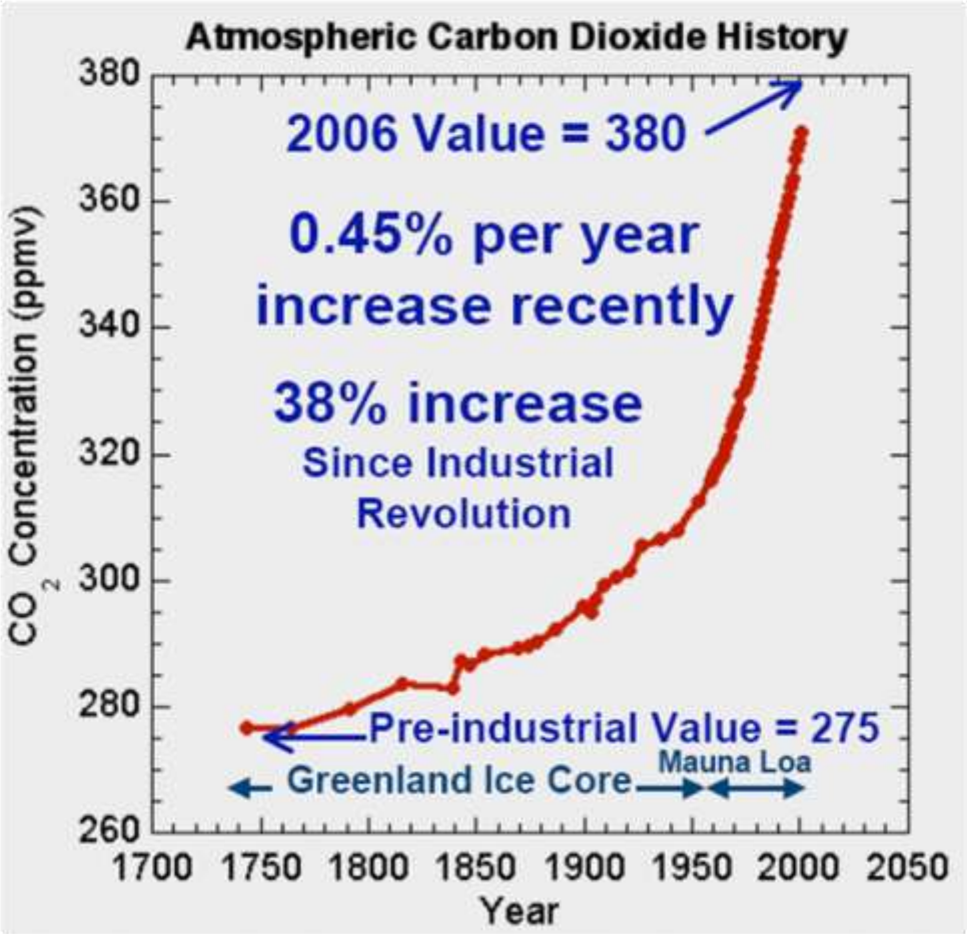


● FIGURE 1.6 Carbon dioxide values in parts per million during the past 1000 years from ice cores in Antarctica (blue line) and from Mauna Loa Observatory in Hawaii (red line). (Data courtesy of Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory.)

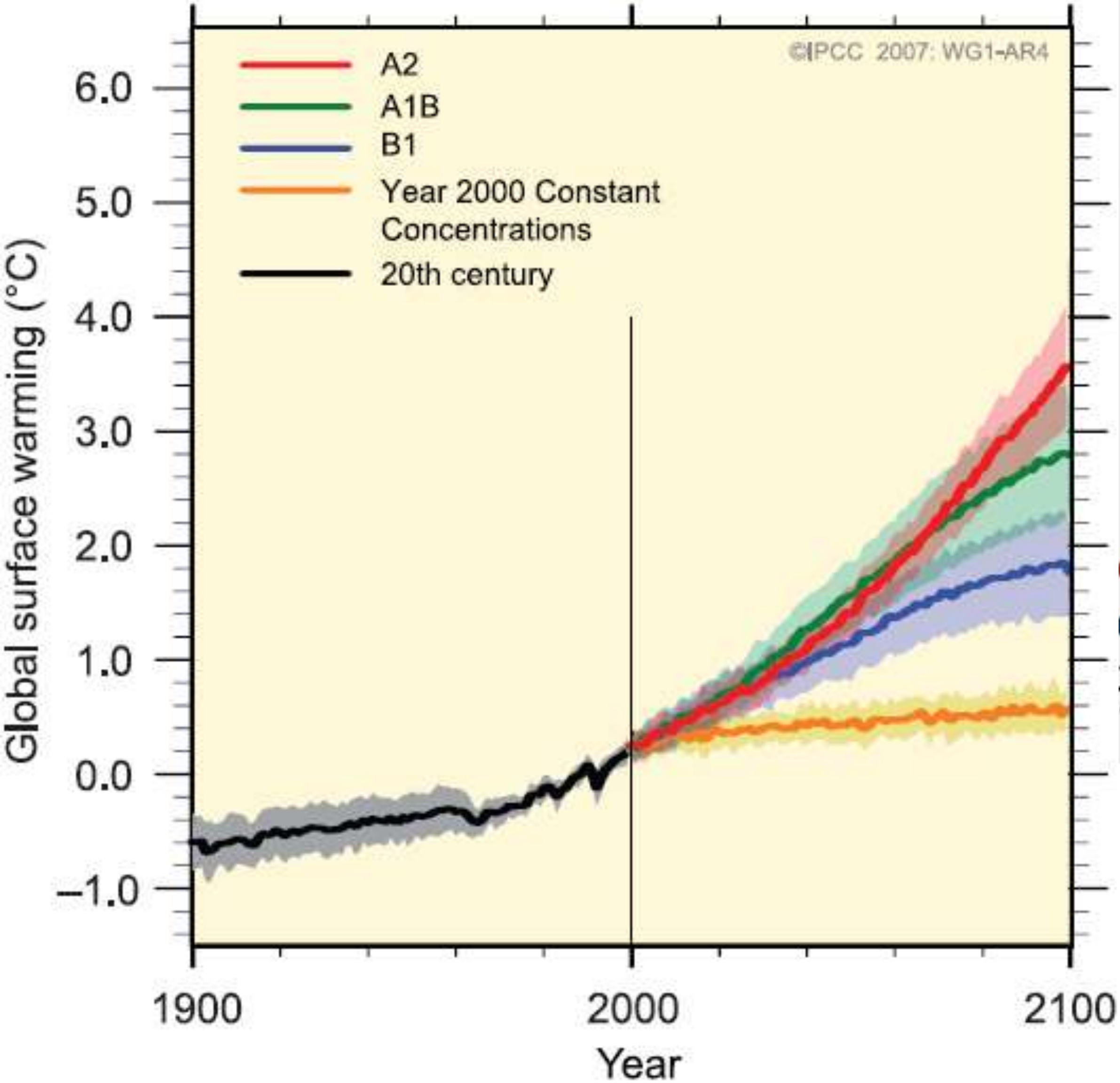


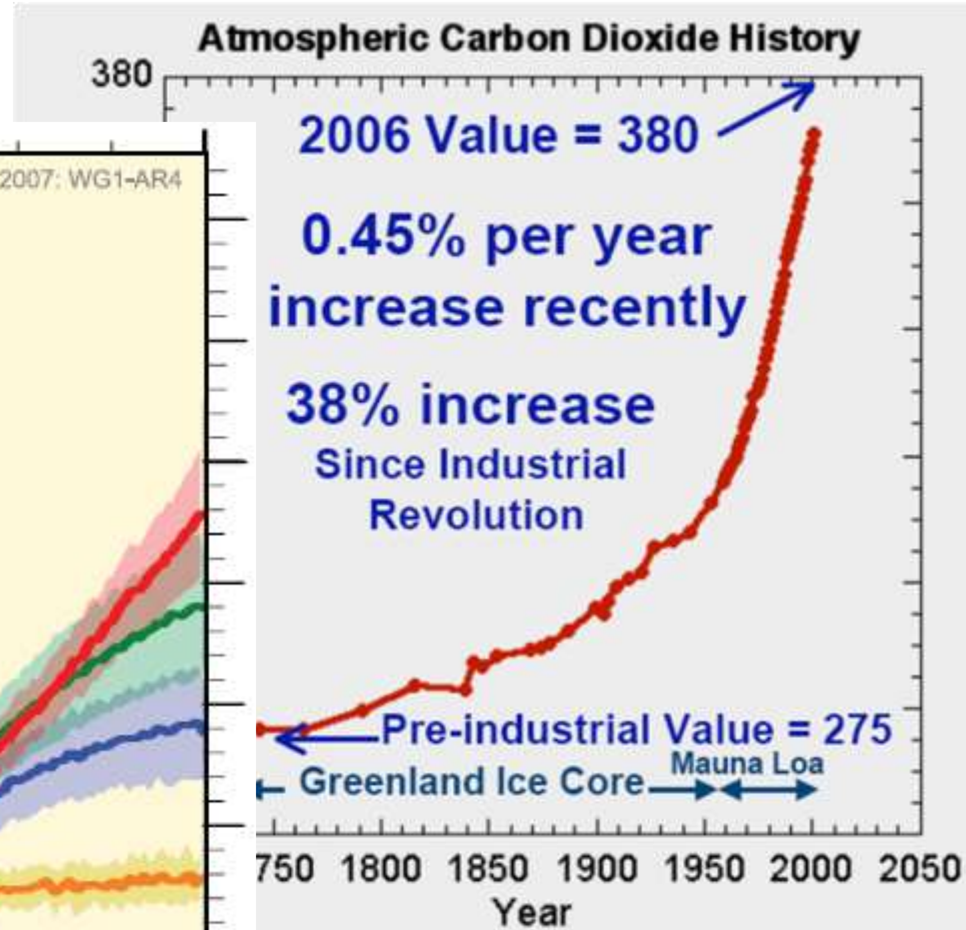
CO_2 e aquecimento global





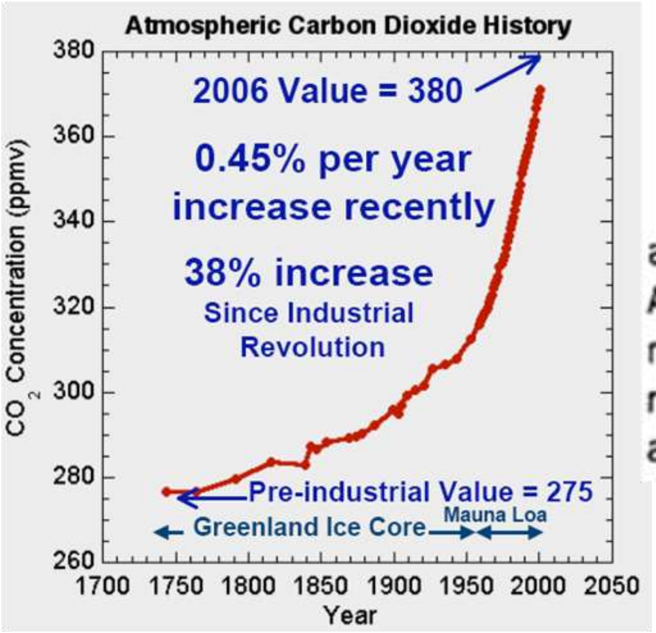
CO_2 e aquecimento global

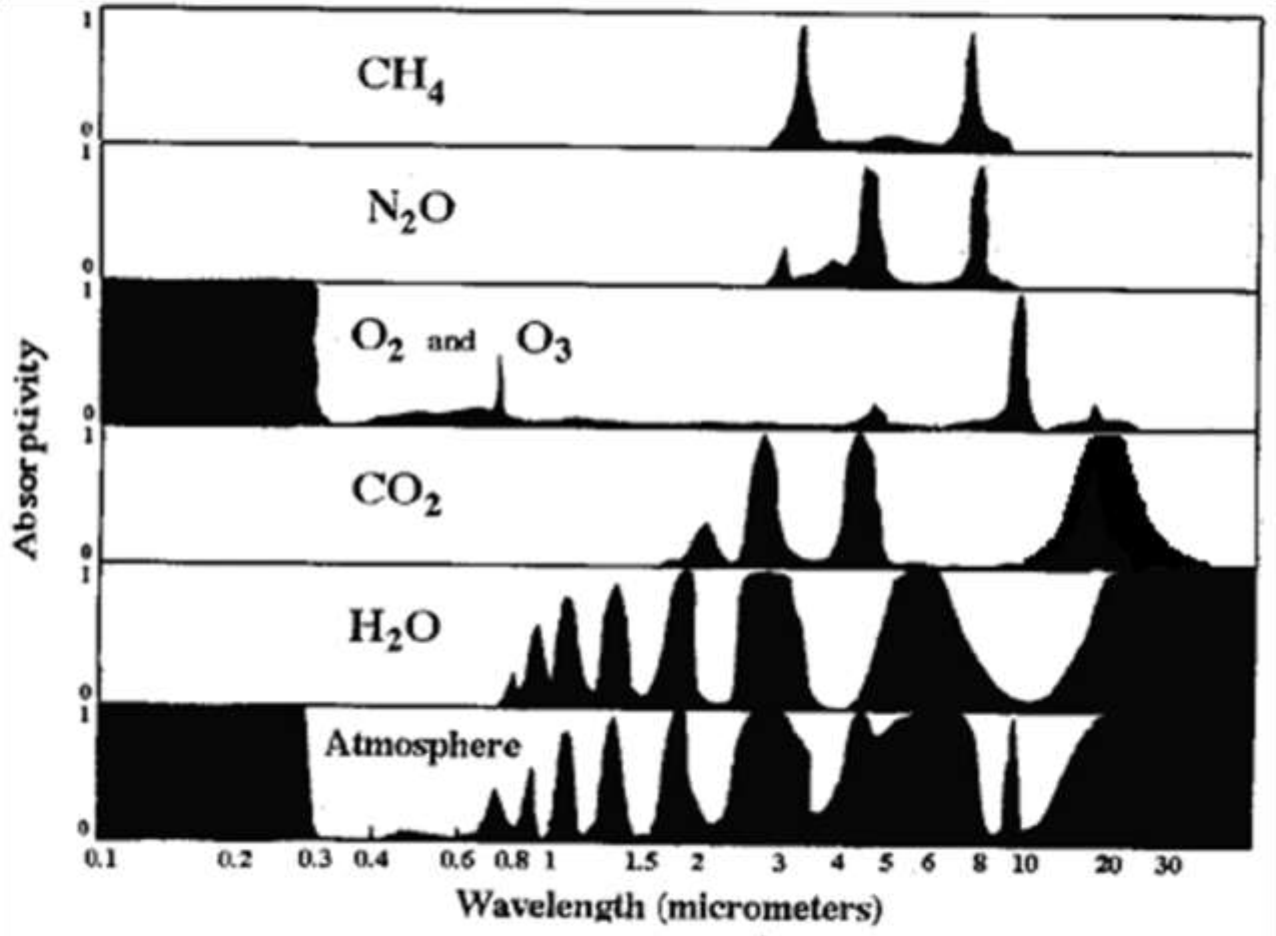




Impacto na Astronomia

Aumento de CO_2: maiores bandas de absorção na atmosfera





Absorptivity of various gases of the atmosphere and the atmosphere as a whole as a function of the wavelength of radiation. An absorptivity of zero means no absorption while a value of one means complete absorption. The dominant absorbers of infrared radiation are water vapor (H_2O) and carbon dioxide (CO_2). Oxygen (O_2) and ozone (O_3) absorb much of the sun's ultraviolet radiation.

bandas de absorção atmosférica (bandas teluricas)

Impacto na Astronomia?

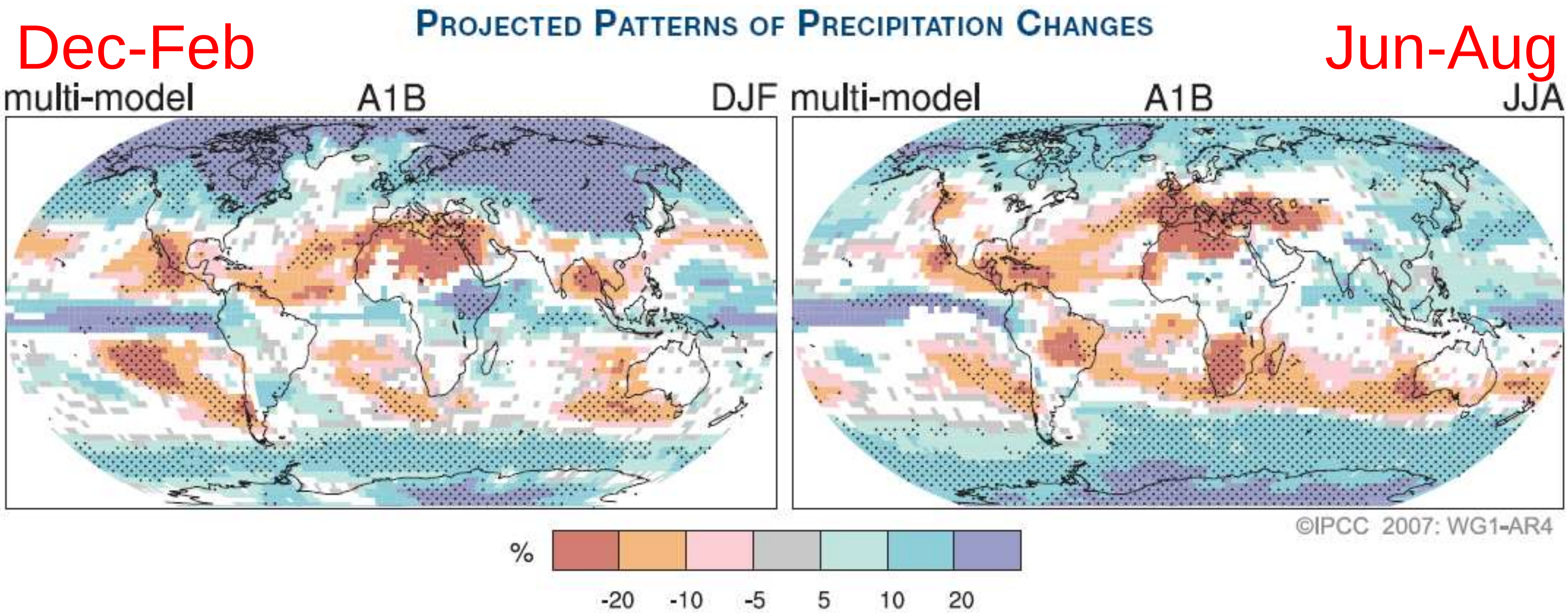


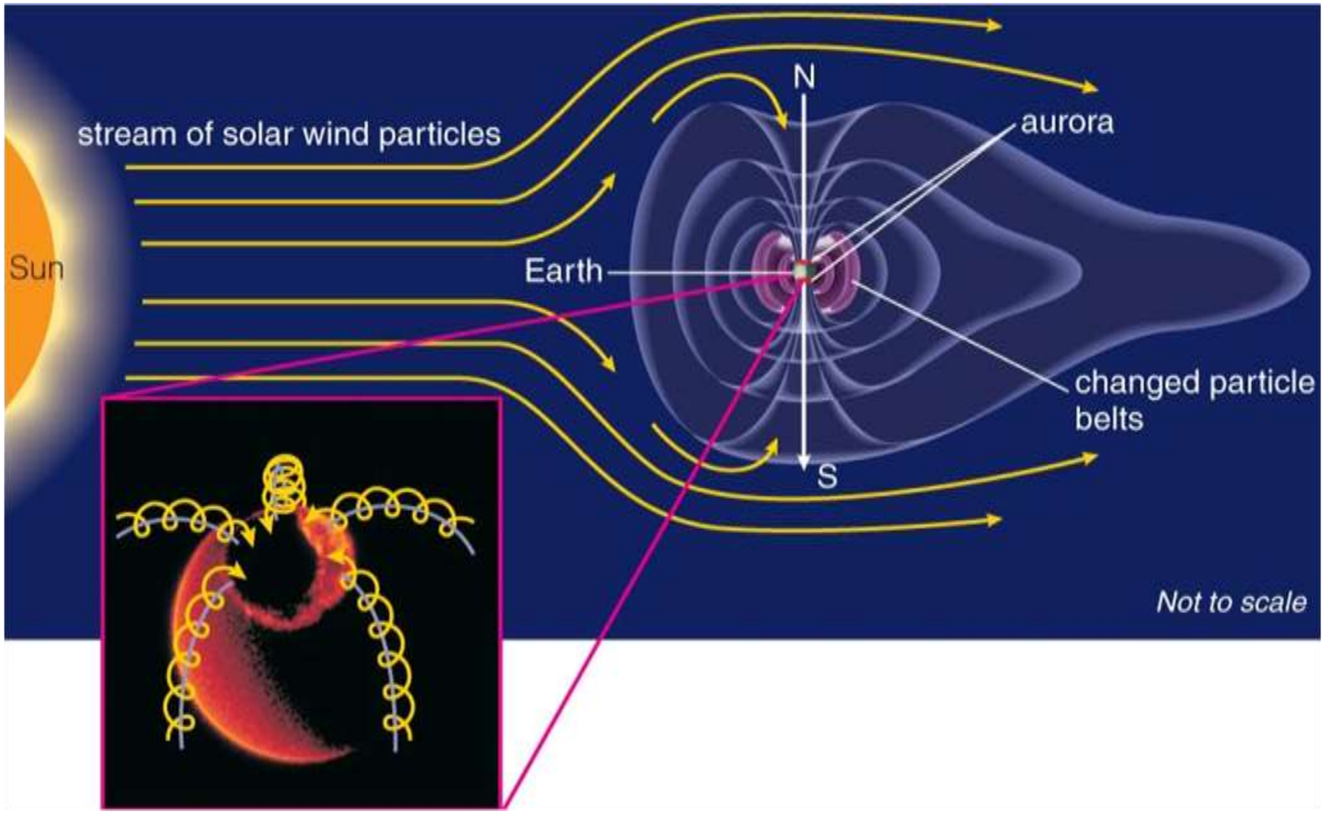
Figure SPM.7. *Relative changes in precipitation (in percent) for the period 2090–2099, relative to 1980–1999. Values are multi-model averages based on the SRES A1B scenario for December to February (left) and June to August (right). White areas are where less than 66% of the models agree in the sign of the change and stippled areas are where more than 90% of the models agree in the sign of the change. {Figure 10.9}*

Íons

•Acima de 60km, radiação solar UV ioniza a atmosfera

•A Ionização varia com altitude, iluminação solar, ativ. solar

•A altas latitudes, “cascatas” de elétrons entram nos polos magneticos, causam as auroras



Íons : Auroras

Íons

- Reações típicas:

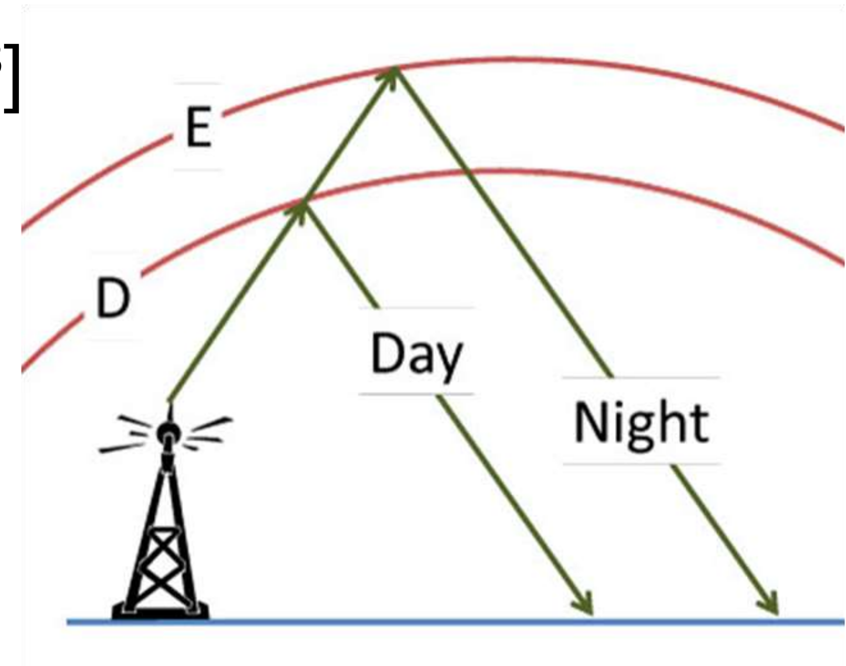
$$\mathrm{O_2 + h\nu \rightarrow O_2^+ + e^-}$$

