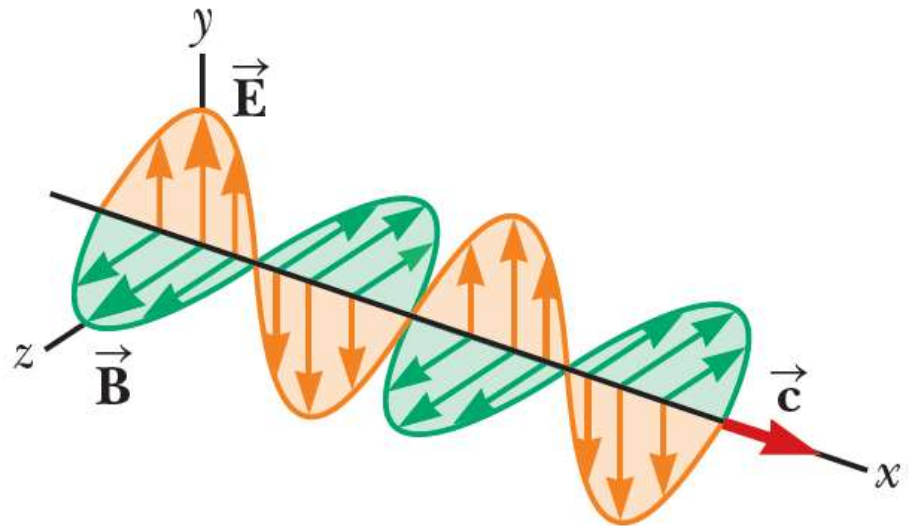


AGA414

Radiação

Fótons e outros mensageiros. Espectros astrofísicos, contínuo e linhas. Aspectos das medidas: posição, intensidade/fluxo, variabilidade, resolução espacial, resolução espectral, cobertura espectral, polarização, S/N.

Prof. Jorge Meléndez



Photon astronomy

- Most astrophysics is based on photons (electromagnetic waves)

VLA

Gemini North



Gregor 1.5m
solar telescope
Tenerife



HST

Compton gamma-ray observatory



Electromagnetic spectrum

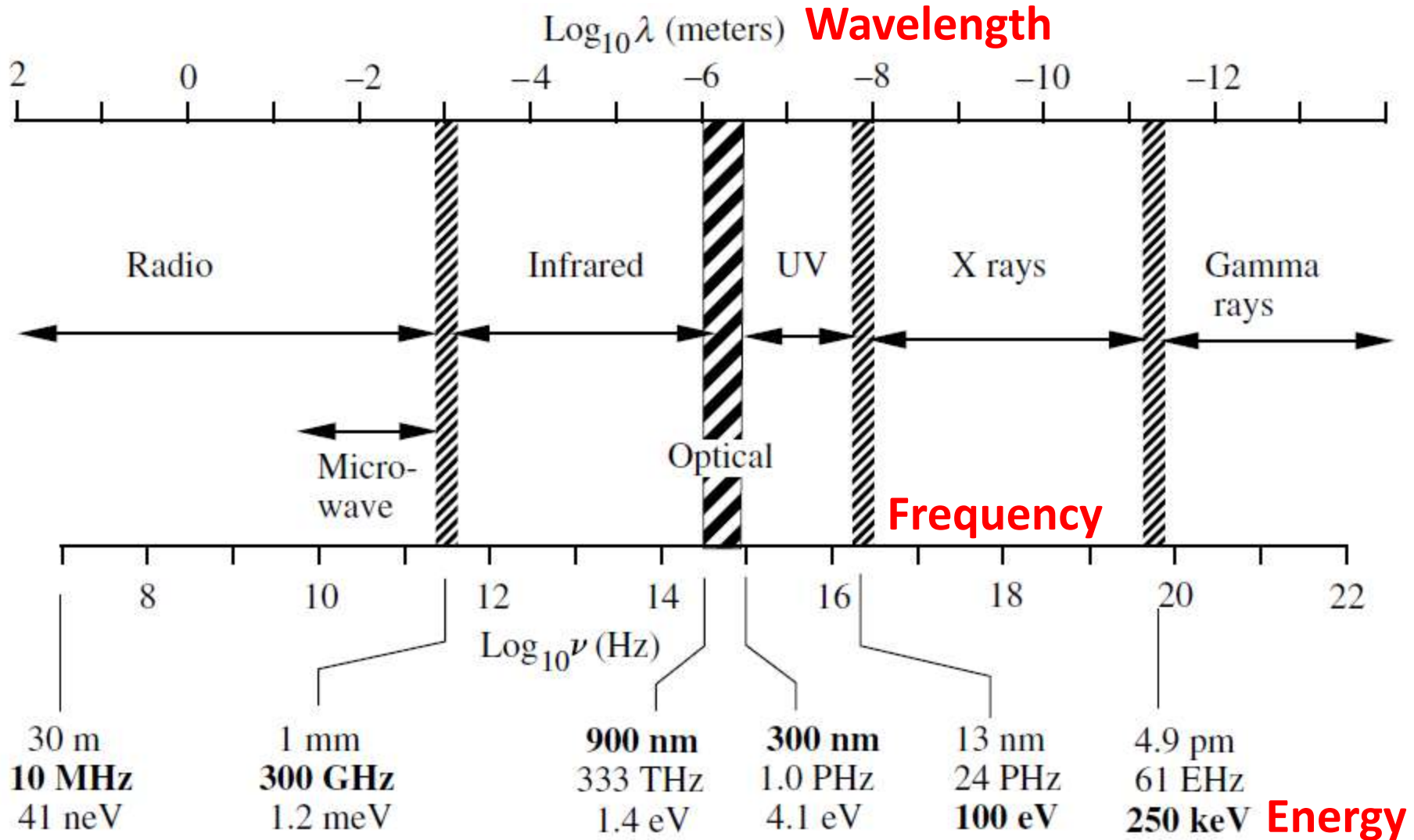


Figure 2.1. The approximate “bands” of the electromagnetic spectrum. The boundaries are not well defined. Radio waves extend further to the left, but the earth’s ionosphere is opaque for the most part below about $\nu = 30$ MHz. Gamma rays extend to the right by many more factors of 10. Values of the boundaries are given in several units below the figure. Among these, commonly used values are shown in boldface. Note that 1 nm = 10 angstroms.

Wavelength (λ), Frequency (ν), Energy (E)

- $\lambda \nu = c$

c : speed of light in a vacuum,

$$c = 2.9979 \times 10^8 \text{ m/s} \approx 3.0 \times 10^8 \text{ m/s}$$

- $1 \mu\text{m} = 10\,000 \text{ \AA}$ (infrared/optical)

- $1 \text{ nm} = 10 \text{ \AA}$ (x ray)

- Wavenumber $\sigma = 1/\lambda_{\text{vacuo}}$ (usually in cm^{-1})