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

- Variação da dens. eletrônica:

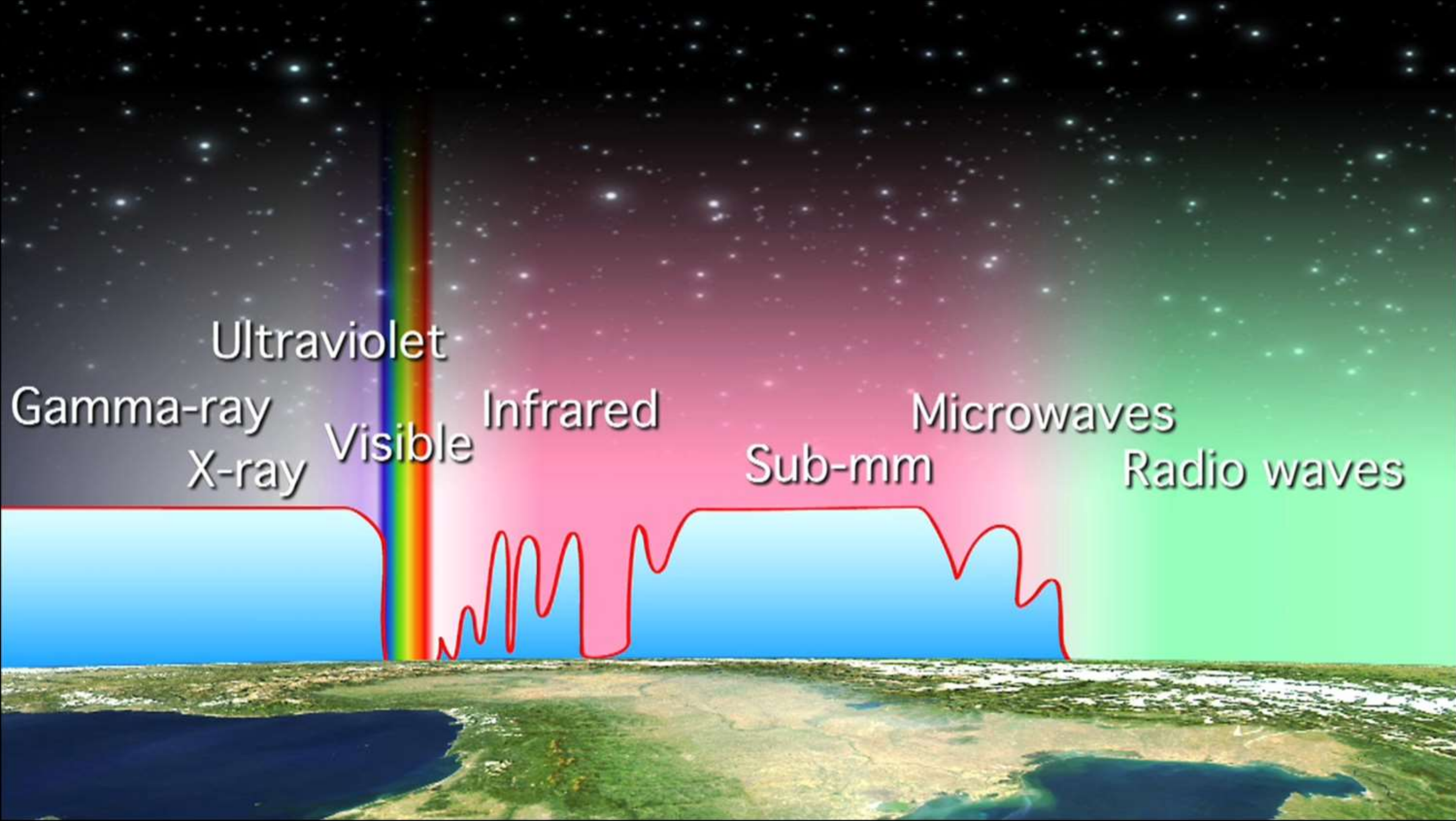
Camada	z(km)	Ne[cm^{-3}]
D	60	10^3
E	100	10^5
F	150-300	$2x10^6$
	> 2000	10^4

- D quase desaparece à noite
- Interfere nas ondas de rádio



Absorção da Radiação

A absorção da atmosfera pode ser total ou parcial



Transições Atômicas e Moleculares

ATÔMICAS: O, N

MOLECULARES:

- Eletrônicas

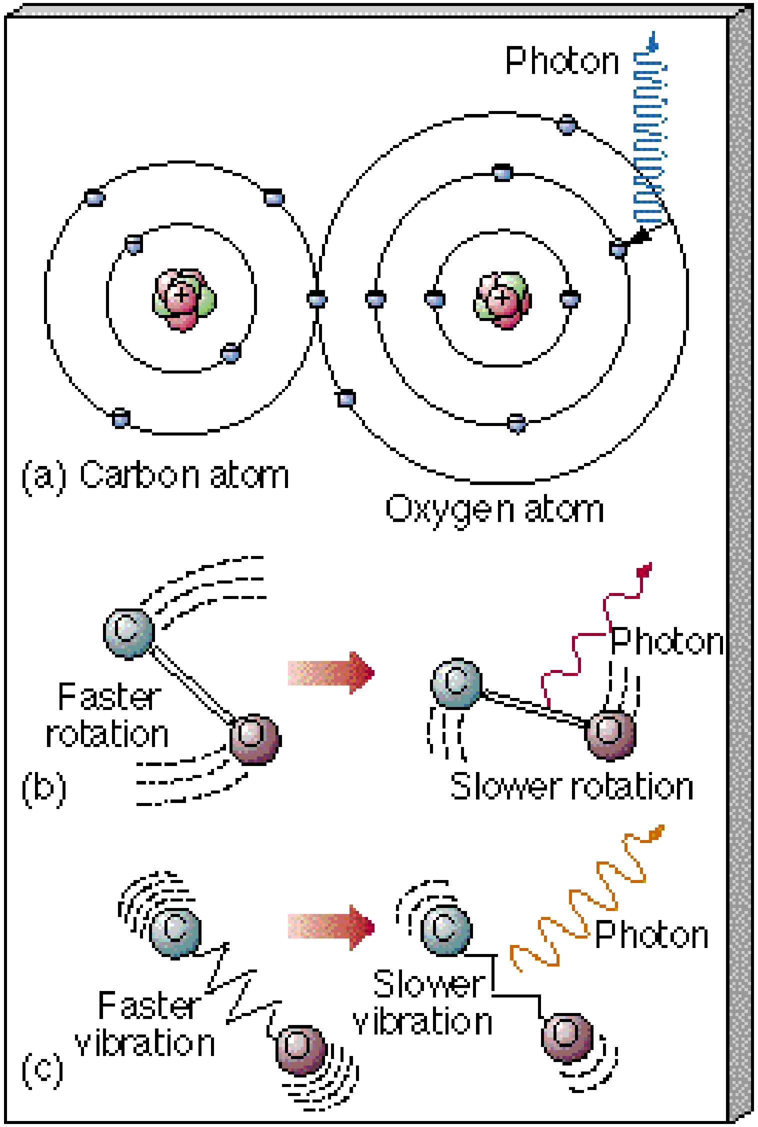
  CH_4, CO, H_2O, O_2, O_3, ...

- Rotacionais:

  H_2O, CO_2, O_3, ...

- Rotationais-Vibracionais:

  CO_2, NO, CO ...

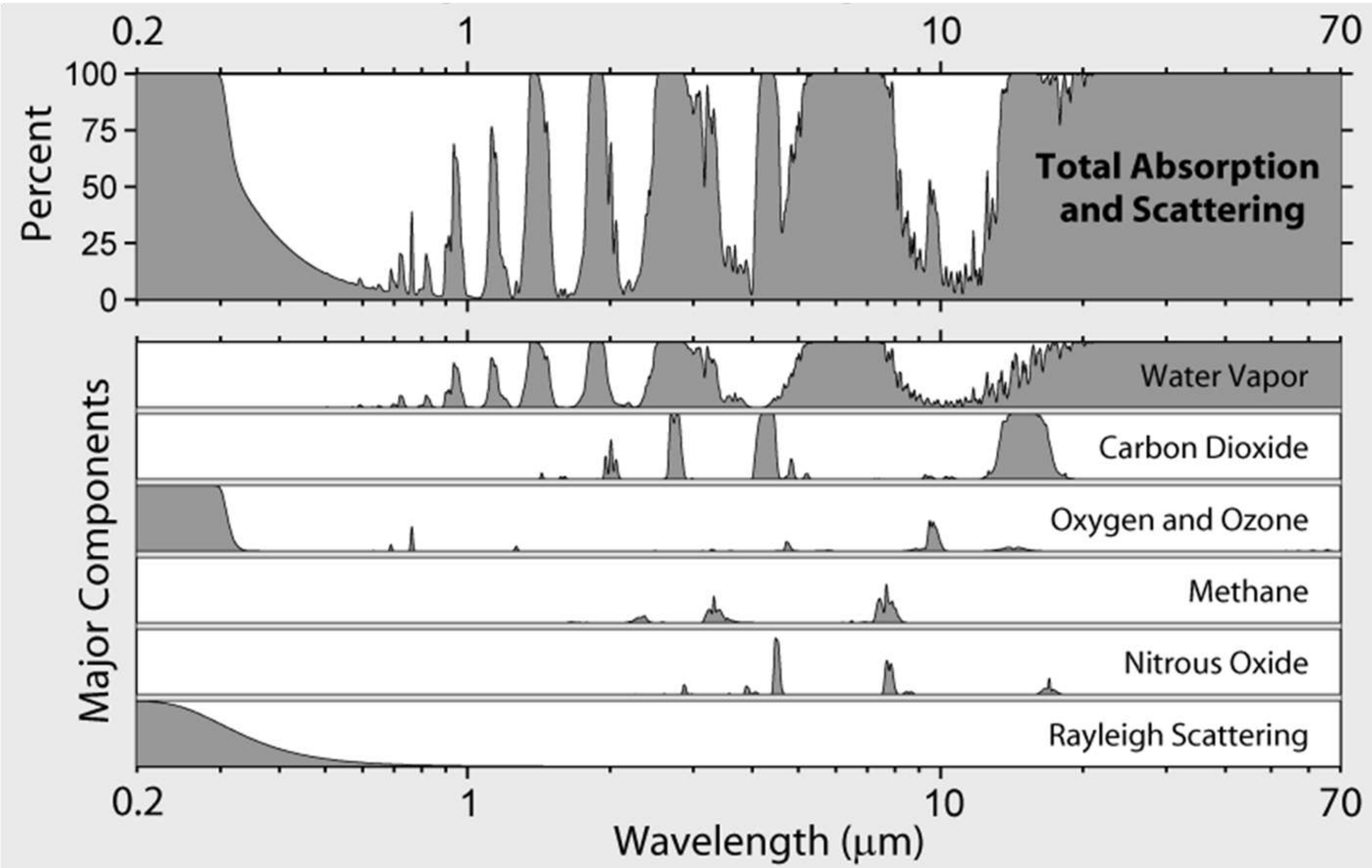


$$E_{el,v'',J''} = [T_e + G_v + F_v(J)]\,hc$$

Bandas de absorção atmosféricas

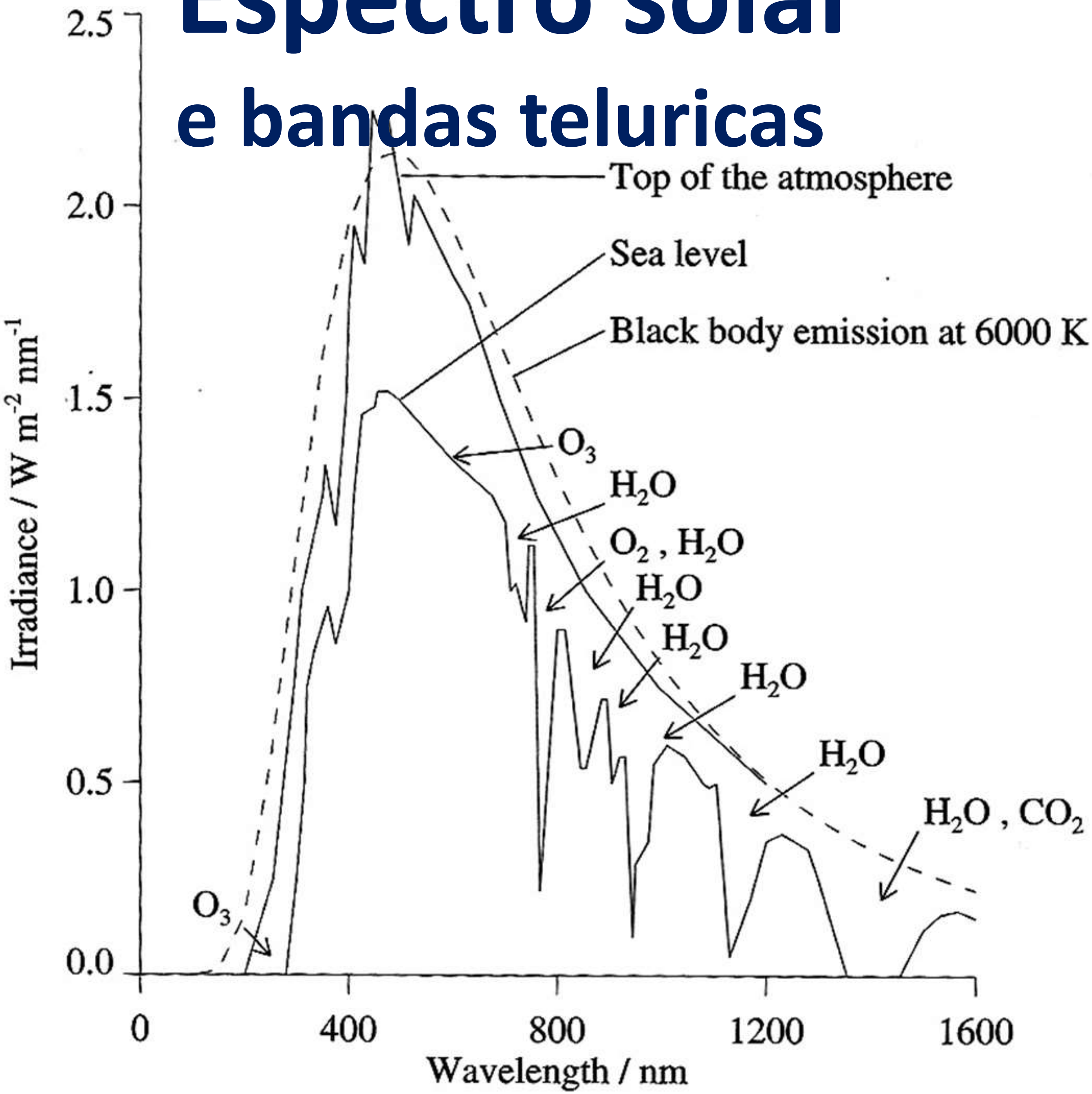
bandas teluricas

A física atóm. e mol. fornece coef. κ ou σ para c/especie



Espectro solar
e bandas teluricas

No otico e infravermelho proximo, O_3, H_2O e CO_2 causam fortes bandas de absorção na atmosfera terrestre



Ground-based observatories

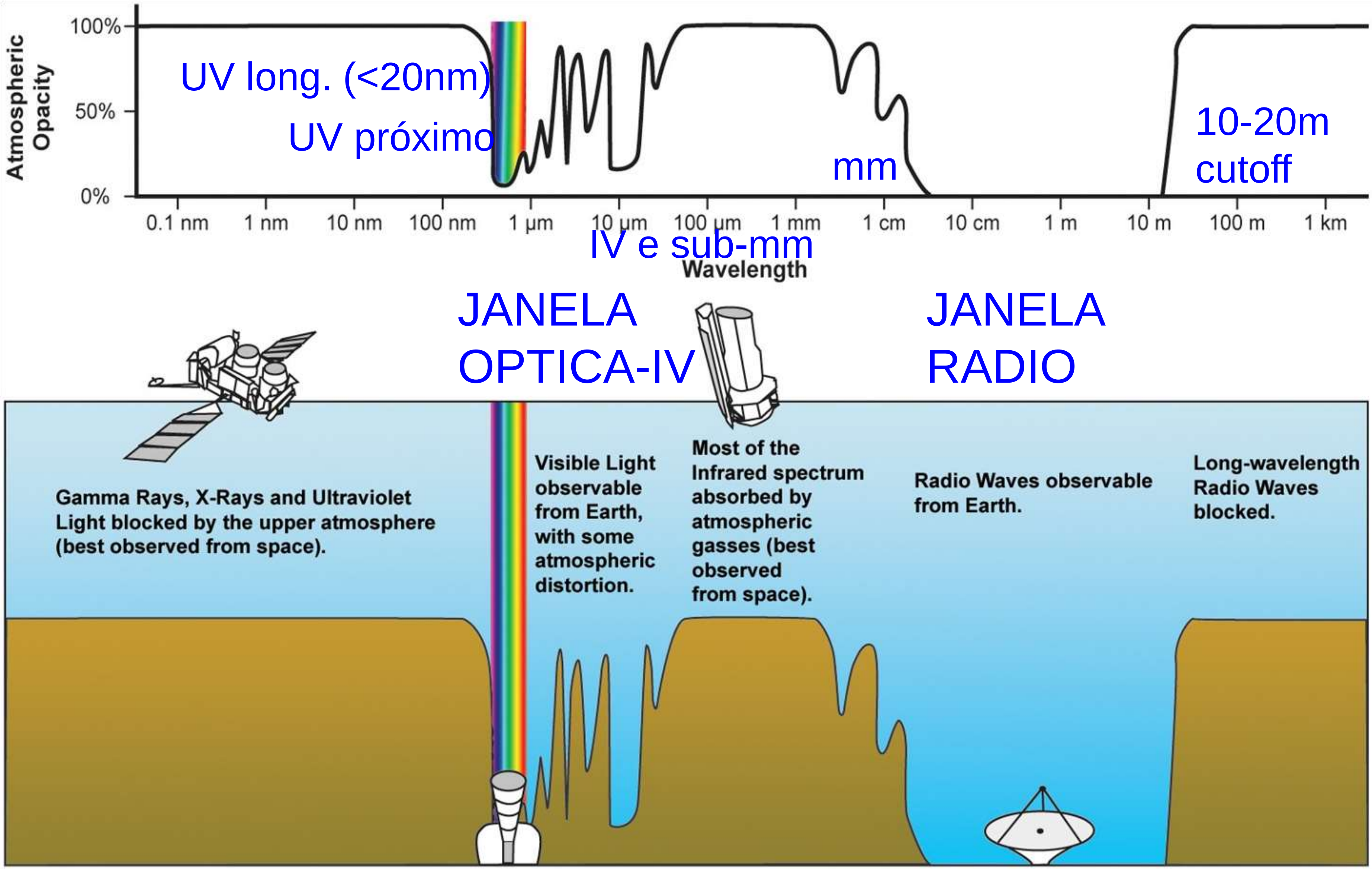
Contínuo N_2

Bandas elet O_2 , O_3, cont O_2

Bandas rot. e v-r H_2O e CO_2

Bandas rot. H_2O e O_2

Plasma ionosferico



ALMA:

66 antennas working together at mm and submm

Emissão Atmosférica

- A atmosfera emite por fluorescência (*airglow*) e termicamente

FLUORESCÊNCIA: recombinação dos elétrons e íons criados nas reações diurnas de dissociação

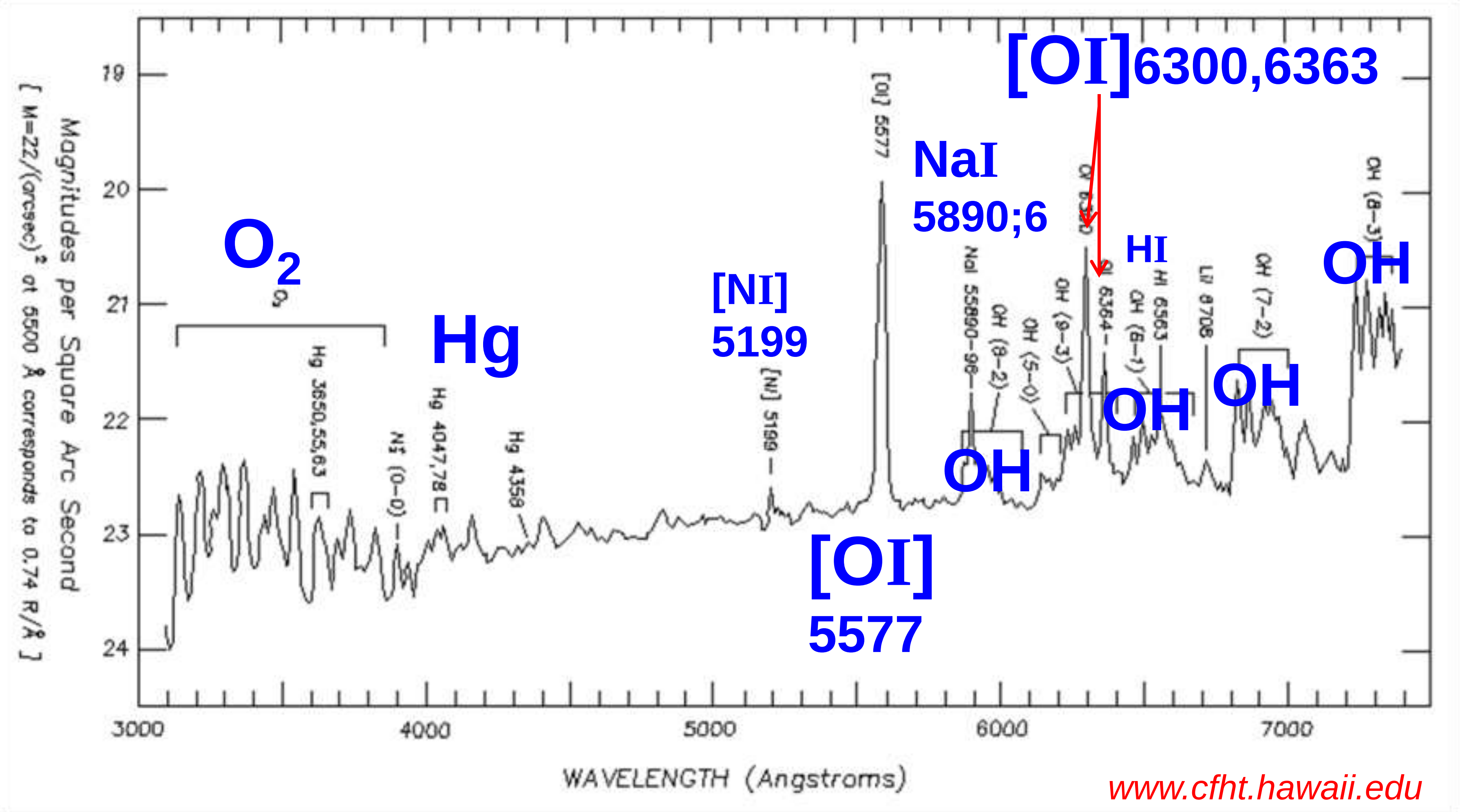
- Contínuo: 1-3 Rayleigh $Å^{-1}$
- Linhas: 500 R