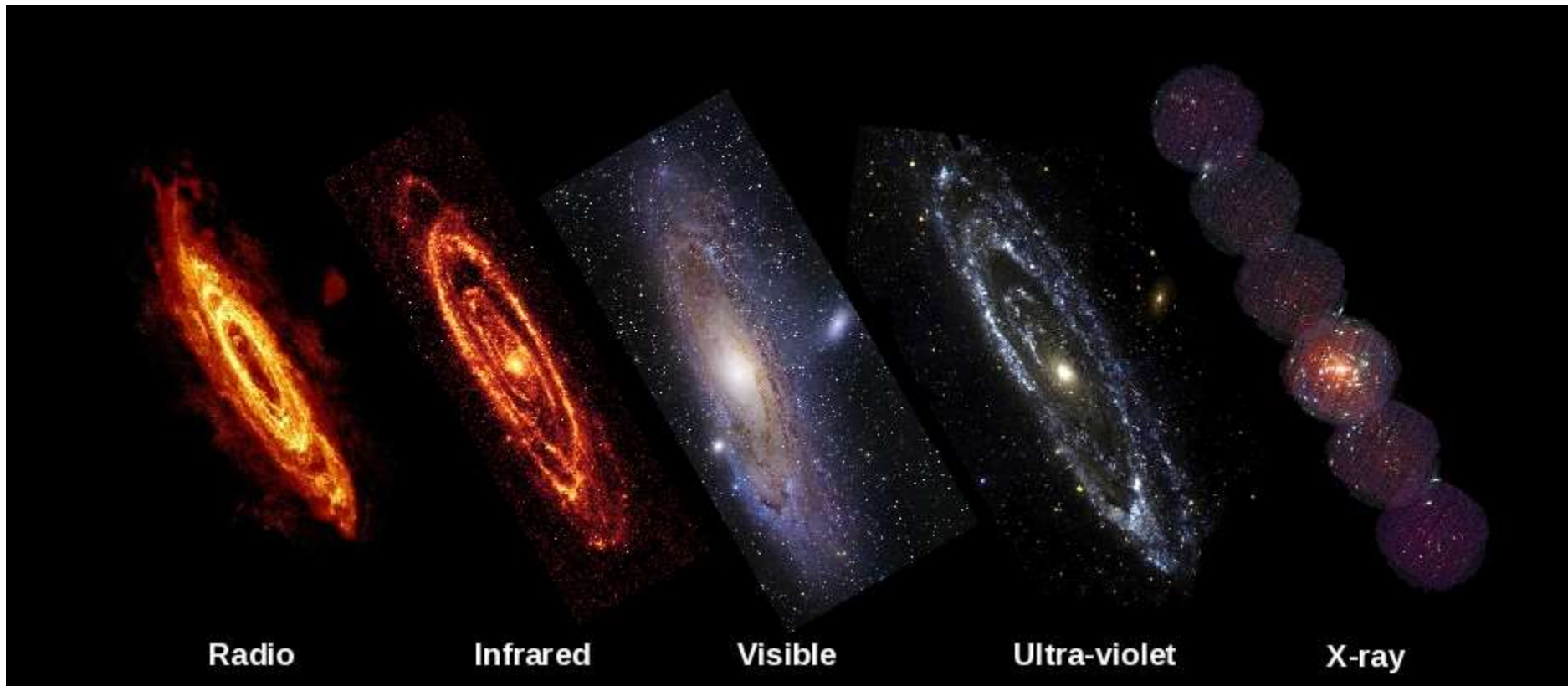
- Angular wavenumber $k = 2\pi/\lambda$

- $E = h\nu$ (J)

$h = 6.626\,069 \times 10^{-34} \text{ J s}$ (Planck constant)

- $1 \text{ eV} = 1.602\,176 \times 10^{-19} \text{ J}$

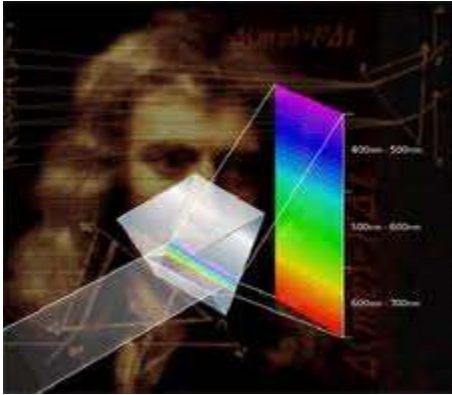
Multi-wavelength Astronomy



HOT → short wavelength
COLD → long wavelength

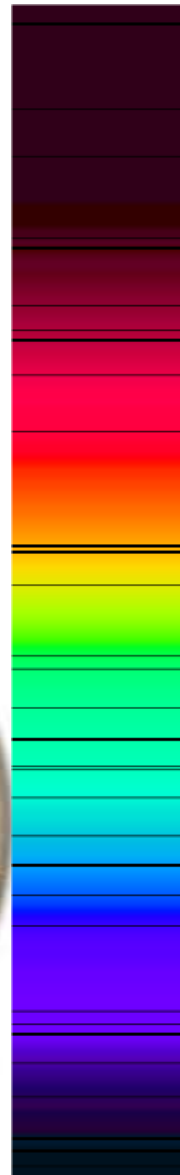
<http://planck.cf.ac.uk/science/mm-wave-astronomy>

Continuous (optical) spectrum



Newton (1666)

Line spectrum



William Hyde Wollaston
(1766-1828)

Wollaston
(1802)
7 lines



Joseph von Fraunhofer
(1787-1826)

Fraunhofer
(1817)
574 lines

Infrared spectrum

William Herschel (1800)

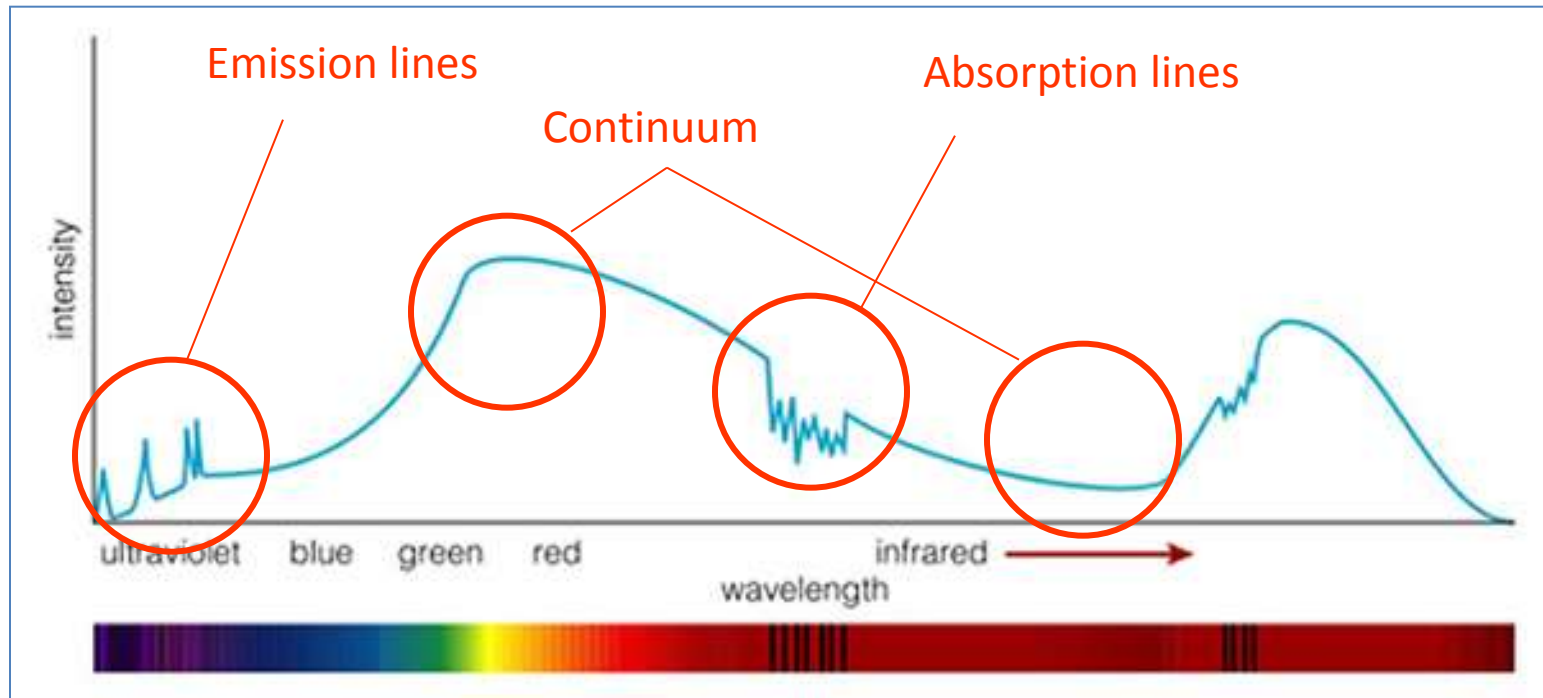


Emission spectrum

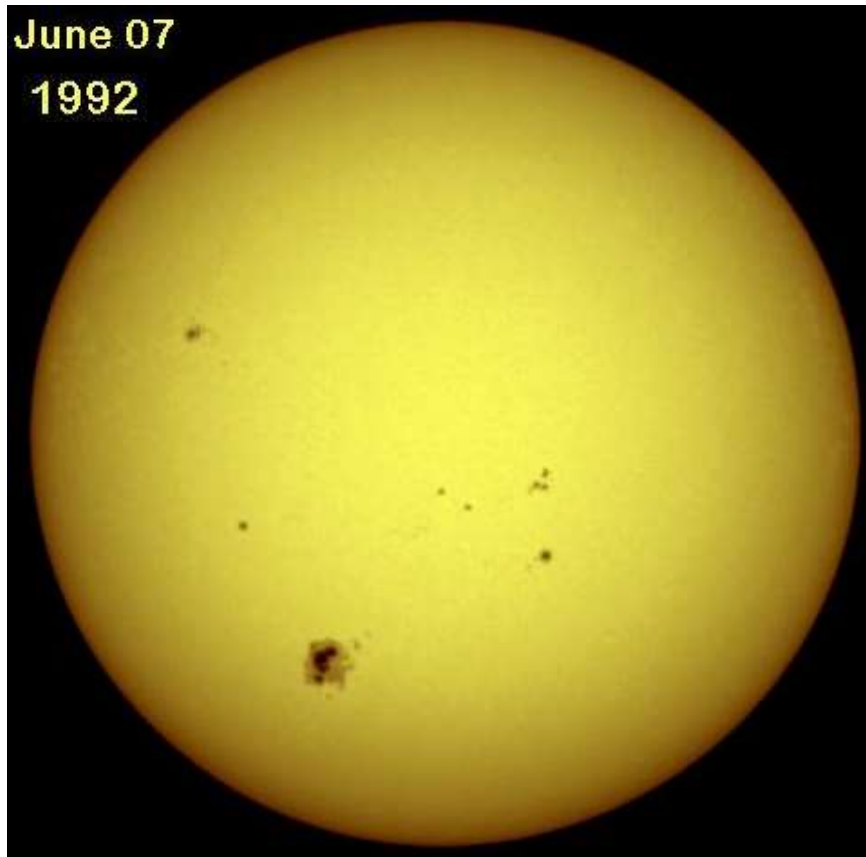
John Herschel (son of William)
and W.H. Fox Talbot (1826)