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

  = $6.8x10^{-17}$ $Wm^{-2}um^{-1}arcsec^{-2}$(em =550nm) = 22 mag $arcsec^{-2}$

- Principais emissores: OI, NaI, O_2, OH, H

Espectro do céu à noite (no ótico)
Mauna Kea (Havaí)



www.cfht.hawaii.edu

Espectro do céu à noite (no ótico e infravermelho)

Observatório de La Palma (Canary Islands)

OH é muito forte no vermelho-infravermelho

Fundo de céu para observações no solo e no espaço próximo à Terra

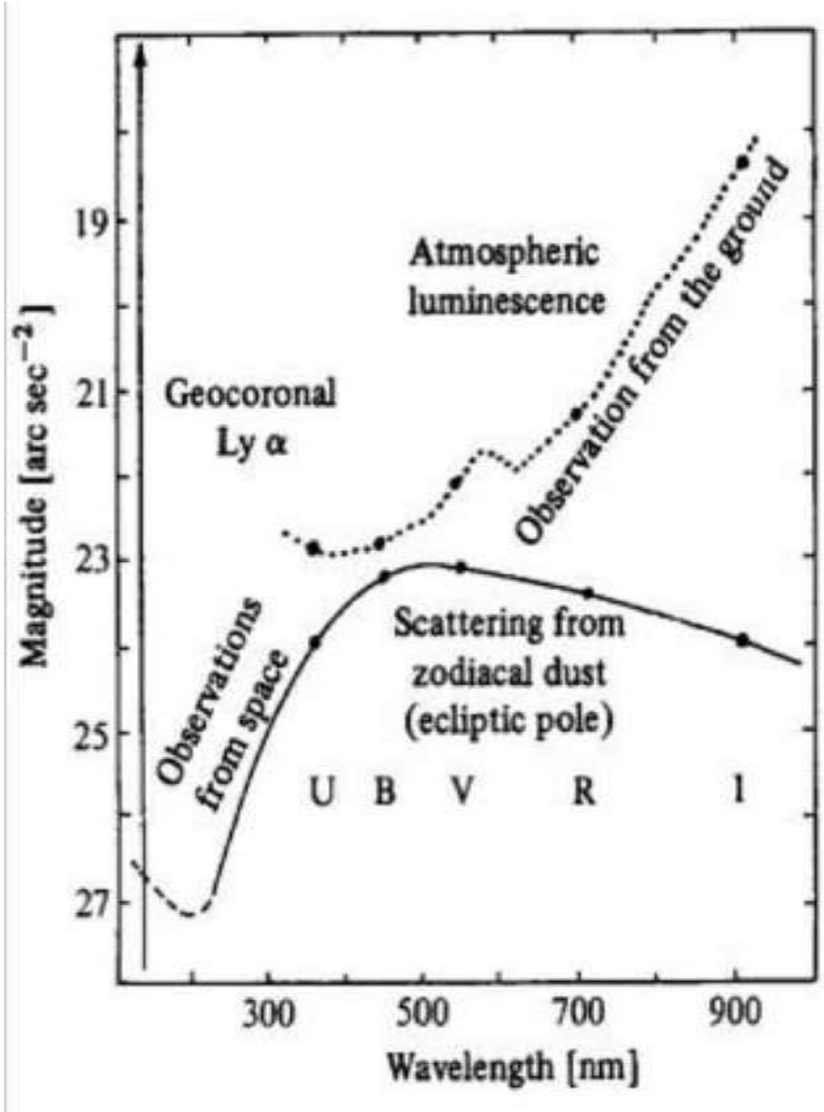
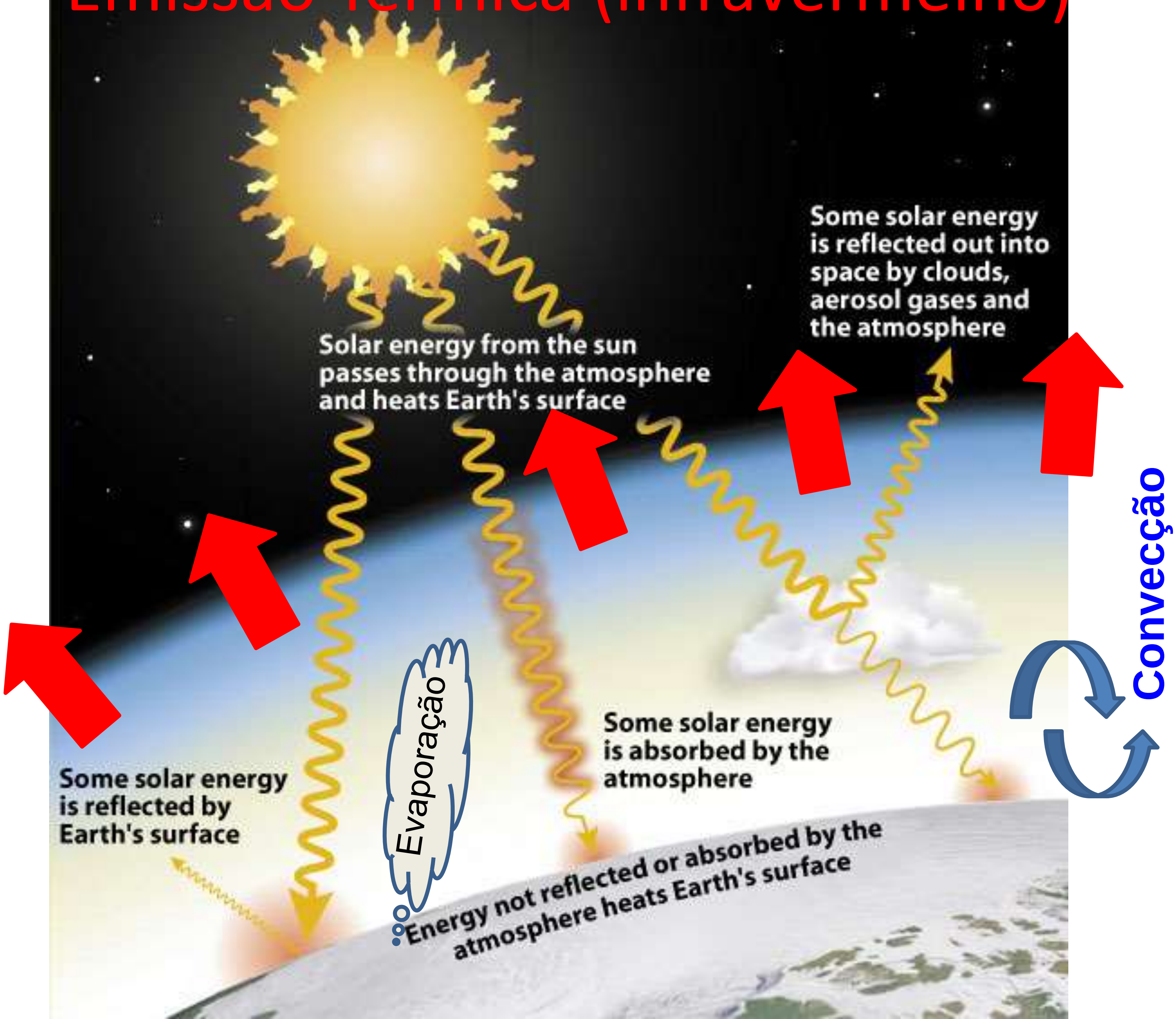


Fig. 2.8. Visible and ultraviolet magnitudes of the sky background per square arc second, for observations from the ground and from space near the Earth. Letters denote the spectral bands of the photometric system (cf. 3.3), corresponding to the points (•). [After Courtès G., personal communication; 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]

Emissão Térmica (infravermelho)



Emissão Térmica

- Atmosfera pode ser considerada um gás em ETL até 40-60km
- Para $\tau << 1$ (profundidade ótica fina), a intensidade de radiação a altitude z e distância zenital θ é:

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

onde B_λ é função de Planck à temperatura média $\bar{T}$ da atmosfera.

$\tau << 1$ e B_λ não é desprezível:

- infravermelho próximo: 1 - 20 μm
- milimétrico: 0.5 – 2 mm

Emissão Térmica

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

Usando temperatura média 250K:

Fontes astronômicas podem ser várias ordens de magnitude mais fracas que a emissão térmica do céu (problema parecido com a emissão fluorescente do céu).

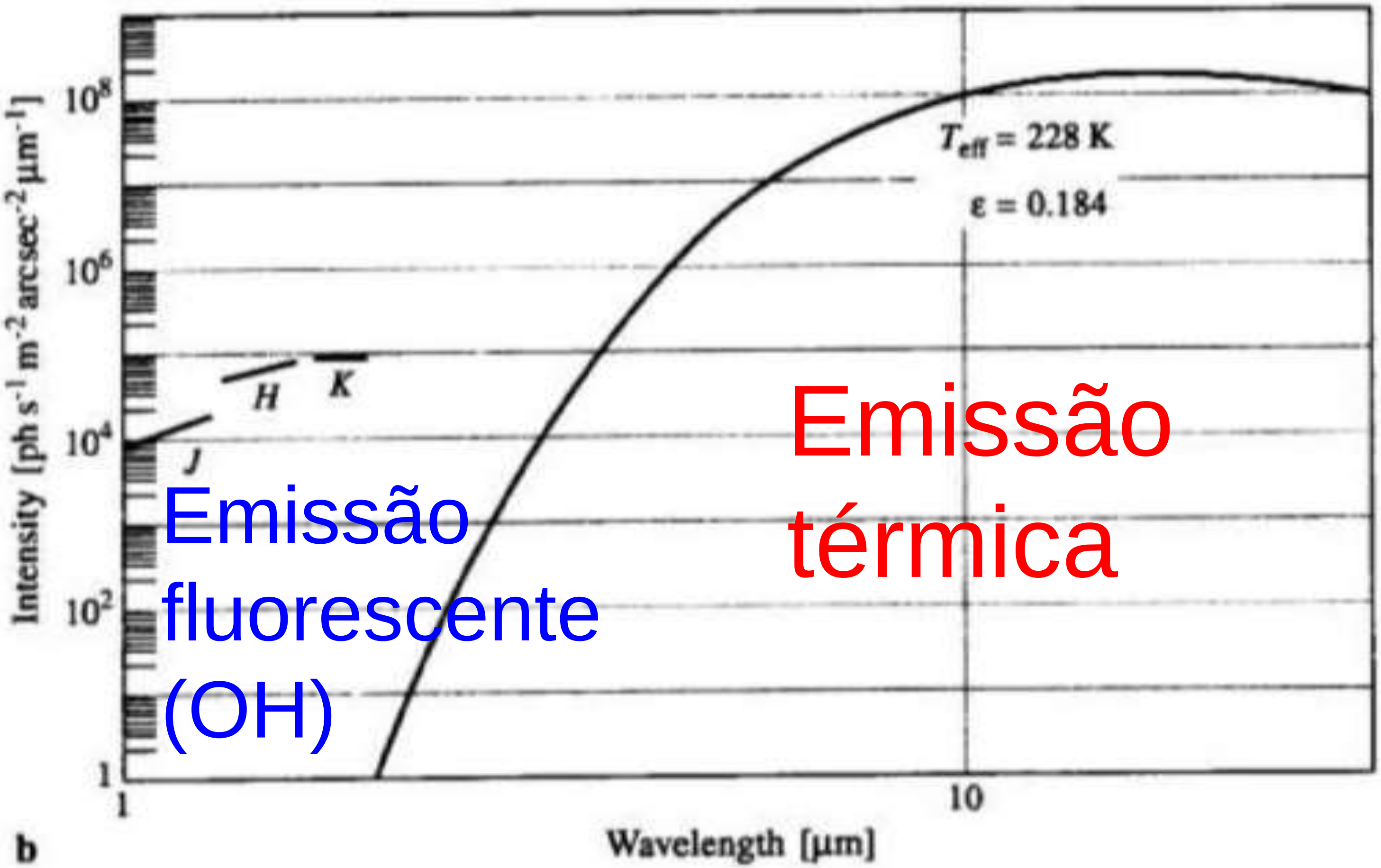
Table 2.3. Mean thermal emission of the atmosphere

Spectral band (cf. Sect. 3.3)	L	M	N	Q
Mean wavelength [μm]	3.4	5.0	10.2	21.0
Mean optical depth τ	0.15	0.3	0.08	0.3
Magnitude [arcsec^{-2}]	8.1	2.0	−2.1	−5.8
Intensity [Jy arcsec^{-2}][a]	0.16	22.5	250	2 100

[a] 1 Jansky = 10^{-26} W m^{-2} Hz^{-1}.

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

Fundo do céu no infravermelho: emissão térmica vs. OH



Brilho de fundo do céu no infravermelho,
em altitude de Mauna Kea (4200m).

Difusão da Radiação: espalhamento Rayleigh e Mie

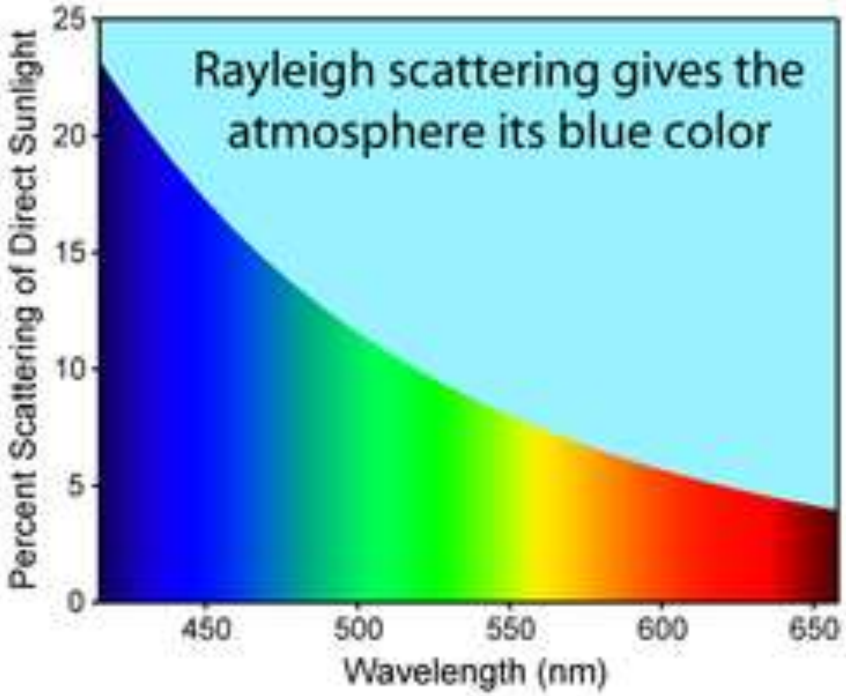
- Causado por moléculas e aerosóis em suspensão
- A influência das particulas do ar depende da altitude, *mas os aerosóis dependem de ventos, clima, estação, ativ. vulcânica, poluição industrial...*

Espalhamento Rayleigh

- Para partículas menores ao comprimento de onda λ da luz

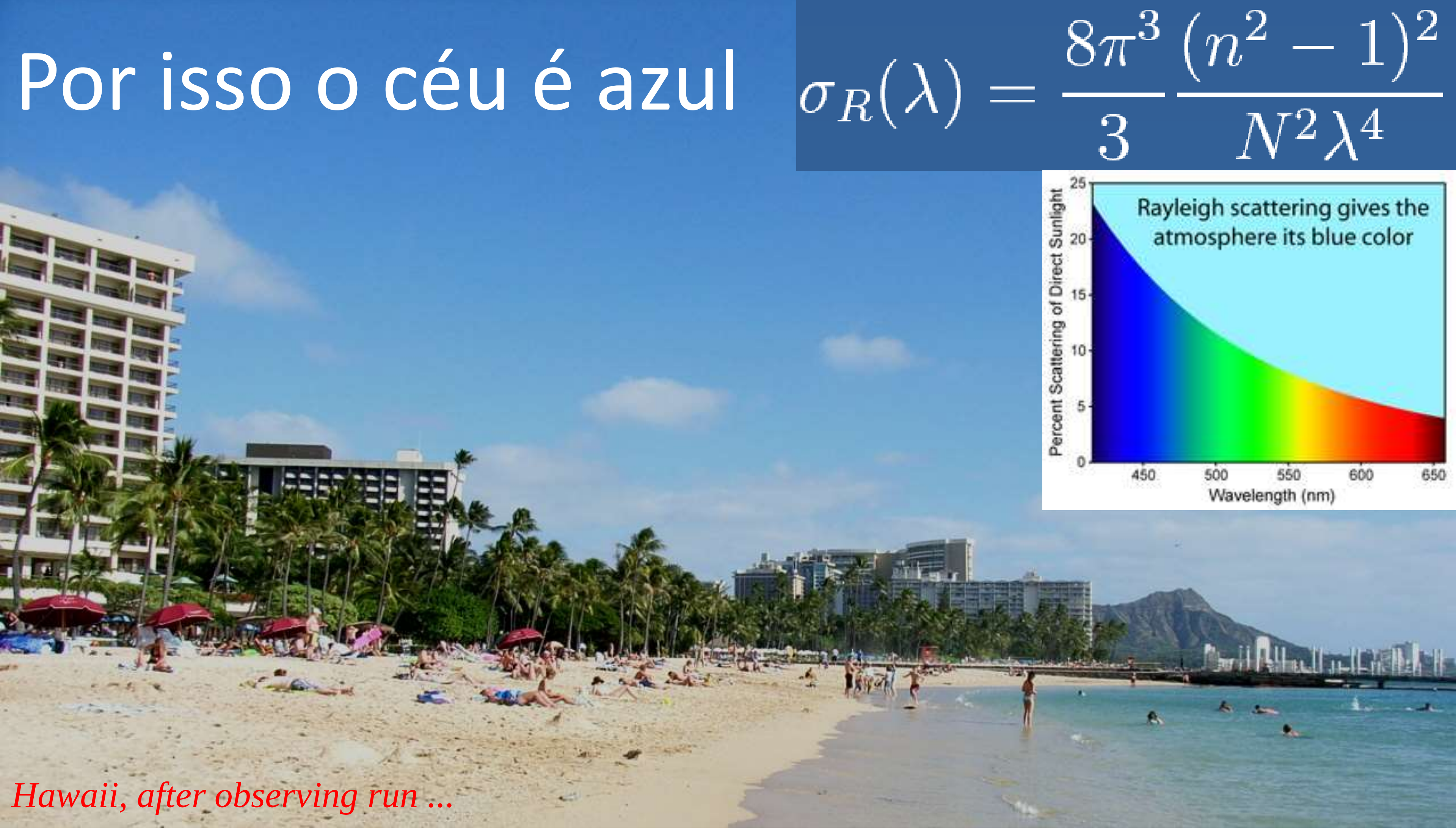
$$\sigma_R(\lambda) = \frac{8\pi^3}{3}\frac{(n^2-1)^2}{N^2\lambda^4}$$

- onde n: índice de refração;
- N: densidade moléculas



Por isso o céu é azul

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



Hawaii, after observing run ...

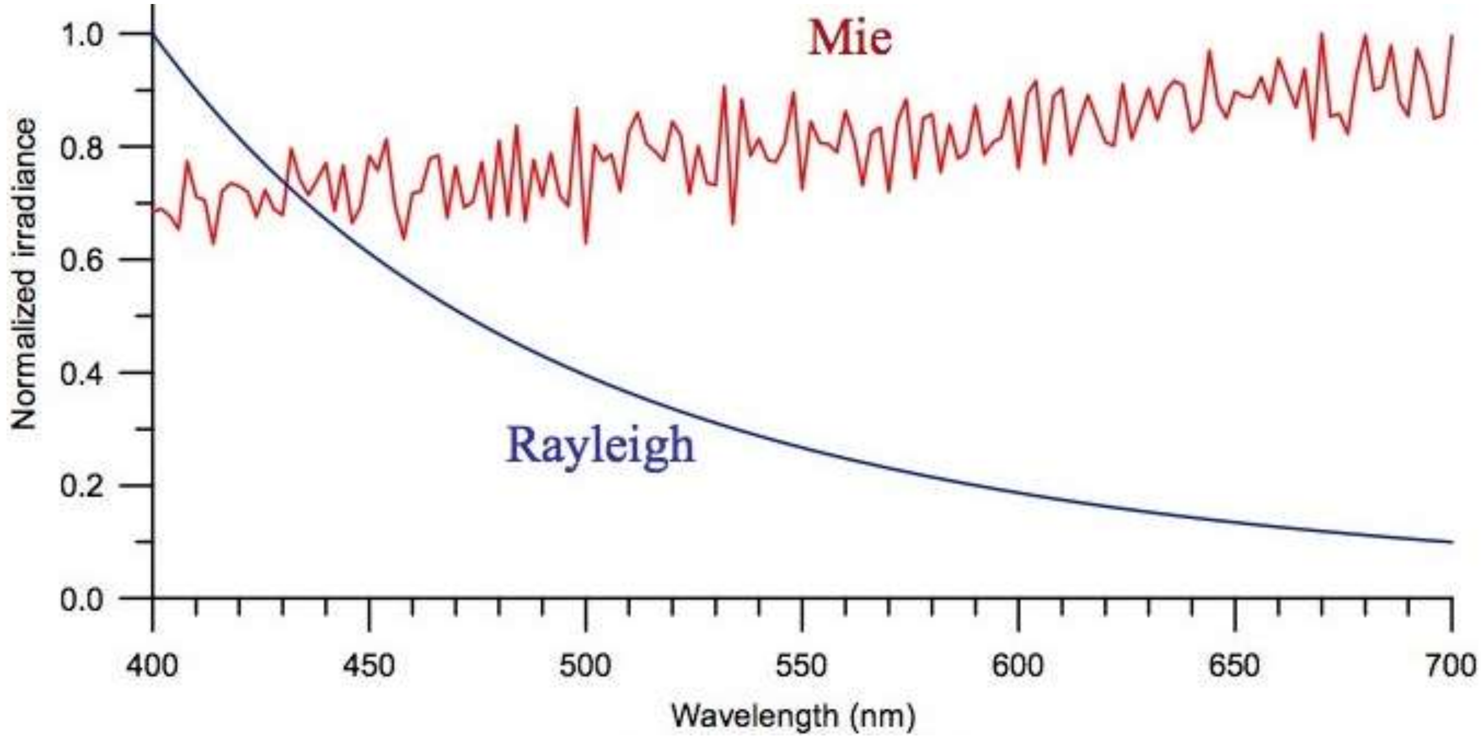
A intensidade do espalhamento Rayleigh depende do ângulo θ de incidência