A Spectrum: Flux (or Intensity) vs. Wavelength



Fluxo e Intensidade



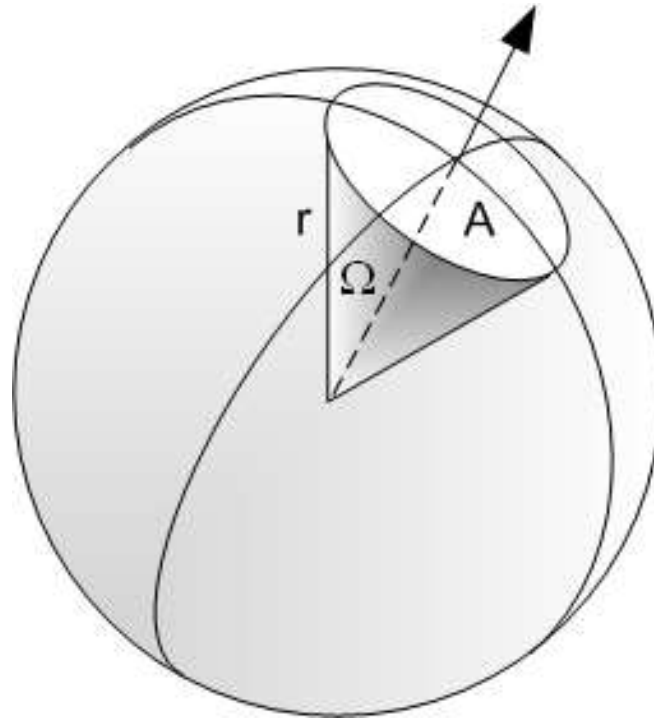
<http://solarscience.msfc.nasa.gov/surface.shtml>