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

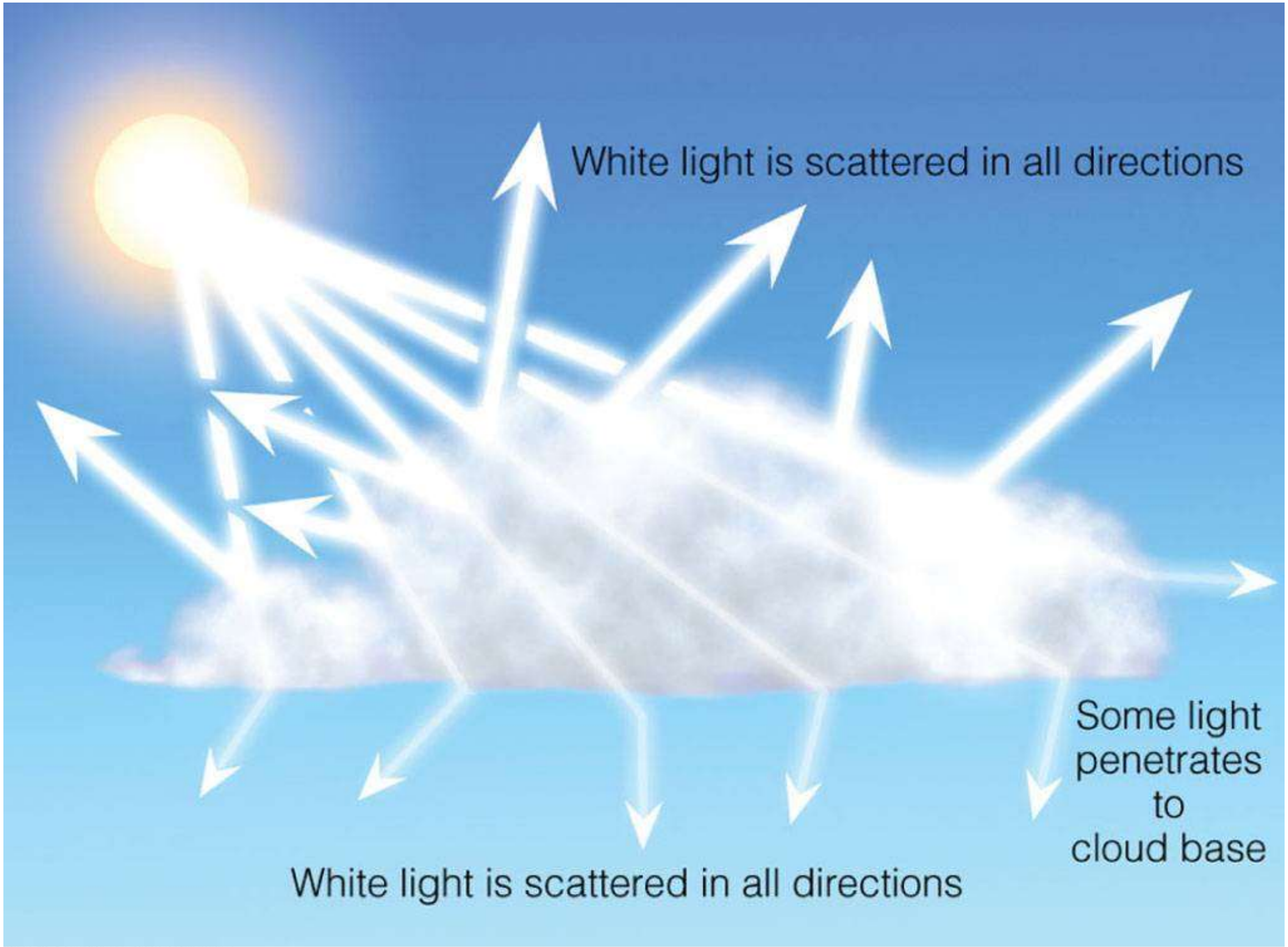
Em z=2km, a 90^0 do Sol, λ=7000A, brilho do céu é 10^{-7} daquele do disco solar

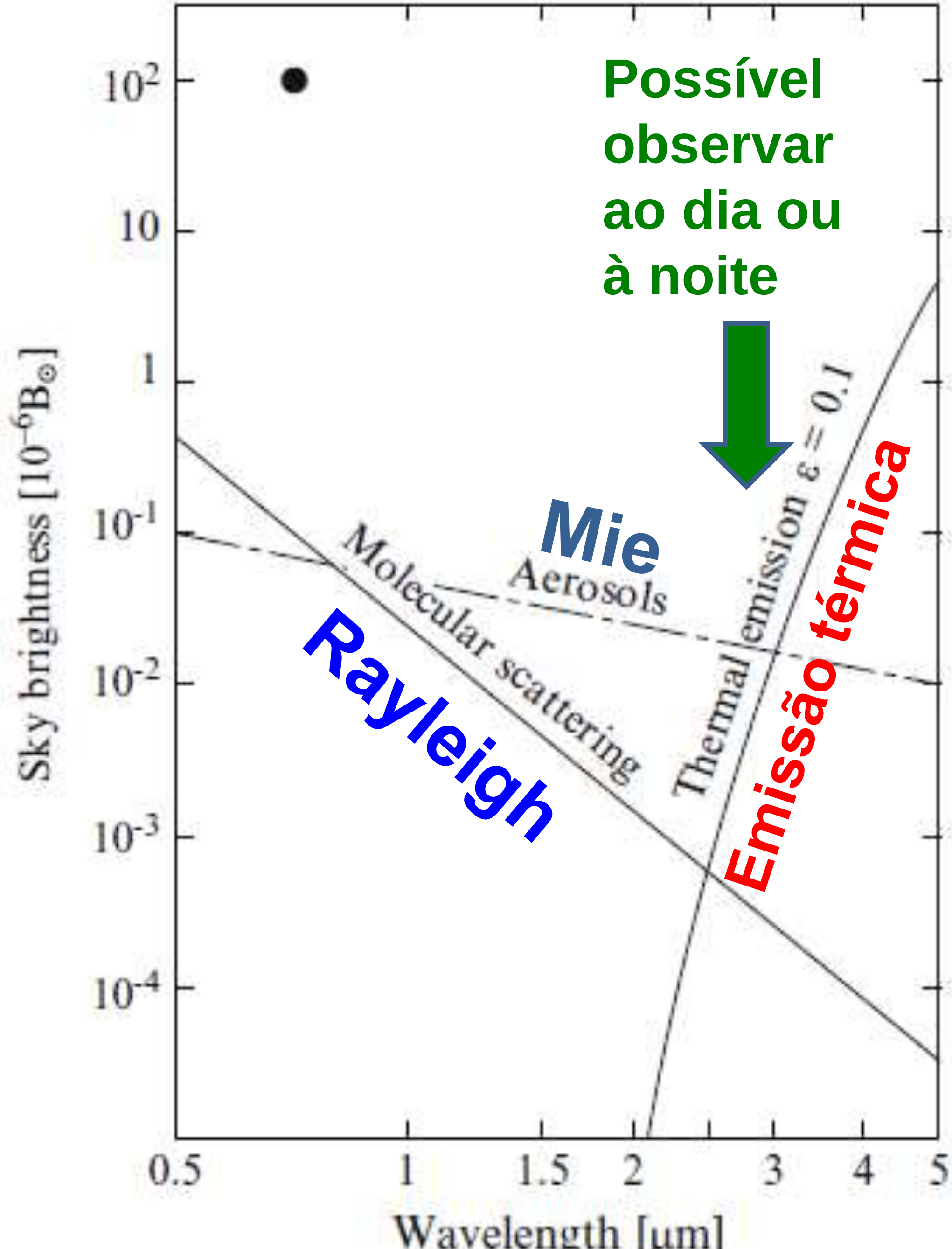
Espalhamento Mie

- Espalhamento por partículas maiores ao comprimento de onda λ da luz
- Não depende muito do comprimento de onda



Espalhamento Mie





Contribuição ao brilho do céu (no dia) na região do ótico e infravermelho

Fig. 2.11 (Lena, Observational Astrophysics). Molecular scattering is given for the altitude z = 2000m, at 90⁰ from the Sun. The wavelength dependence is λ^{-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 λ^{-1}. For comparison, (•) marks the sky brightness measured at 0.5 arcmin from the Sun's limb at Kitt Peak (Arizona)

Outros fatores atmosféricos: Turbulência atmosférica

Vincent ***van Gogh***

Geração de turbulência na atmosfera terrestre

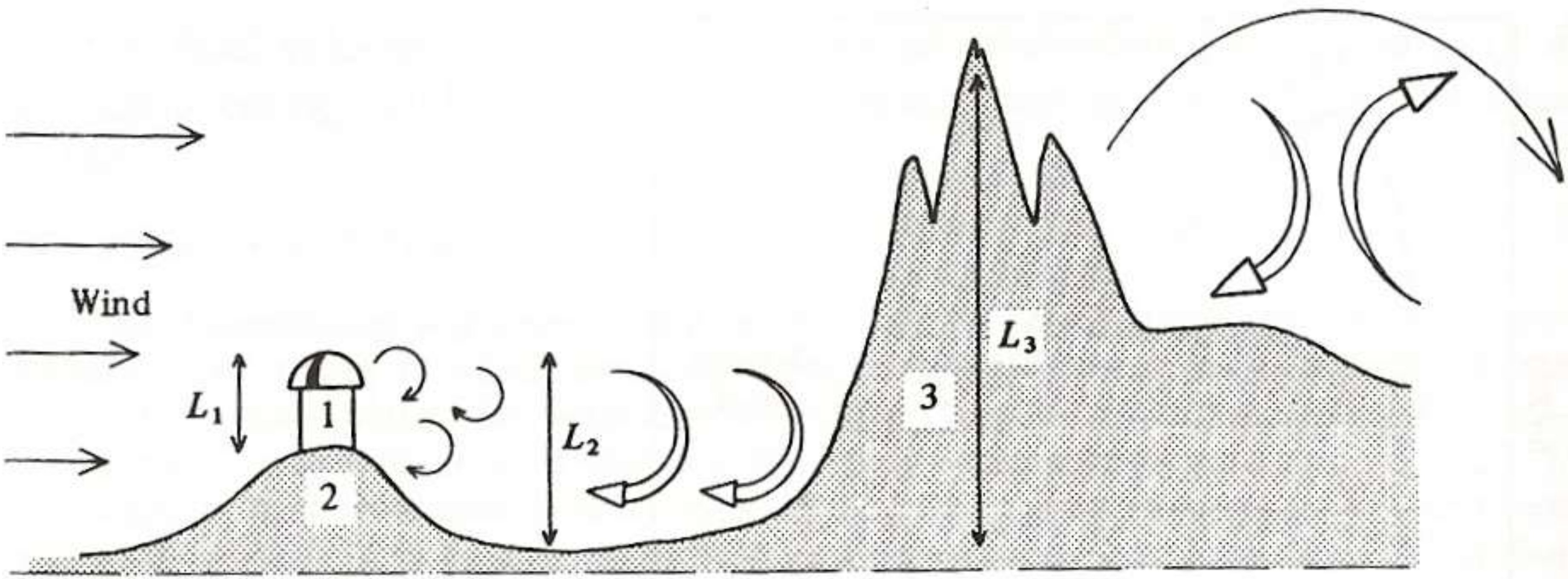
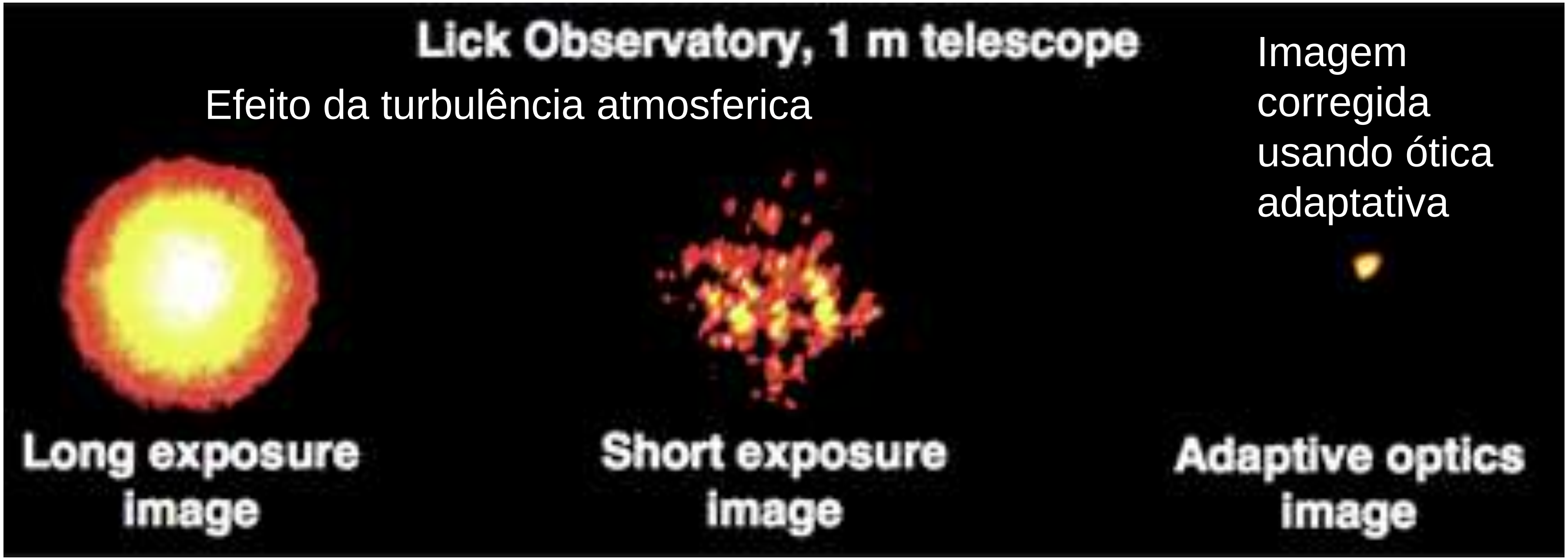


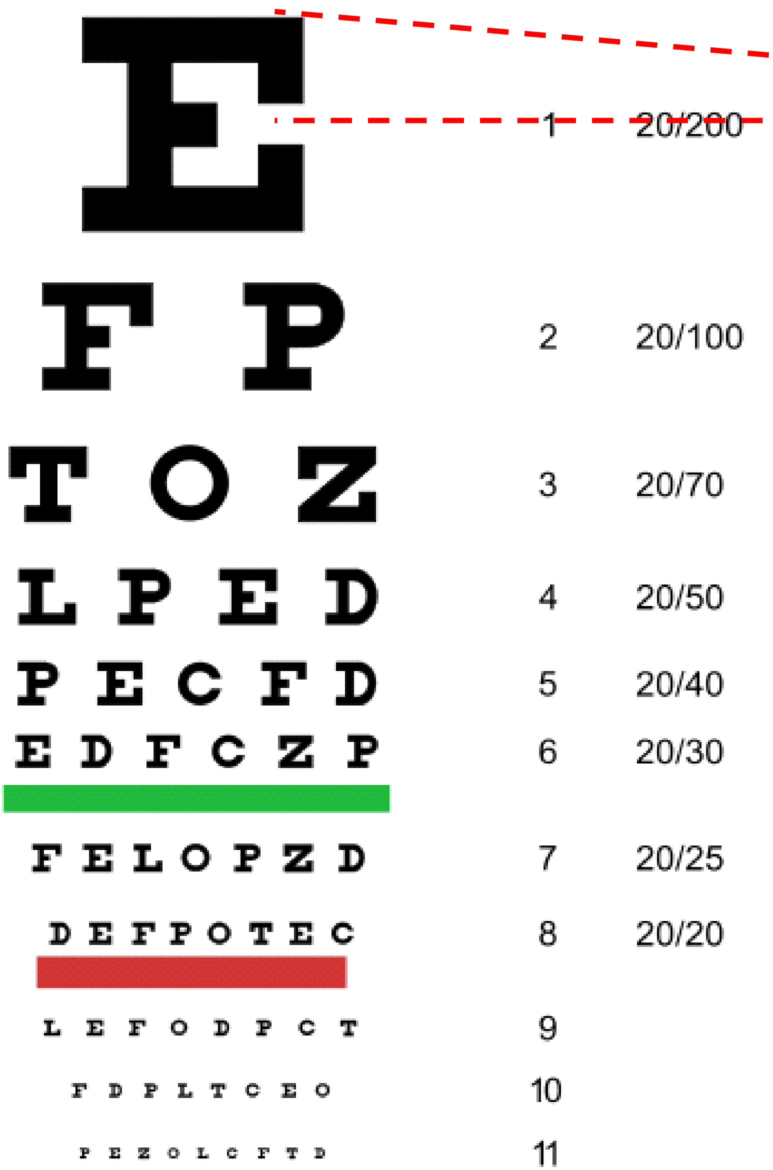
Fig. 2.13. Schematic representation of the generation of turbulence in the atmosphere by different obstacles. The amplitude of the temperature fluctuations depends on the amplitude of the turbulence and on the deviation of the actual temperature gradient from the adiabatic gradient. The scales L_1, L_2,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

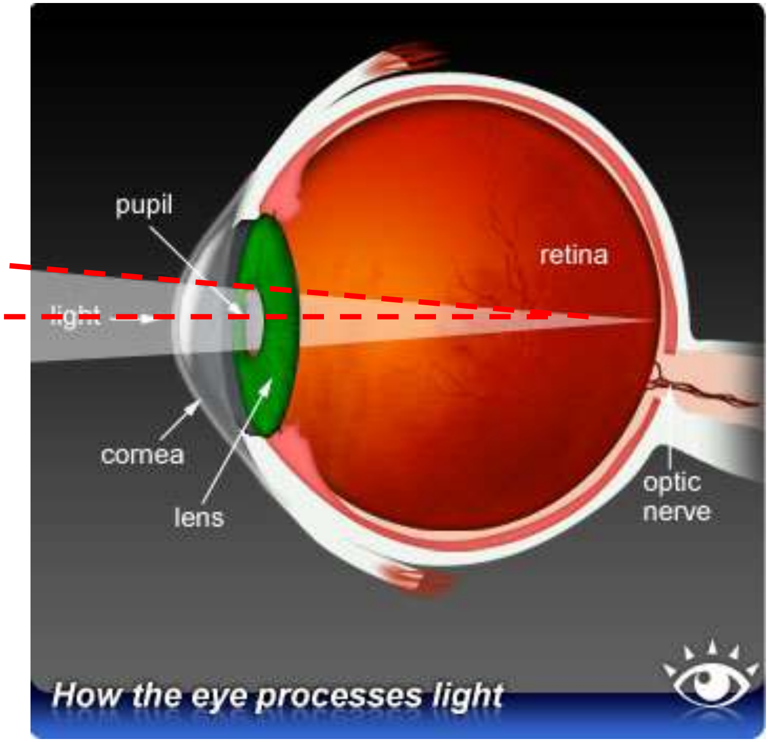
Turbulência atmosférica causada pelo relevo

A turbulência da atmosfera terrestre afeta a qualidade de imagem



Resolução angular





É o menor ângulo que pode ser discernido

Resolução angular de um telescopio de diâmetro ***d*** no comprimento de onda ***λ***

$$\alpha\ [\text{rad}] = 1{,}22\ \lambda / d$$

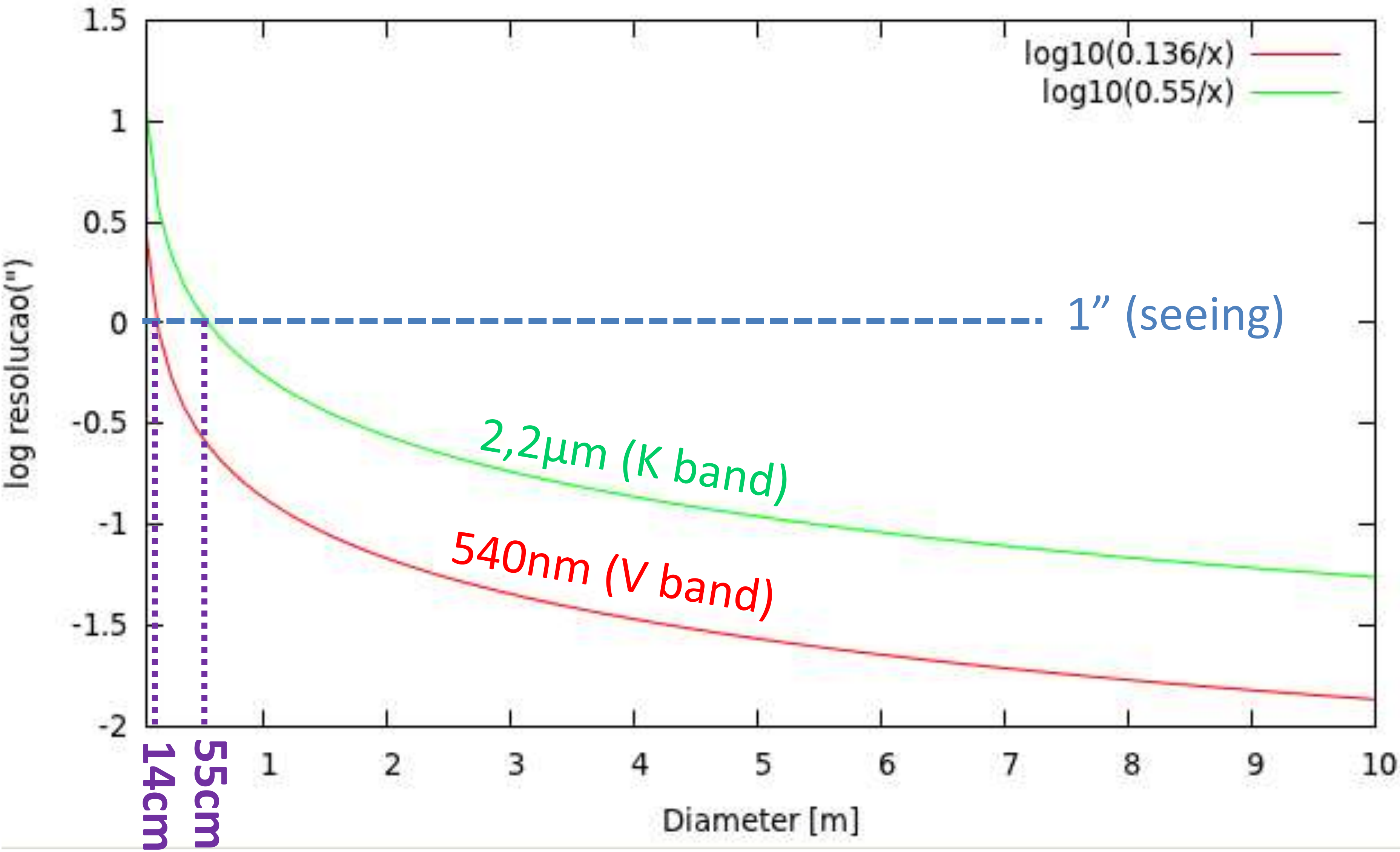
For V = 540nm:

$$\alpha[''] = 0{,}136 / d[\text{m}]$$

For K = 2,2μm:

$$\alpha[''] = 0{,}55 / d[\text{m}]$$

Um telescópio com ***d* = 14 cm** alcança no ótico uma **resolução angular de 1"**, da mesma ordem que o limite imposto pelo ***seeing* (~ 1")**




```
gnuplot> set xr [0.05:10]; plot log10(0.136/x), log10(0.55/x); set xlabel 'Diameter [m]'; set ylabel 'log resolucao(")'
```