<http://www.twanight.org/newtwan/photos.asp?ID=3001503>

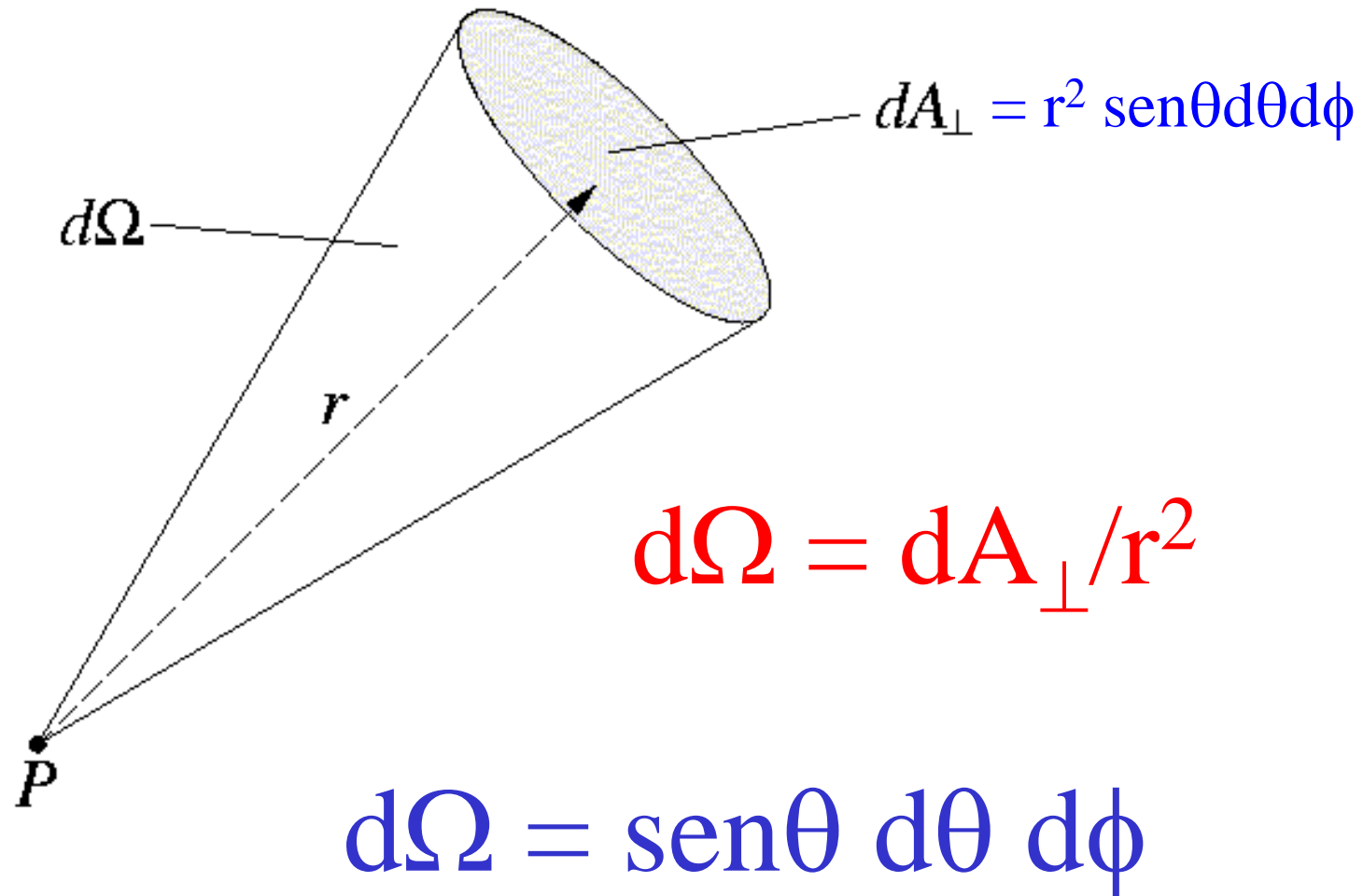
Ângulo Sólido

ângulo subtendido por um objeto de área A a uma distância r .



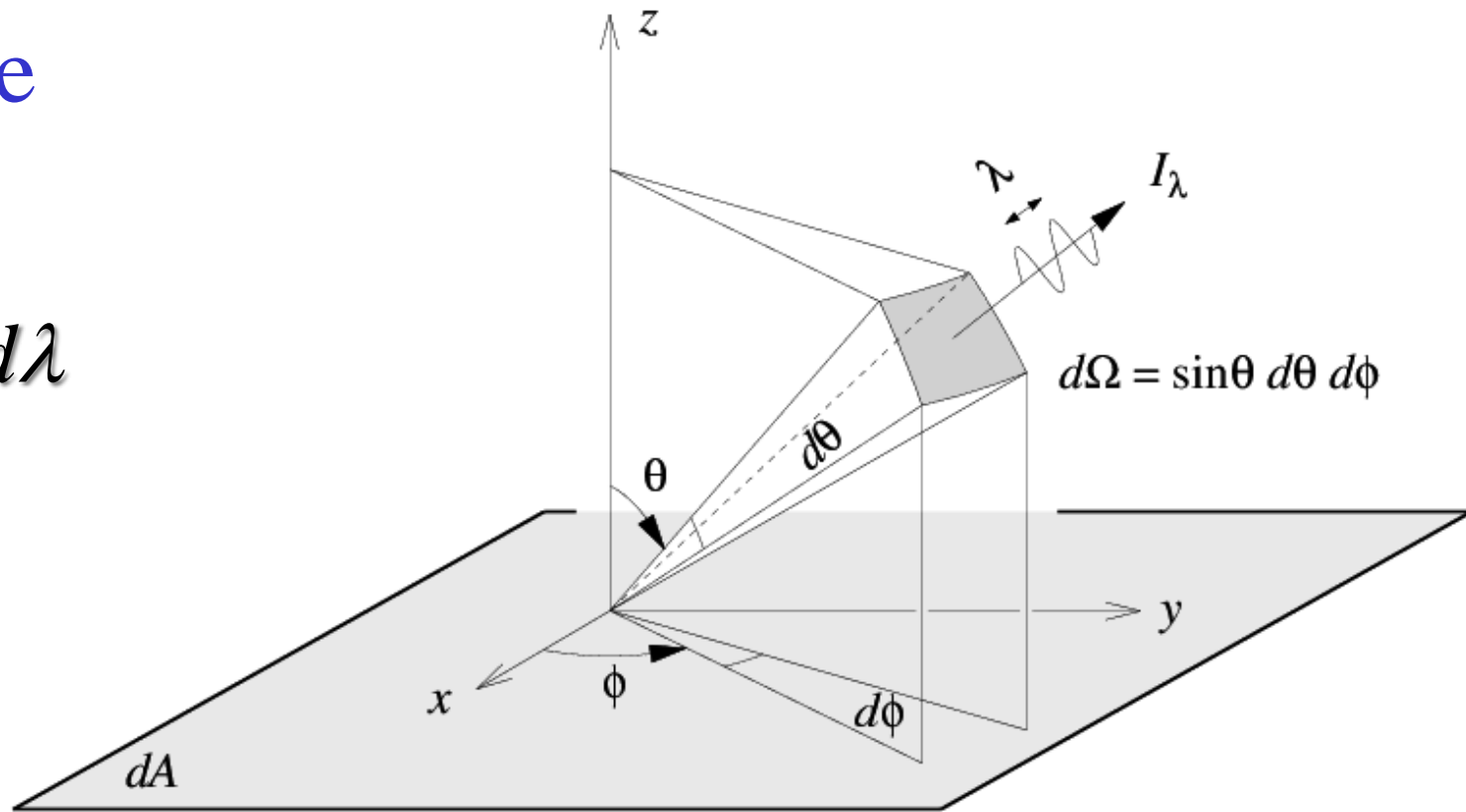
$$\Omega = A/r^2$$

Ângulo Sólido



Intensidade específica

$$I_\nu d\nu = I_\lambda d\lambda$$



$$I_\nu = \lim_{dA d\Omega d\nu dt \rightarrow 0} \left(\frac{\Delta E_\nu}{\cos \theta dA d\Omega d\nu dt} \right)$$

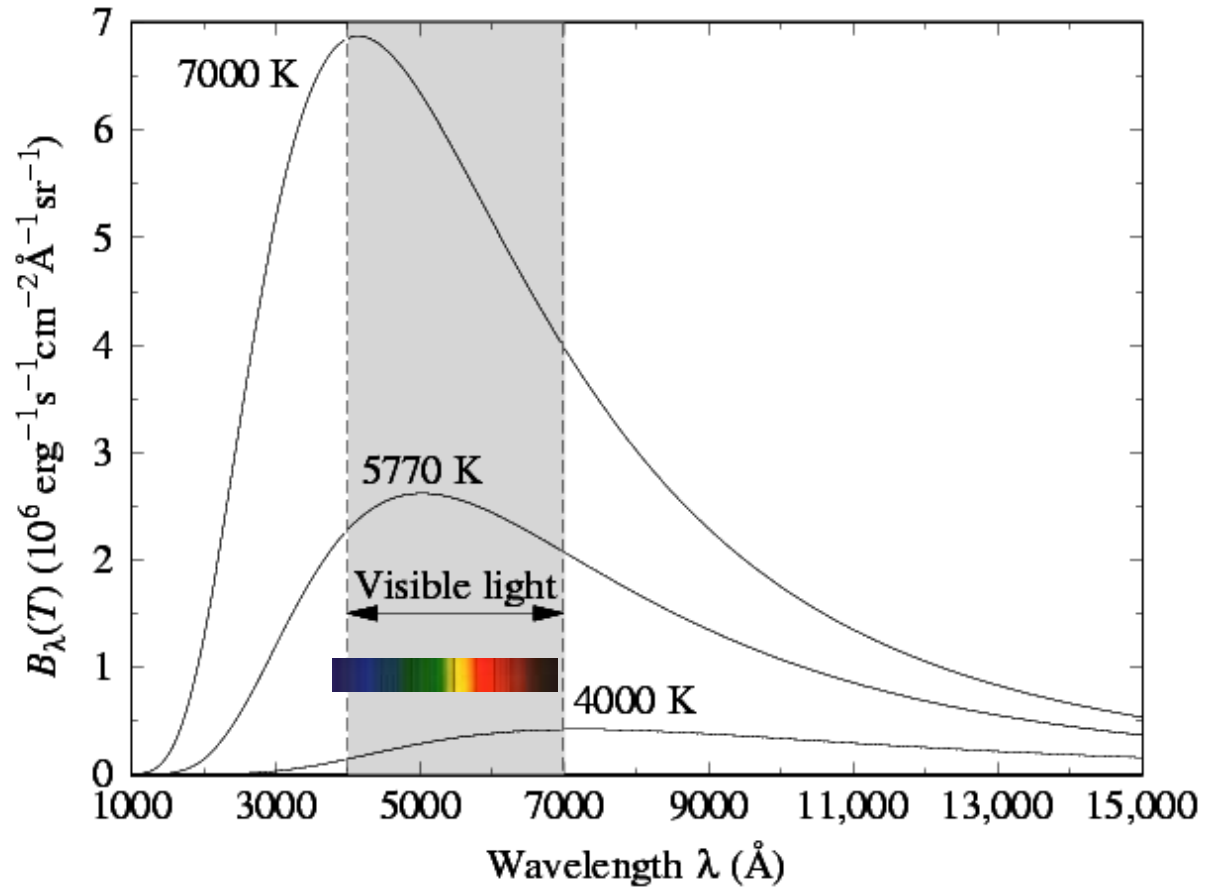
I_ν : energia através de uma A_\perp à radiação ($dA \cos \theta$), por unidade de $d\Omega$, por unidade de intervalo de frequência ($d\nu$), por unidade de tempo (dt).