Effects of atmospheric turbulence

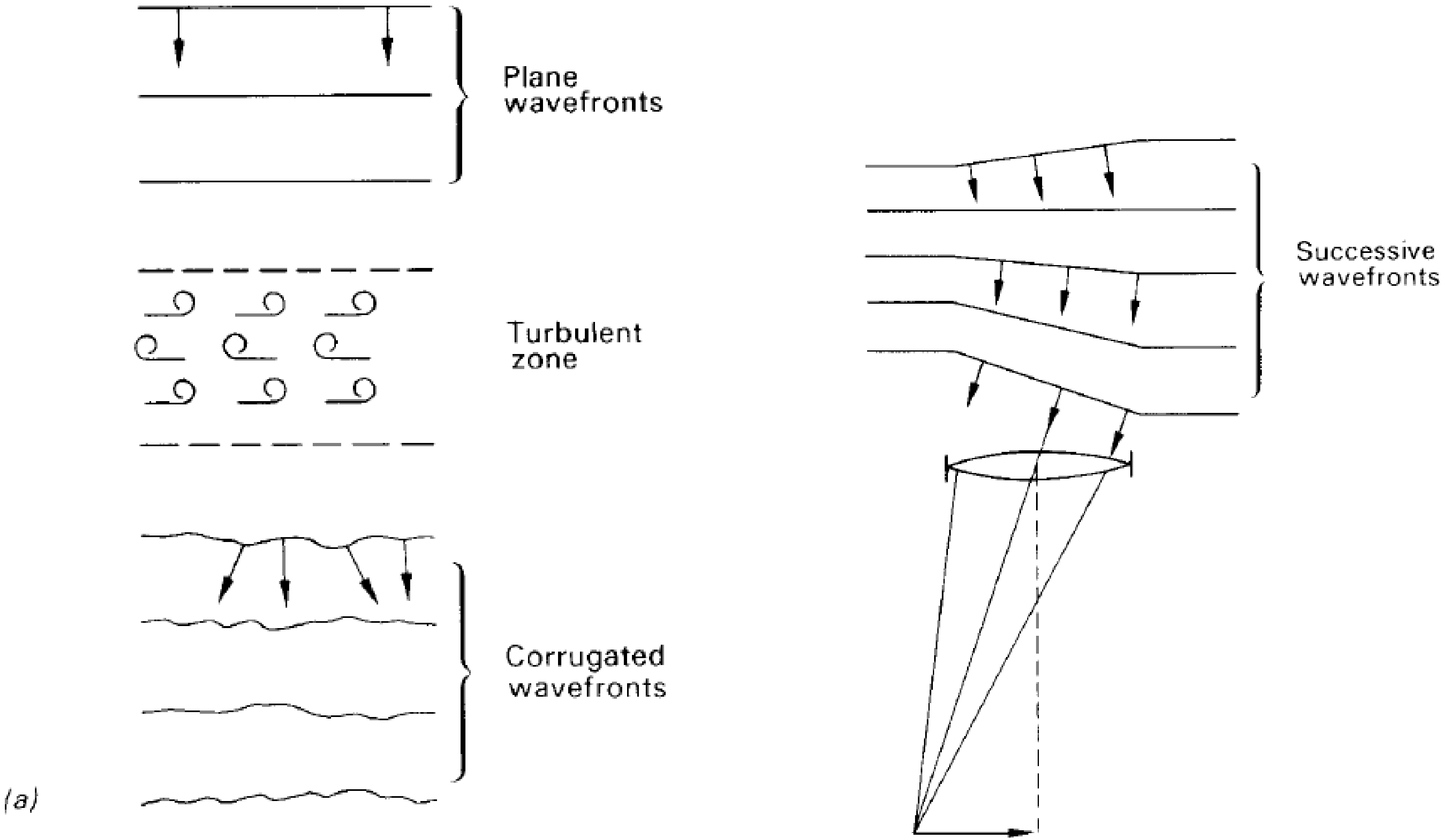
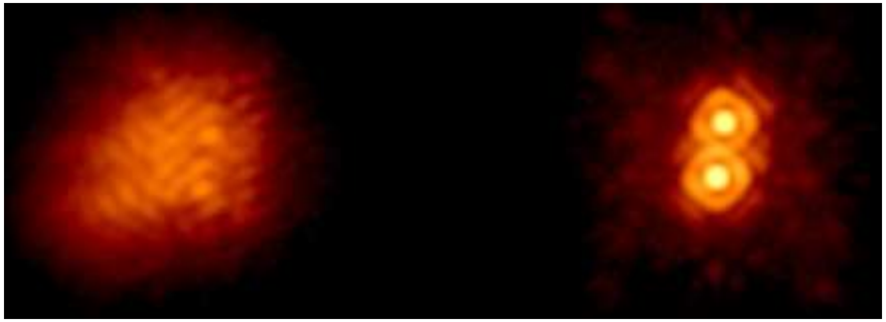


Figure 19.7. (*a*) The effect of atmospheric turbulence.

(*b*) The dancing effect of a star image when viewed with a small telescope.

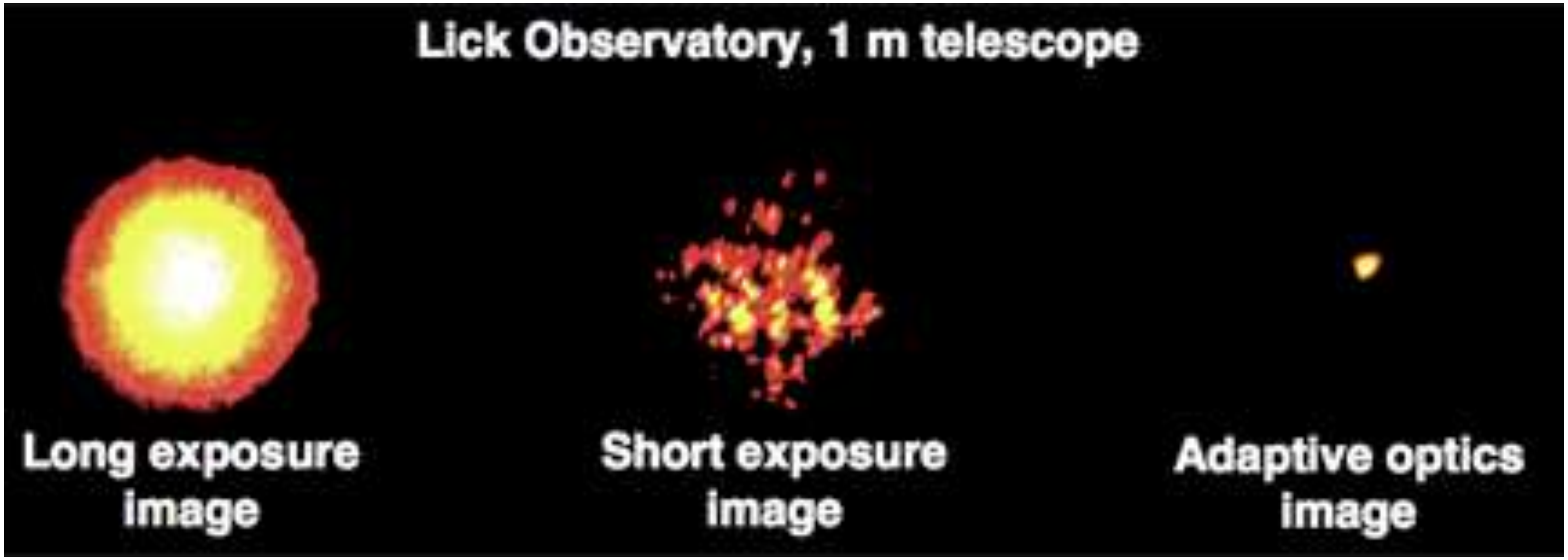
Ótica adaptativa



Without adaptive optics
(Palomar 200 inch telescope)

The binary star IW Tau is revealed through adaptive optics. The stars have a 0.3 arc second separation. The images were taken by Chas Beichman and Angelle Tanner of JPL.

Bright Star (Arcturus)



http://www.ucolick.org/~max/max-web/History_AO_Max.htm

Escala de tempo da turbulência?

Coherence length is ~ 10cm at 0,5μm

Turbulent layer wind speed is ~ 10 m/s

Portanto escala de tempo ~ 0,01 s (= 10ms).

Escala de tempo da turbulência no ótico ~ 1 - 10ms

Seeing vs. Diffraction (angular resolution) limit

Airy disc, I_A. The ratio, $S = I_S/I_A$, is referred to as the **Strehl index** and it is not uncommon for it to be no greater than a few per cent.

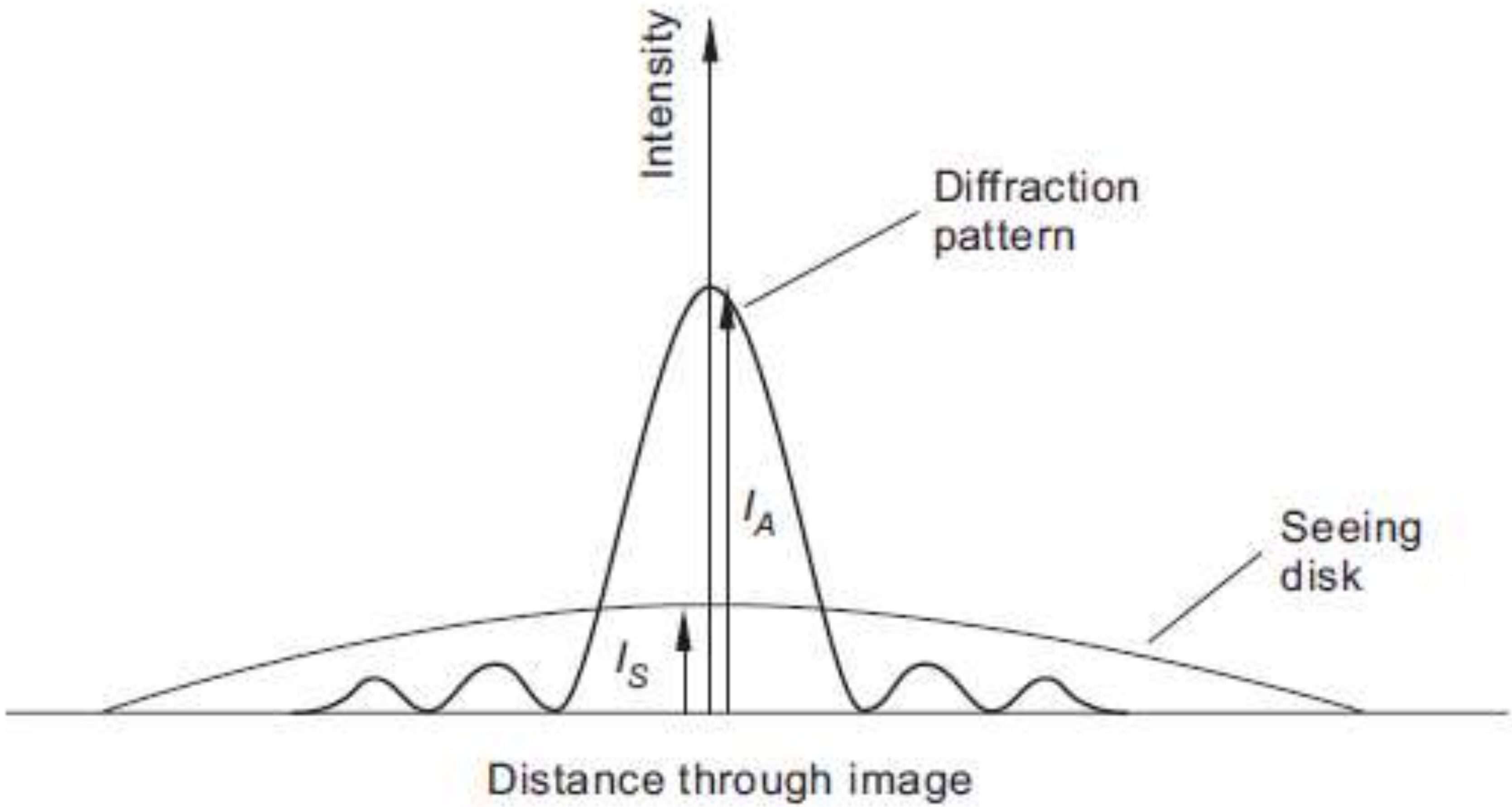
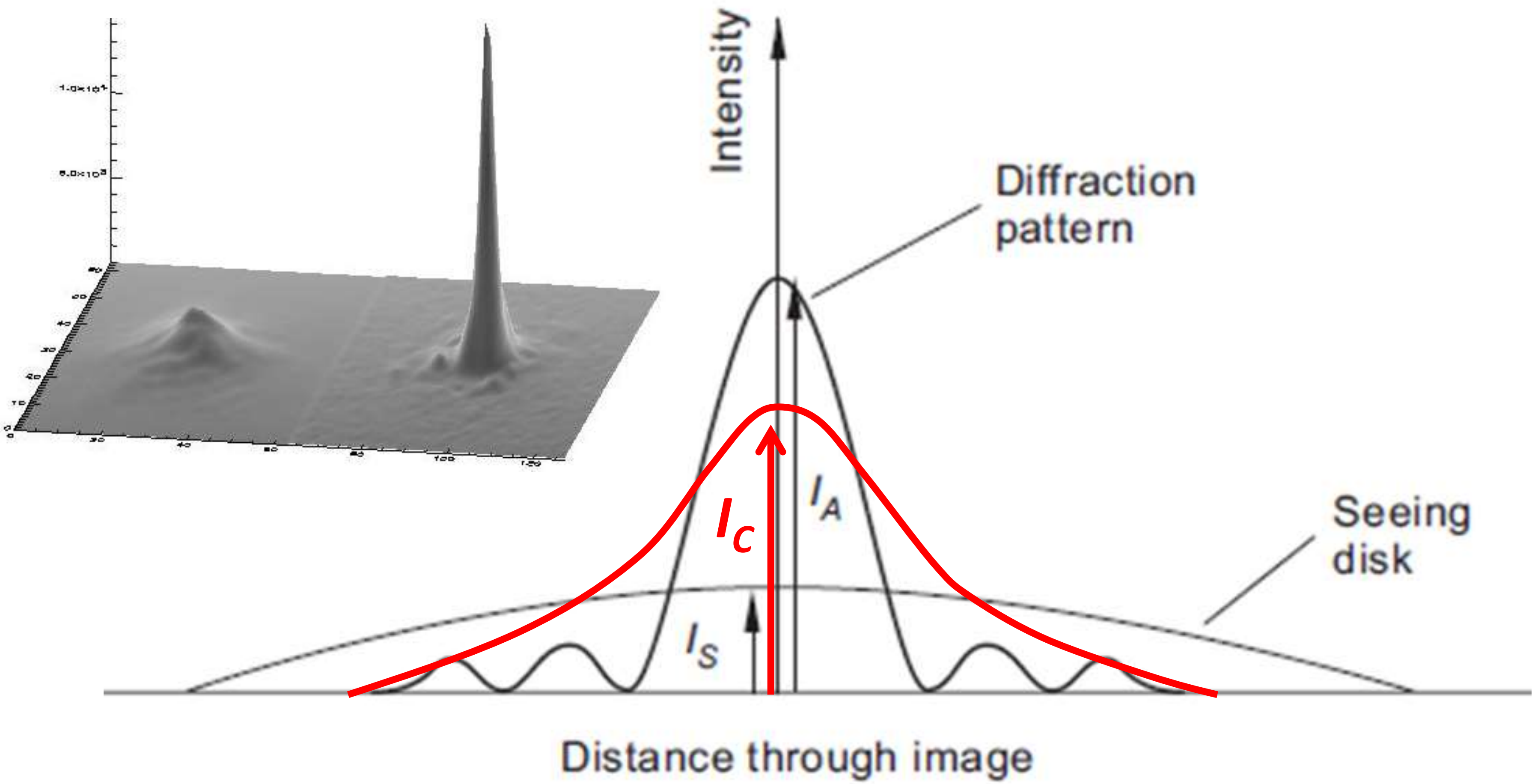


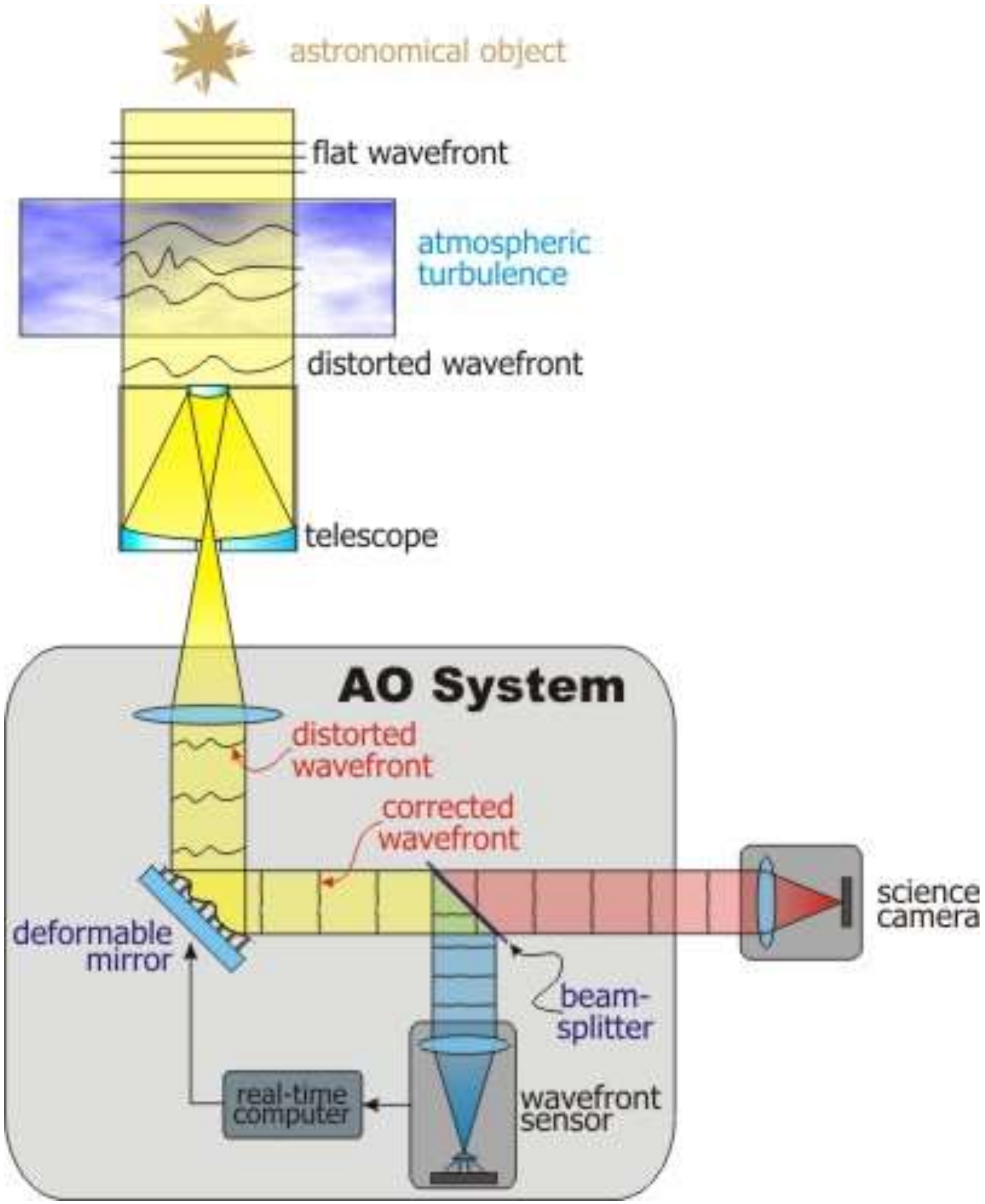
Figure 19.8. The seeing disc of a star is superposed in the theoretical diffraction pattern in the image plane. The ratio of the peak intensities, I_S/I_A is referred to as the Strehl index.

Qualidade da correção: Strehl ratio

Strehl ratio = $I_{corrigida}/I_{difração}$

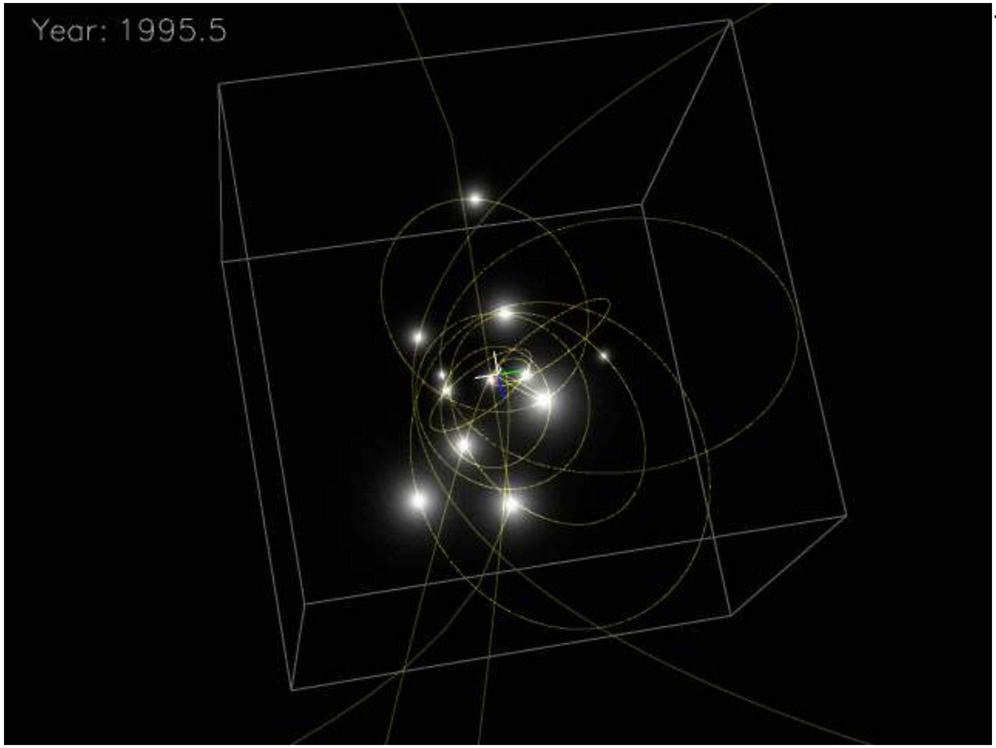


Ótica adaptativa



Centro da nossa Galáxia

Stars orbiting the Galactic center



http://astro.uchicago.edu/cosmus/projects/UCLA_GCG/

Andrea Ghez
Orbits around the Galactic center imply **black hole of 4 million solar masses**

Professor Ghez has actively disseminated her work to a wide variety of audiences through more than 100 refereed papers and 200 invited talks, as well features in textbooks, documentaries, and science exhibits. She has received numerous honors and awards including the Crafoord Prize, a MacArthur Fellowship, election to the National Academy of Sciences and the American Academy of Arts & Sciences, the Aaronson Award from the University of Arizona, the Sackler Prize from Tel Aviv University, the American Physical Society's Maria Goeppert-Mayer Award, the American Astronomical Society's Newton Lacy Pierce Prize, a Sloan Fellowship, a Packard Fellowship, and several teaching awards. Her most recent service work includes membership on the National Research Council's Board on Physics & Astronomy, the Thirty-Meter-Telescope's Science Advisory Committee, the Keck

TEDTALK:

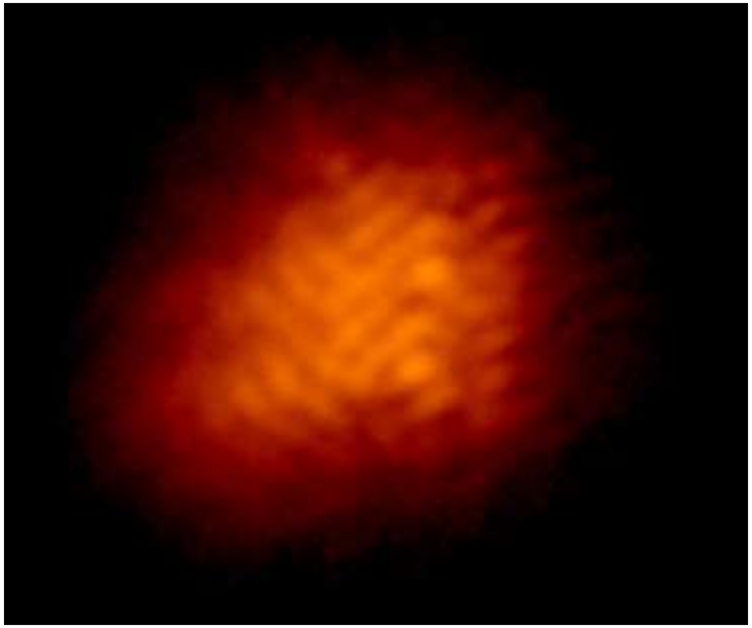
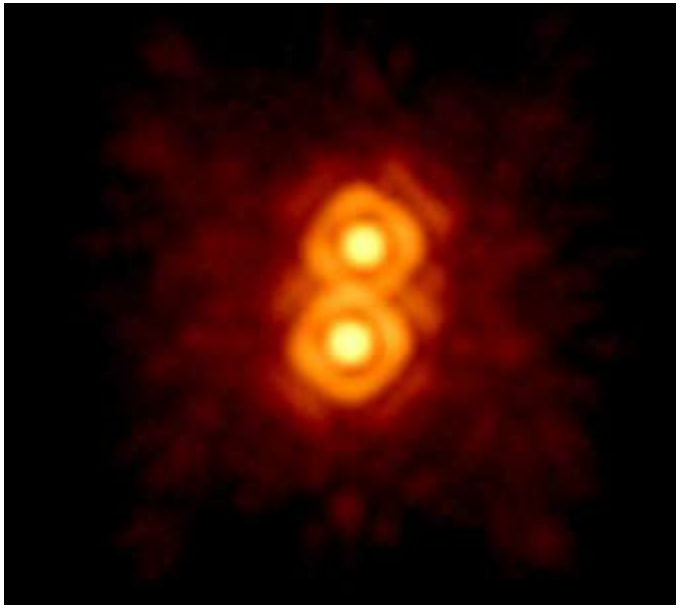


Imagem de sistema binário (sem correção)

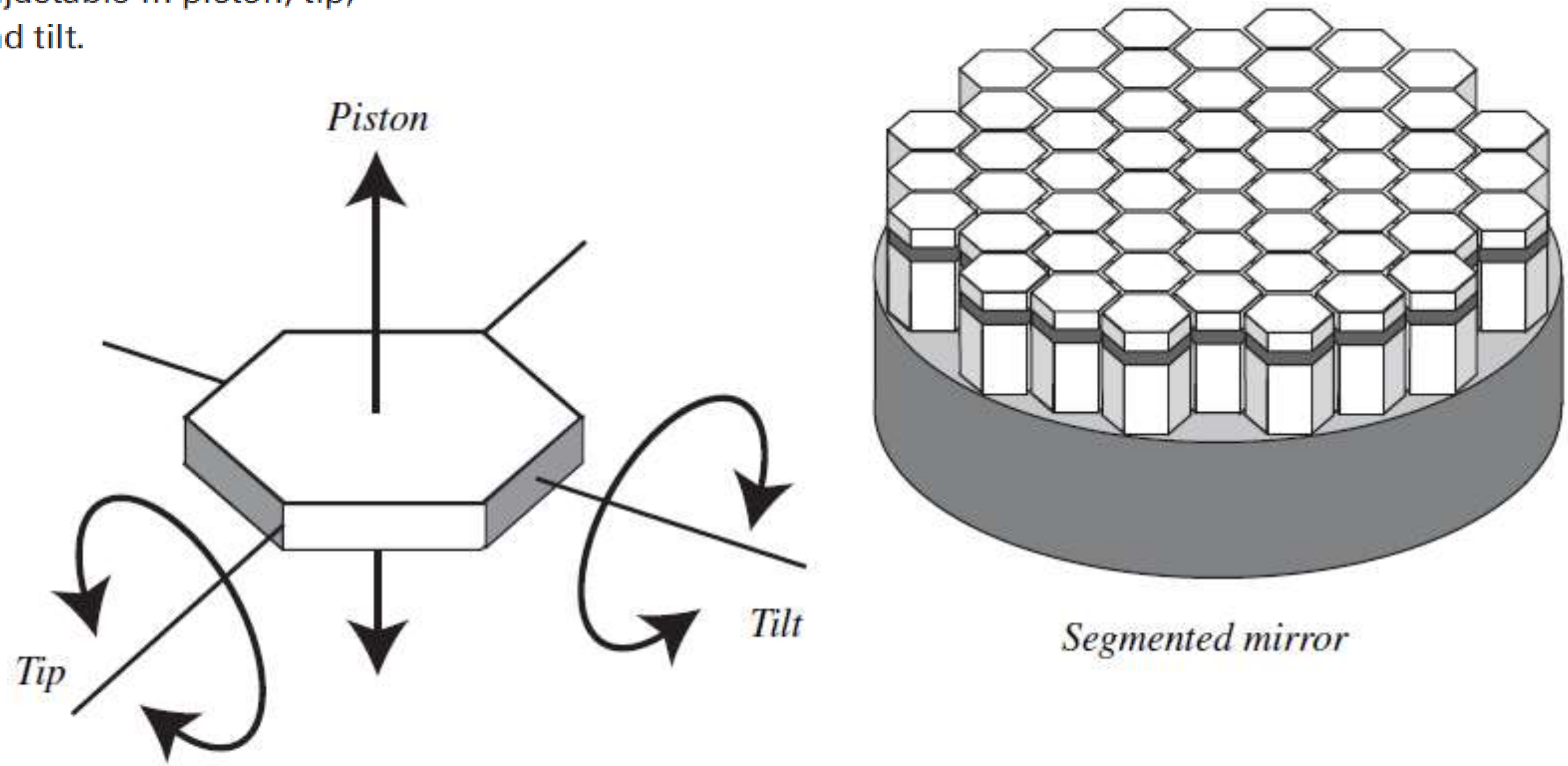


Com ótica adaptativa

The binary star IW Tau is revealed through adaptive optics. The stars have a 0.3 arc second separation. The images were taken by Chas Beichman and Angelle Tanner of JPL

Segmented mirror for Adaptive Optics

Fig. 6.16 A segmented, adjustable mirror for adaptive optics. Individual hexagonal segments (left) are adjustable in piston, tip, and tilt.



Shack-Hartmann sensor for AO

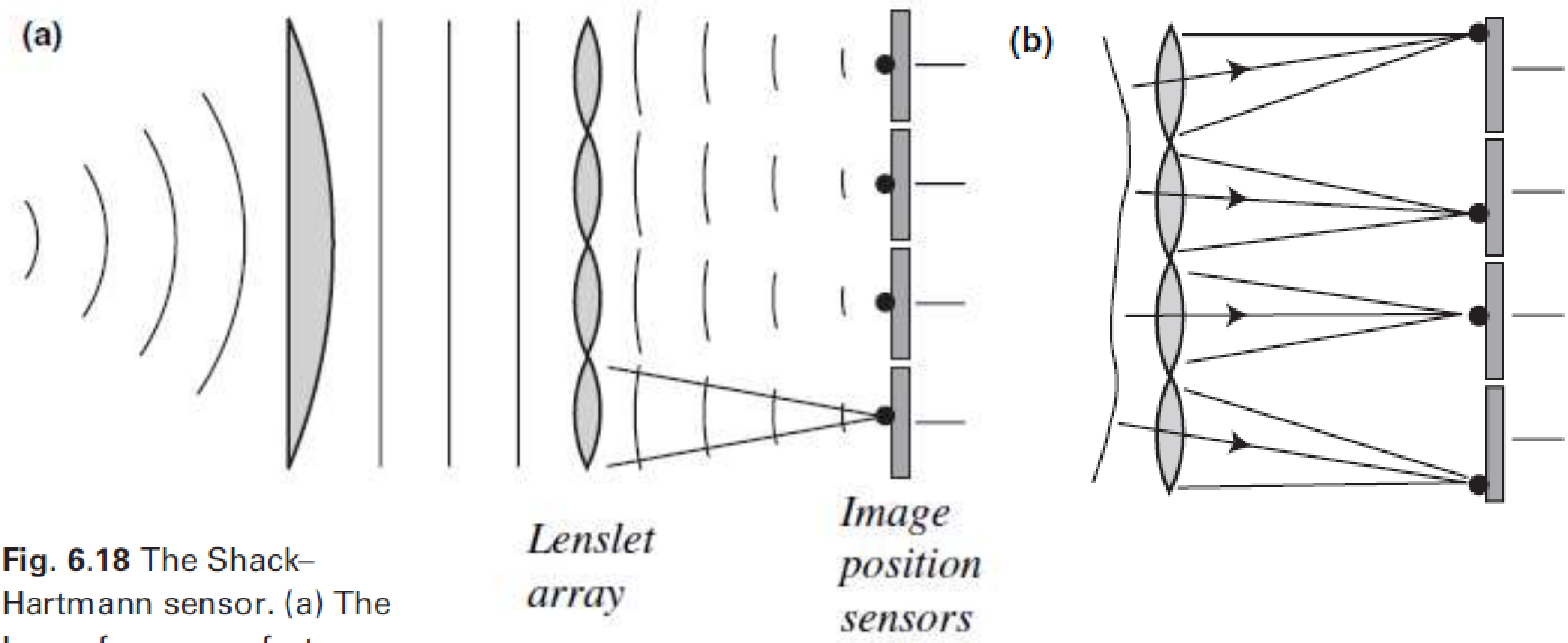


Fig. 6.18 The Shack–Hartmann sensor. (a) The beam from a perfect point source – all images on the sensors are in the null position. (b) A distorted wavefront and the resulting image displacements from tilted segments.

WFS stars must be nearby

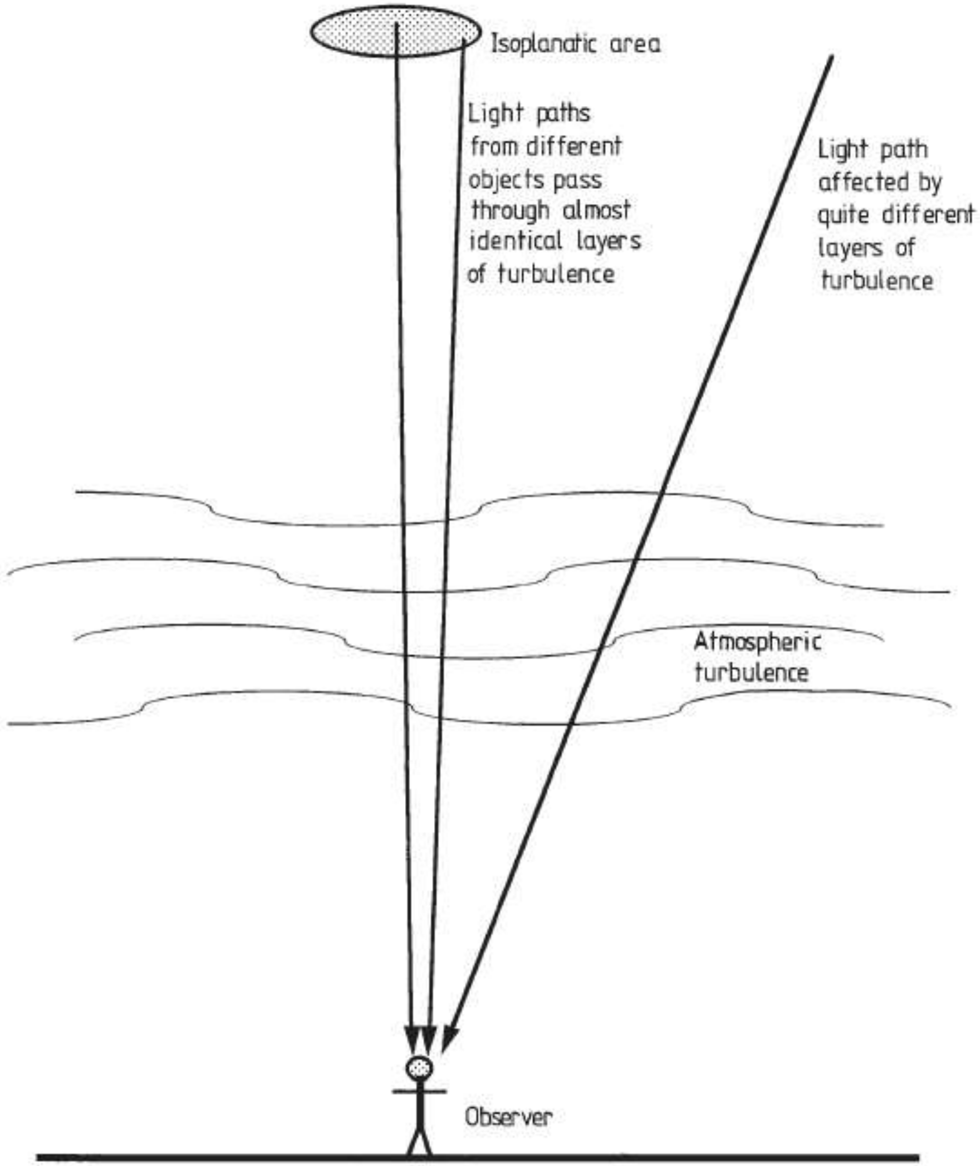


Figure 1.1.53. The isoplanatic area.

WFS stars must be bright

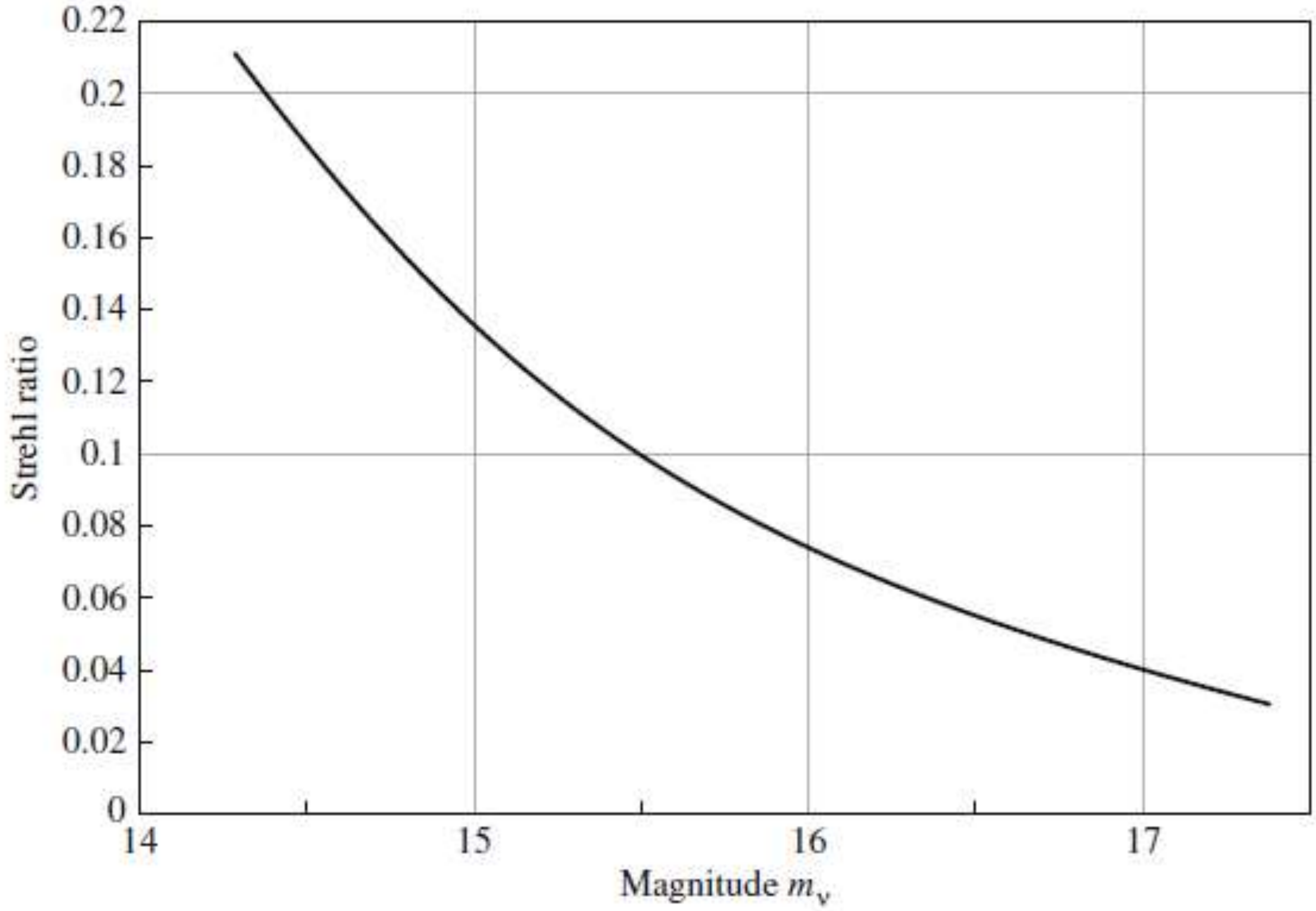
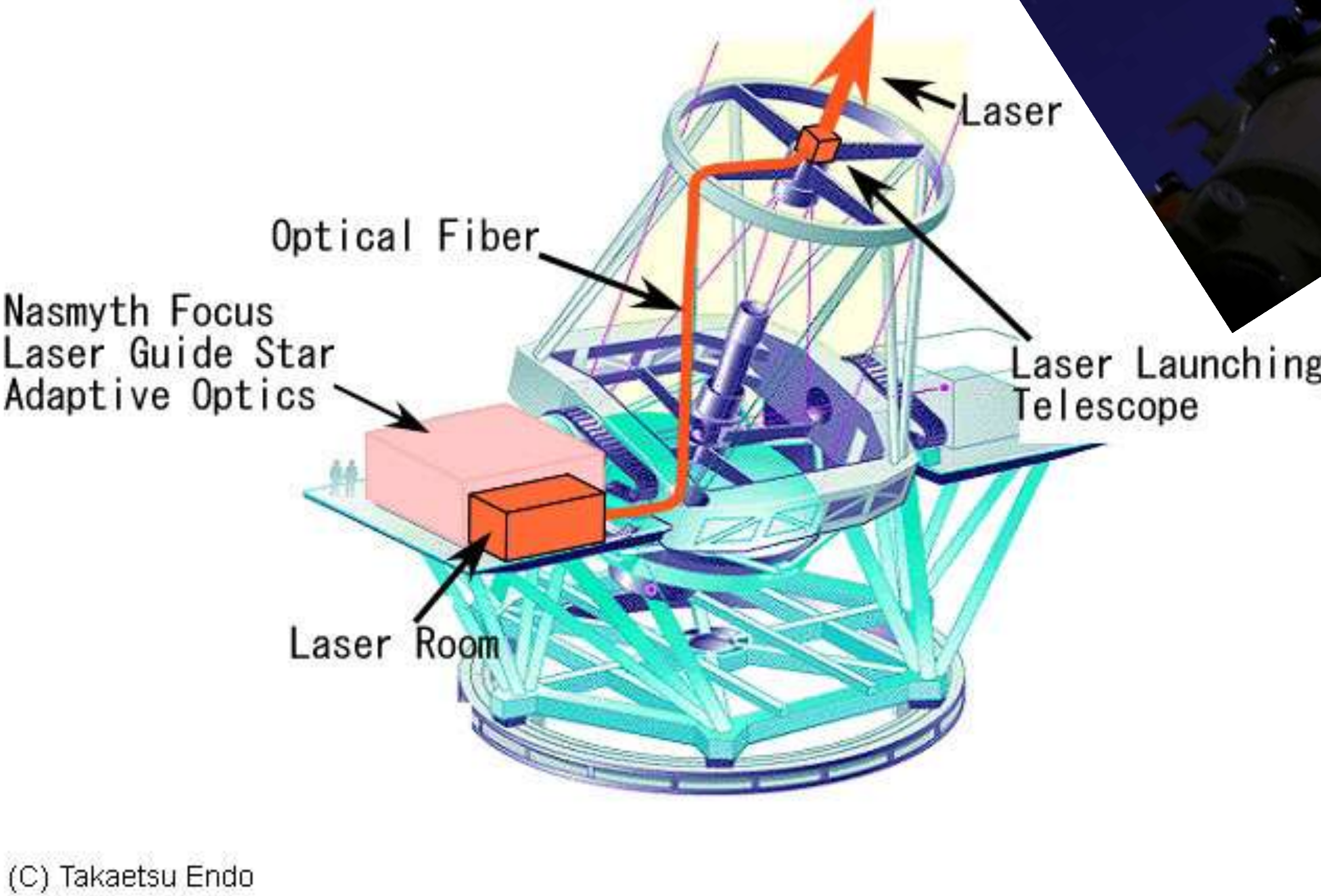


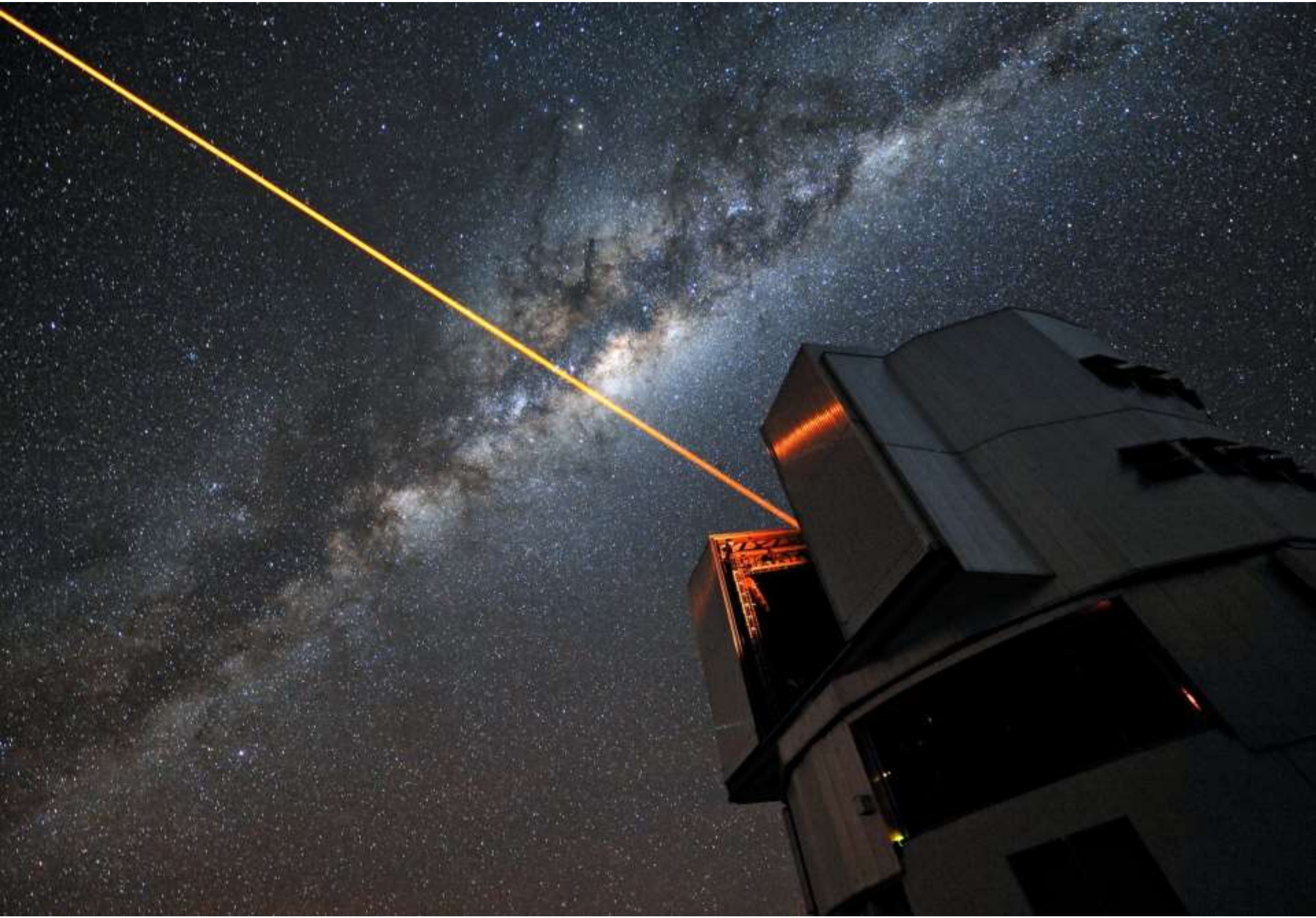
Fig. 6.20 Sensitivity of adaptive optics. *Ordinate*: Strehl ratio $\mathscr{S}$ for an image corrected at $\lambda = 2.2\ \mu m$ (spectral band K), in average turbulence conditions. *Abscissa*: Magnitude m_V of the source used by the wavefront analyser (hence analysis wavelength $\lambda_0 = 0.55\ \mu m$). We assume here that the sensor is equipped with a detector with high quantum efficiency (CCD, $\eta = 0.6$) and a very low readout noise ($2e^-$ rms). From Gendron E., doctoral thesis, 1995

No stars in your field? Create your own star!

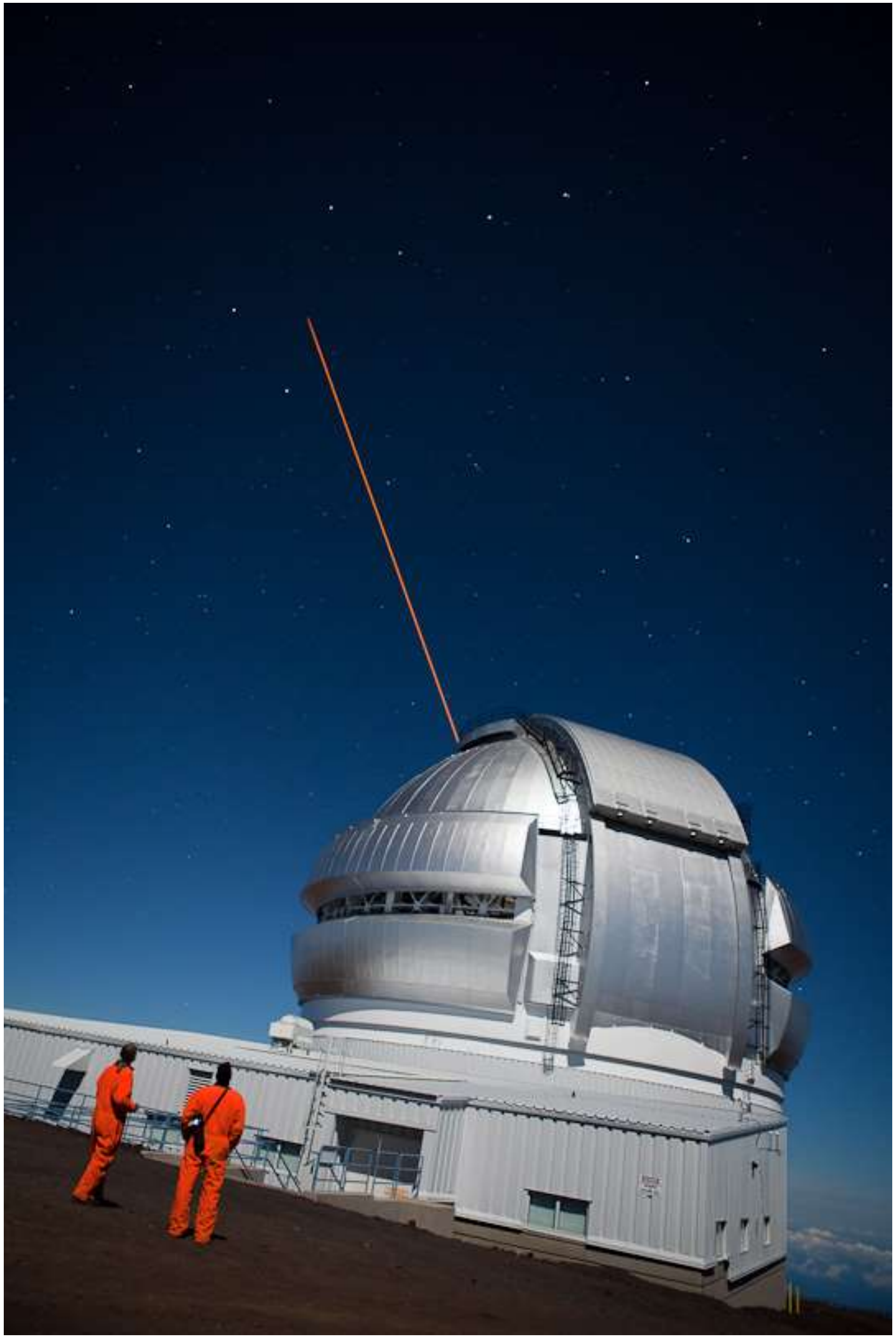


http://subarutelescope.org/Pressrelease/2005/07/

VLT laser



Spotters no observatório Gemini



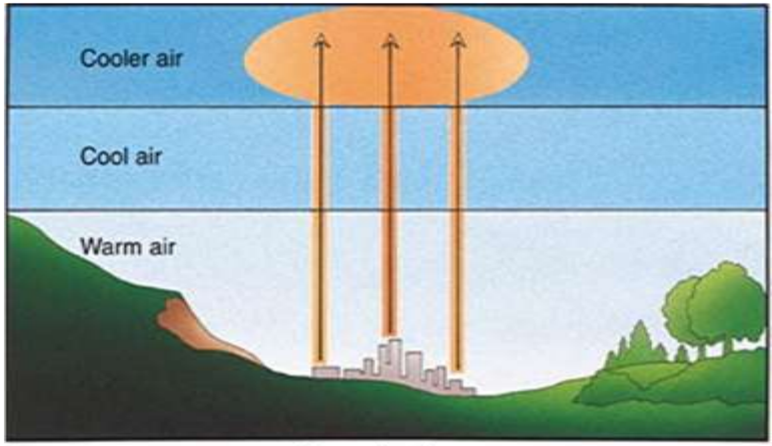
Two aircraft spotters make sure no aircrafts pass close to the laser beam.

http://www.paulanthonywilson.com/blog/why-do-some-telescopes-use-laser-beams/

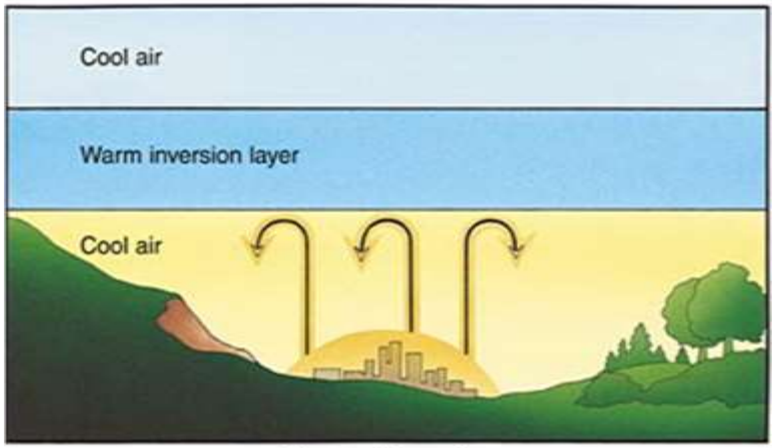
Outros fatores atmosféricos:

Camada de inversão

- Fator na escolha de um sítio astronómico de solo
- Camada de inversão, ~ 2km, mas pode ocorrer a menores *z*



Normal pattern

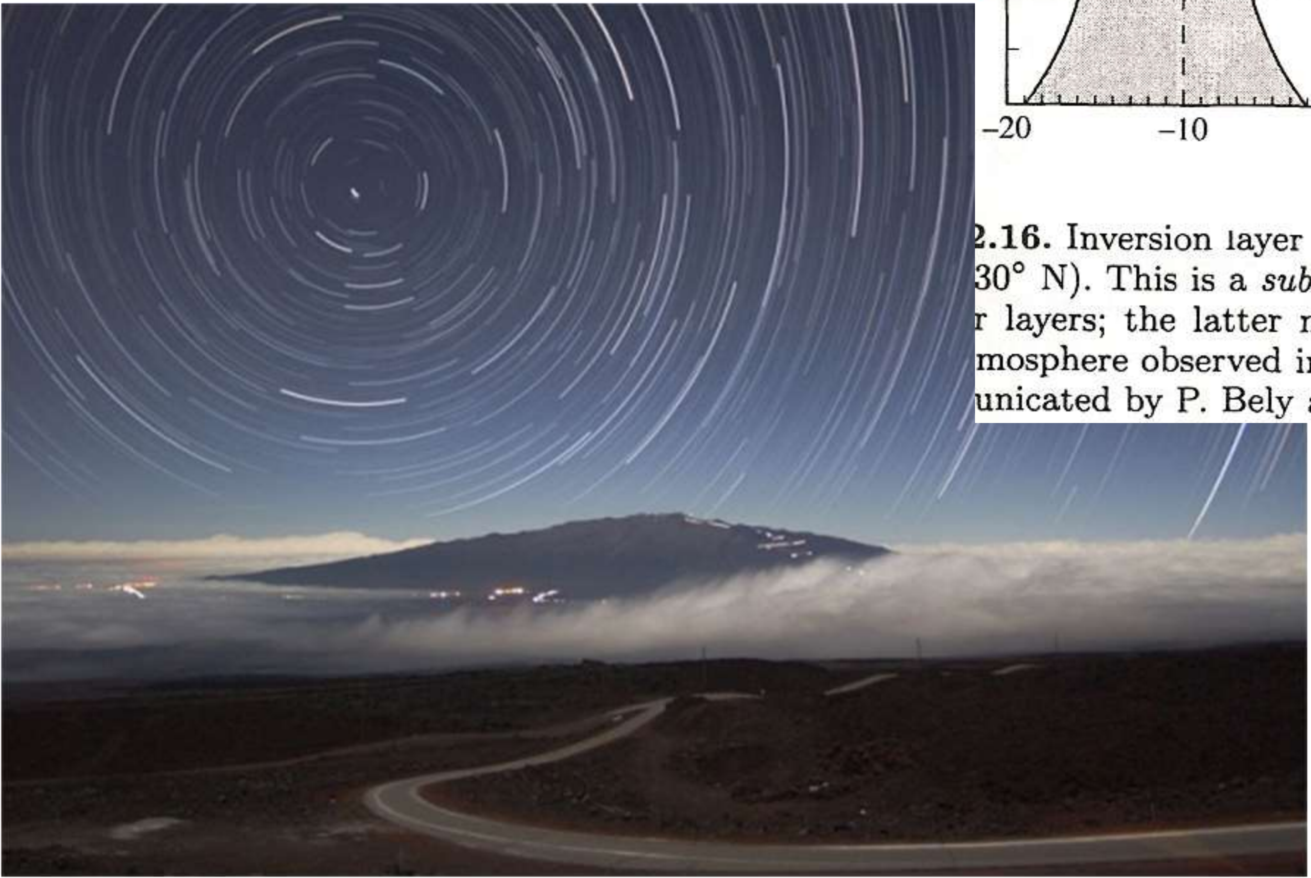


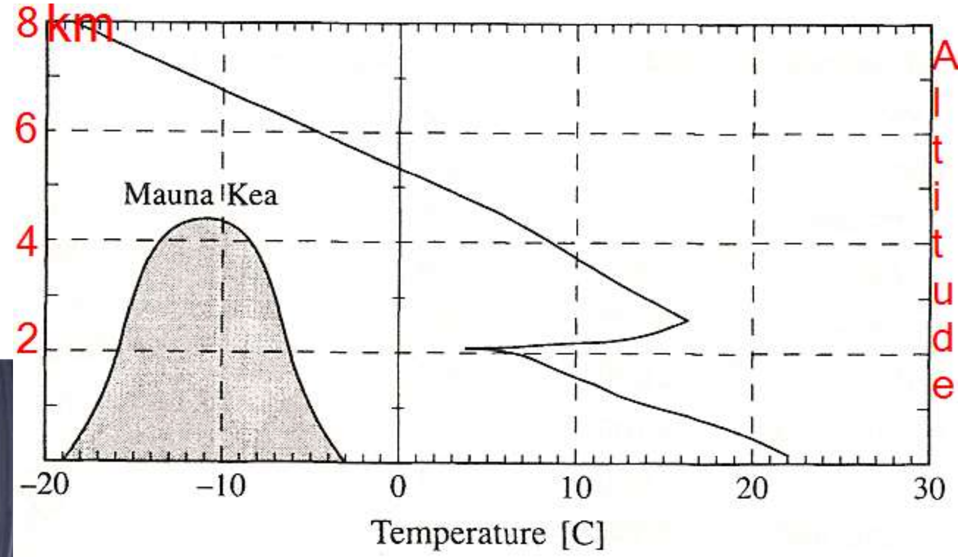
Thermal inversion

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

Camada de inversão

- Camada de inversão sobre o oceano pacífico em volta da ilha de Havai





2.16. Inversion layer above the Pacific Ocean, near the isla
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

Maior altura → menos nuvens

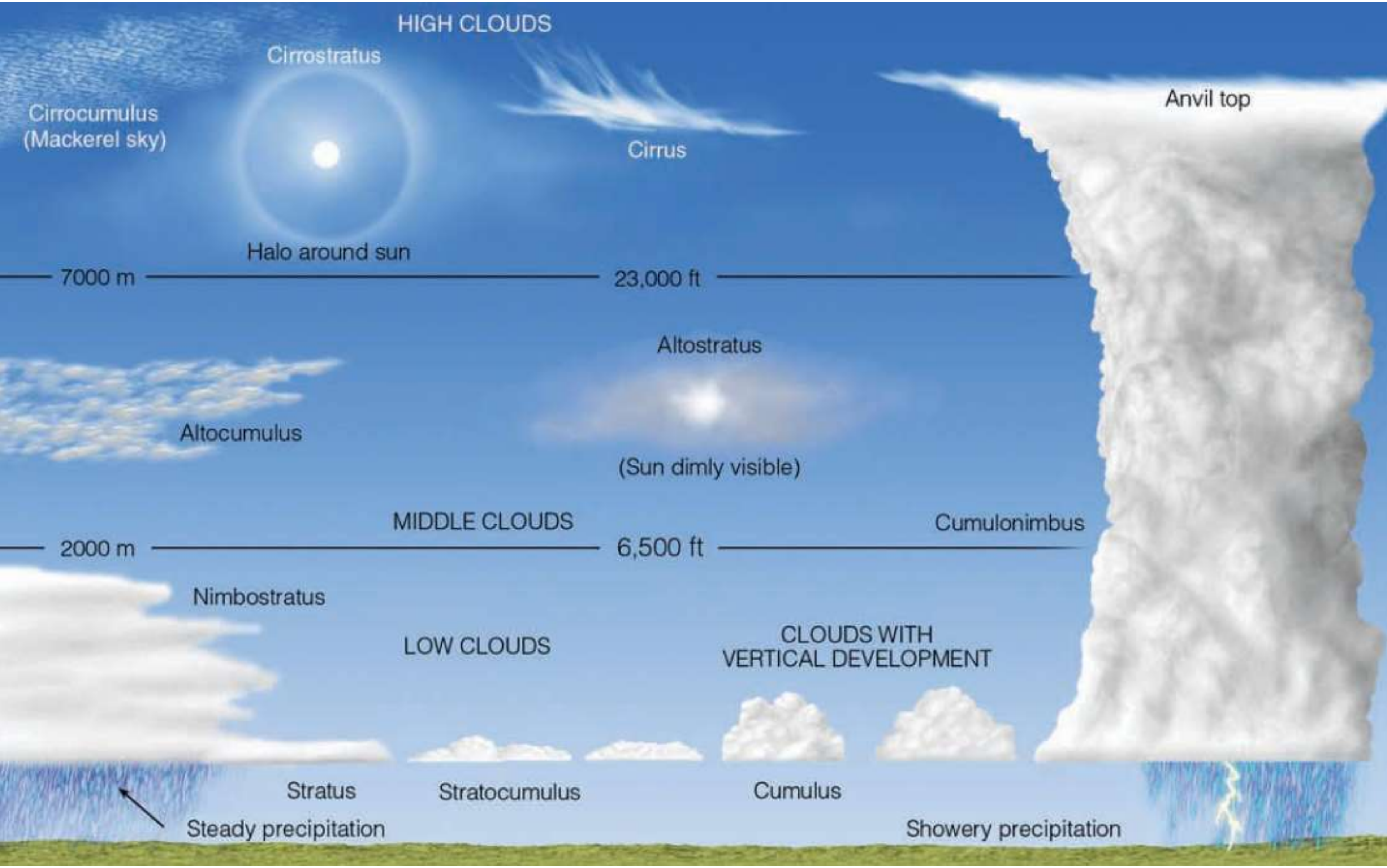
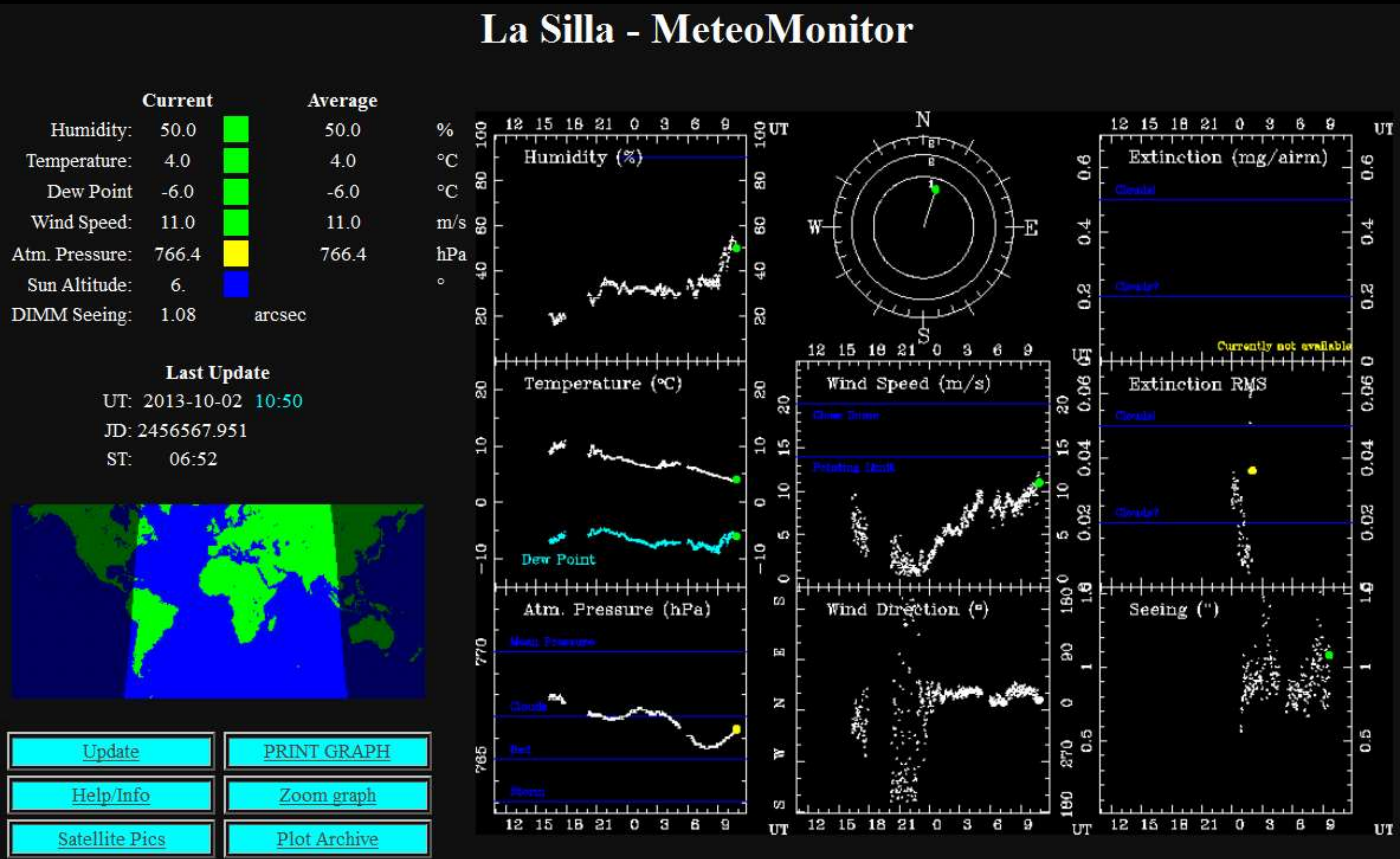


FIGURE 5.24 A generalized illustration of basic cloud types based on height above the surface and vertical development

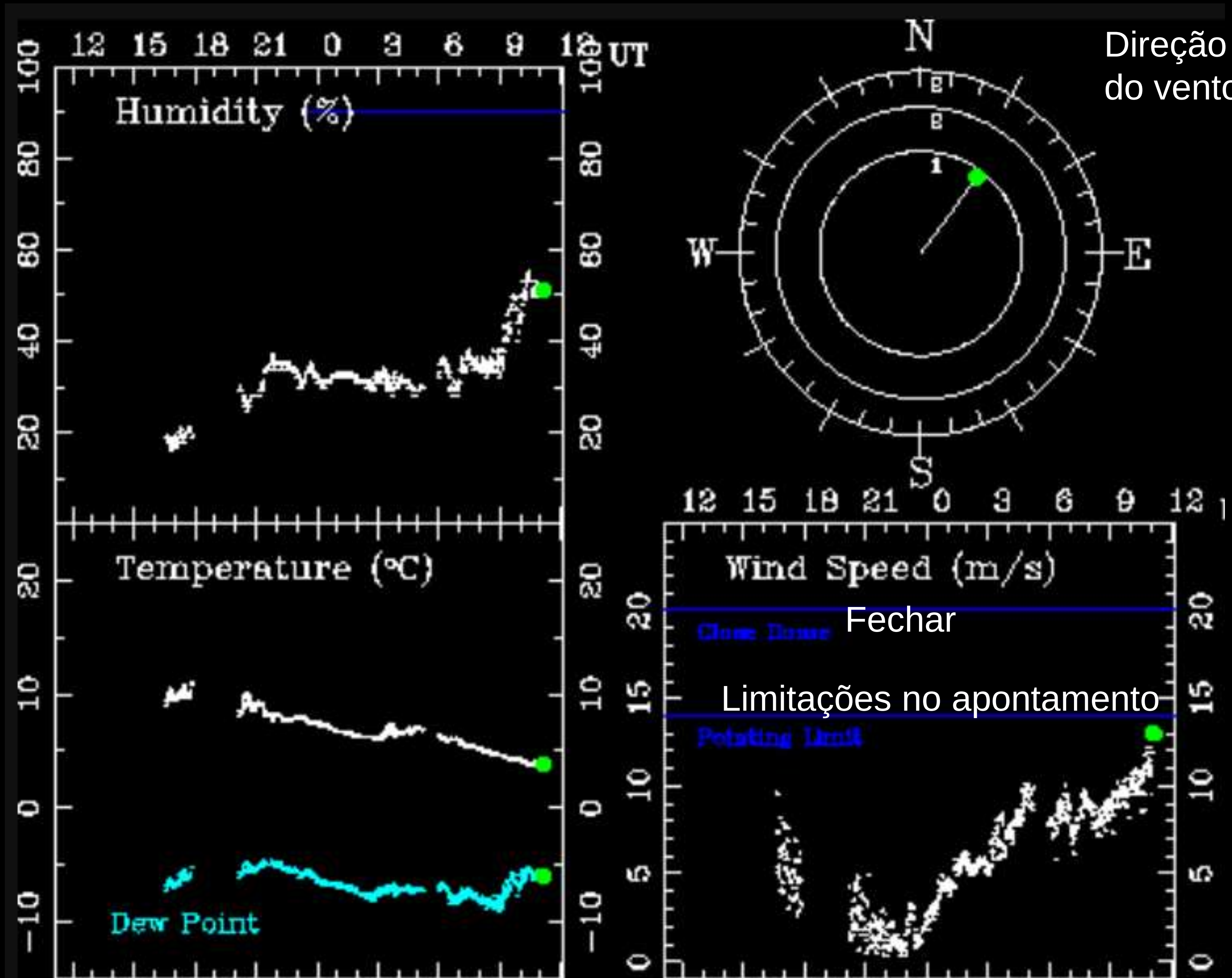
Condições meteorológicas em La Silla (Chile)

Estudantes brasileiros @ La Silla, 20/9/2013

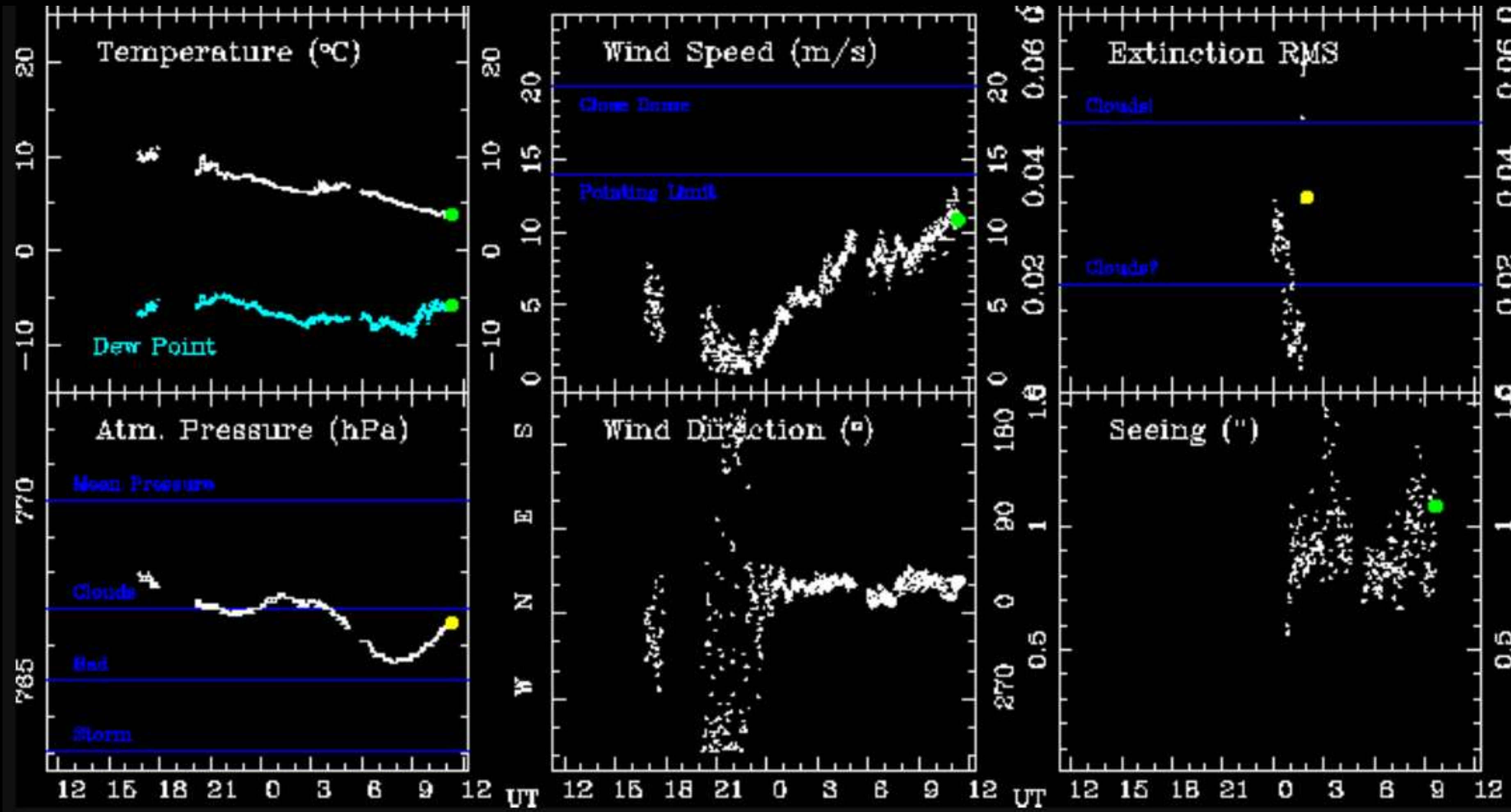
1/10/2013



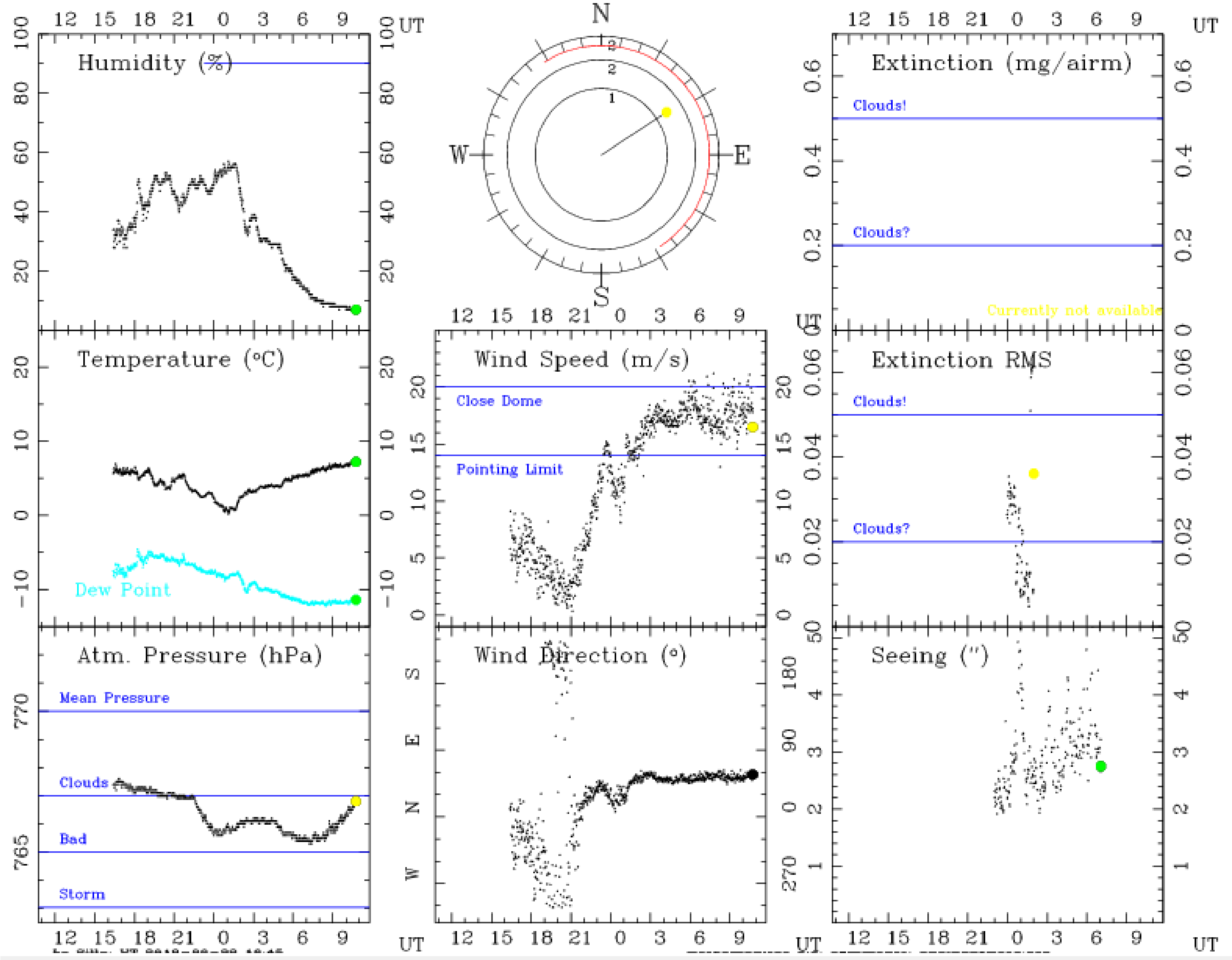
La Silla - MeteoMonitor
Current Average
Humidity: 50.0 50.0 %
Temperature: 4.0 4.0 °C
Dew Point -6.0 -6.0 °C
Wind Speed: 11.0 11.0 m/s
Atm. Pressure: 766.4 766.4 hPa
Sun Altitude: 6. °
DIMM Seeing: 1.08 arcsec
Last Update
UT: 2013-10-02 10:50
JD: 2456567.951
ST: 06:52
Update
PRINT GRAPH
Help/Info
Zoom graph
Satellite Pics
Plot Archive
Humidity (%)
Temperature (°C)
Dew Point
Atm. Pressure (hPa)
Wind Speed (m/s)
Wind Direction (°)
Extinction (mg/airm)
Currently not available
Extinction RMS
Seeing (")
N
S
E
W
UT



Direção do vento
N
W
E
S
UT
Humidity (%)
Temperature (°C)
Dew Point
Wind Speed (m/s)
Fechar
Limitações no apontamento


Temperature (°C)
Dew Point
Atm. Pressure (hPa)
Mean Pressure
Clouds
Bad
Storm
Wind Speed (m/s)
Close Dome
Pointing Limit
Wind Direction (°)
Extinction RMS
Clouds!
Clouds?
Seeing (")
UT
12 15 18 21 0 3 6 9 12

La Silla, 22/9/2013



Hawaii

Hawaii, 18/8/2013

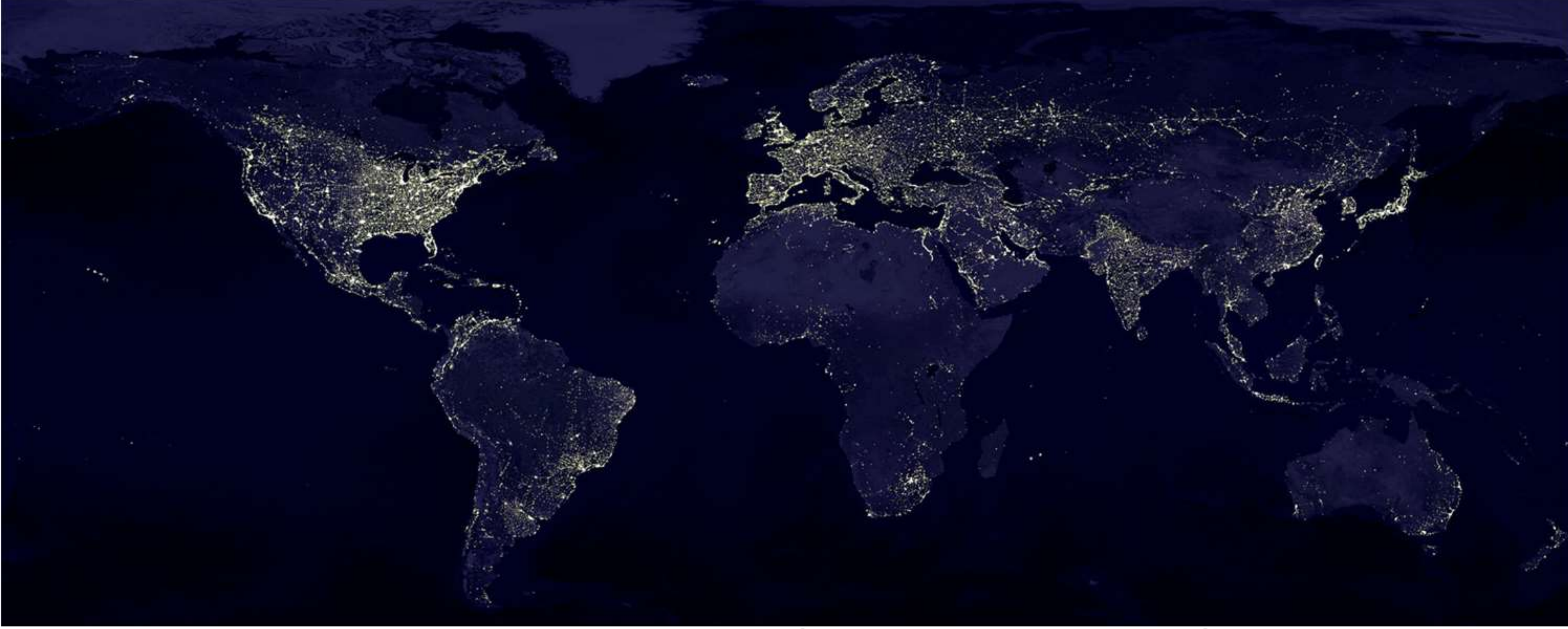
Mauna Kea Weather conditions

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	

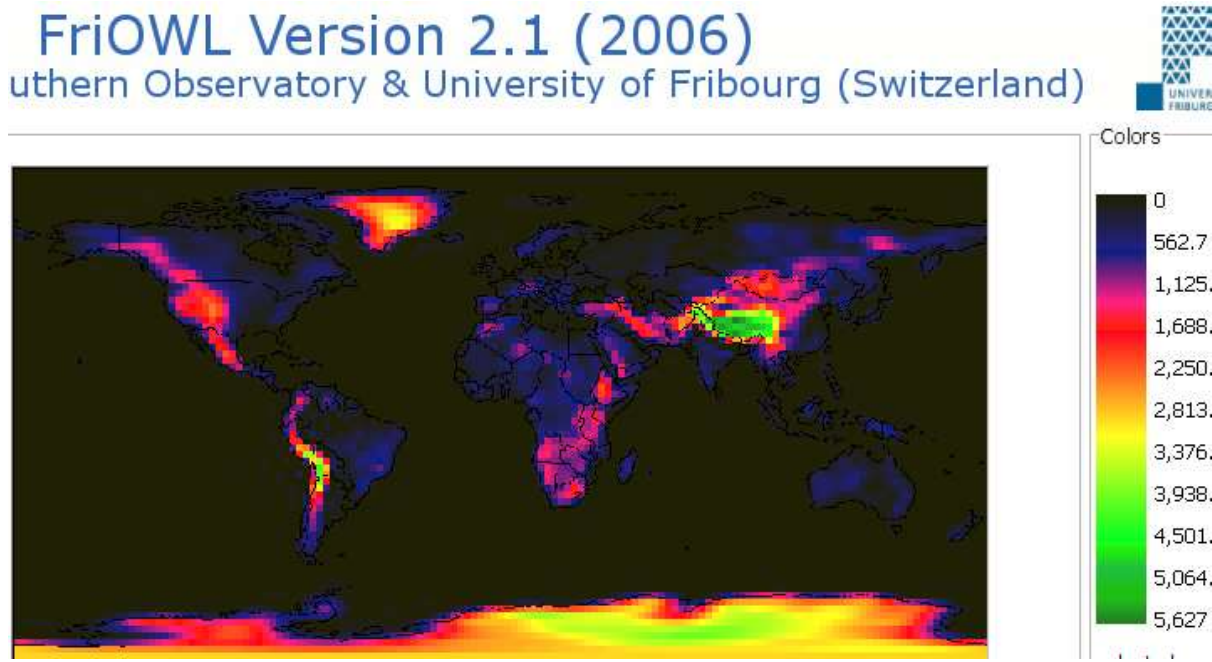


Escolha de um sítio astronômico

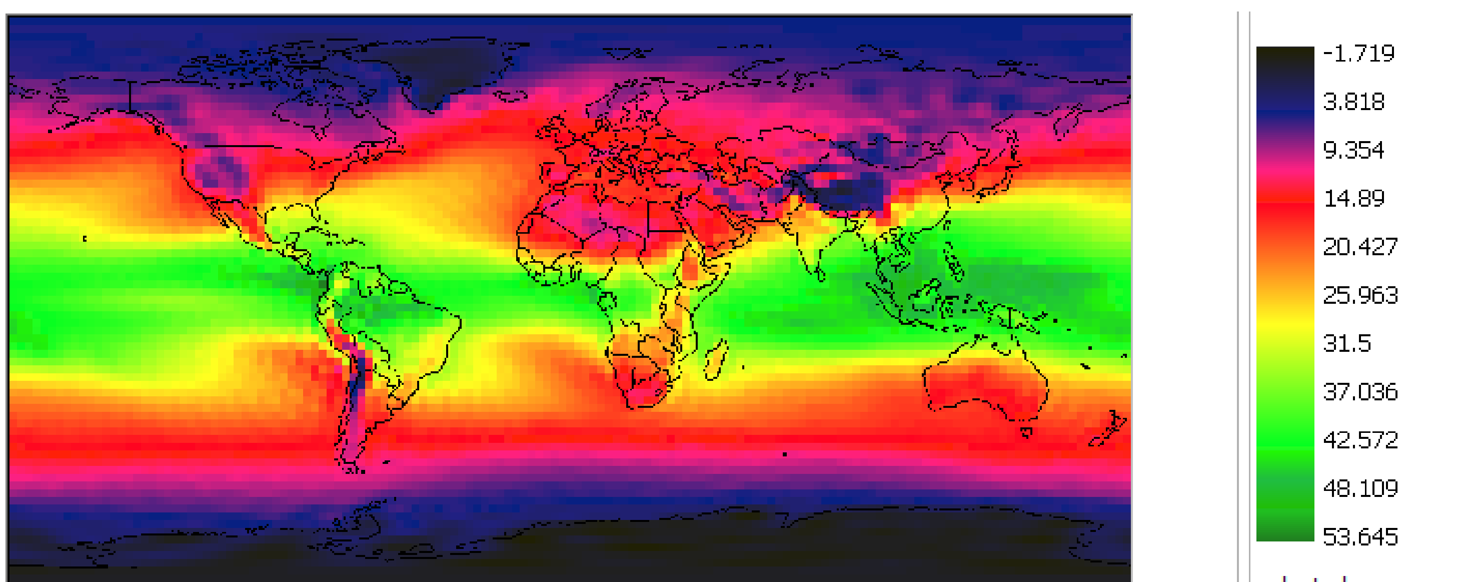
- Ausência de nuvens (ligada à camada de inversão)
- Qualidade fotométrica (estab. transparência atmos.)
- Transparência no IV e mm (baixo vapor H_2O atmosférico)
- Qualidade da imagem (variações na temperatura e índice de refração do ar)

Escolha de um sítio astronômico

Altitude

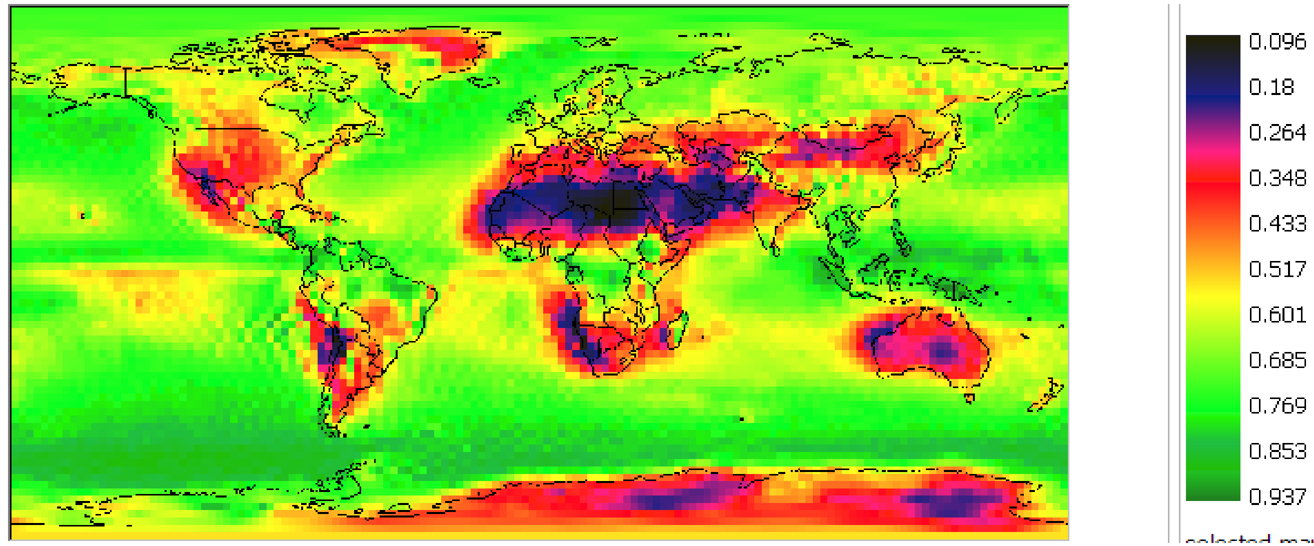


precipitable H_2O

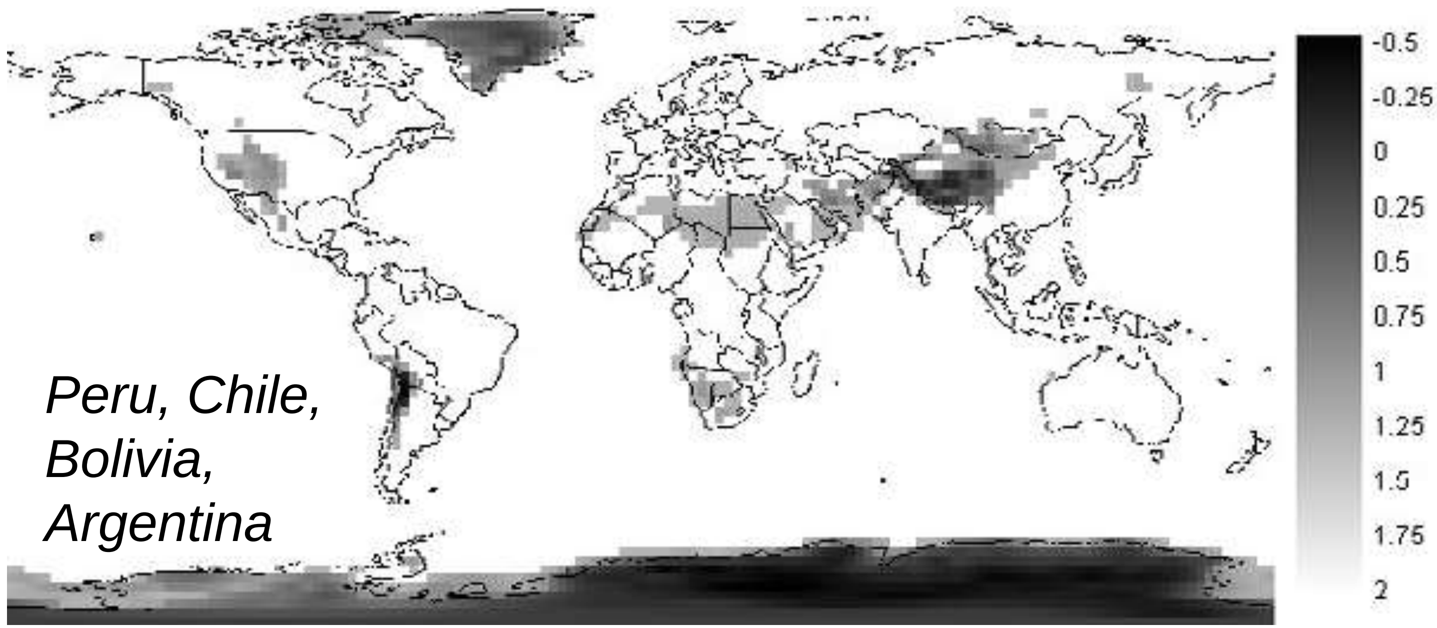


Escolha de um sítio astronômico

Cloud coverage



BEST SITES
High summits + low cloudiness + low precipitable water vapor



Se o solo não for bom, podemos ir ao espaço