$$I_\nu \text{ (erg cm}^{-2} \text{ sr}^{-1} \text{ Hz}^{-1} \text{ s}^{-1}) \text{ , } I_\lambda \text{ (erg cm}^{-2} \text{ sr}^{-1} \text{ \AA}^{-1} \text{ s}^{-1})$$

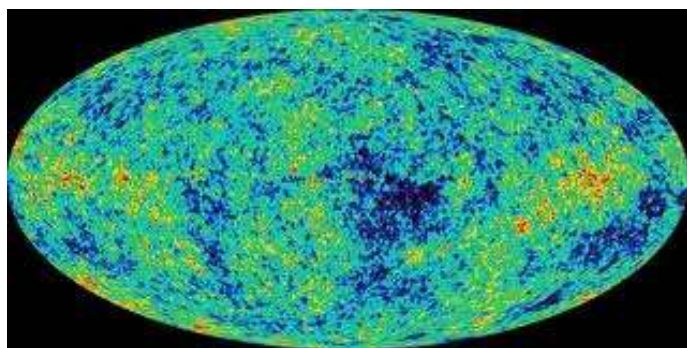
$$E = h\nu = hc/\lambda$$

Radiação de corpo negro

Corpo Negro:
Emissor ideal
(absorve toda a energia incidente)

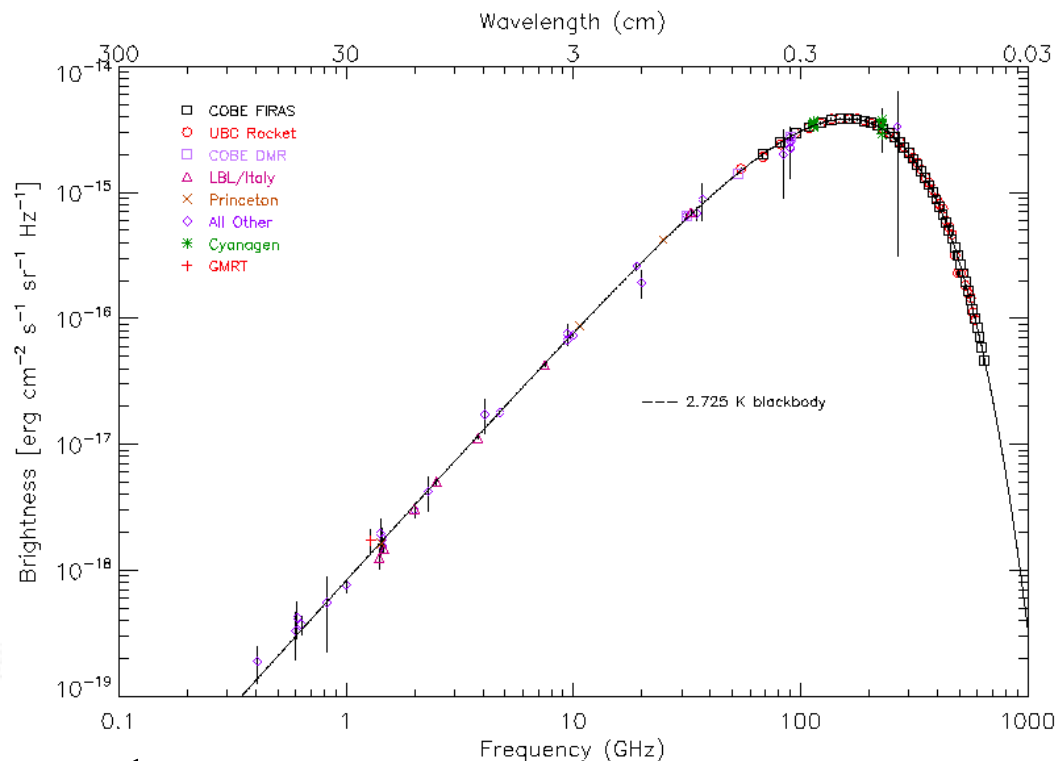
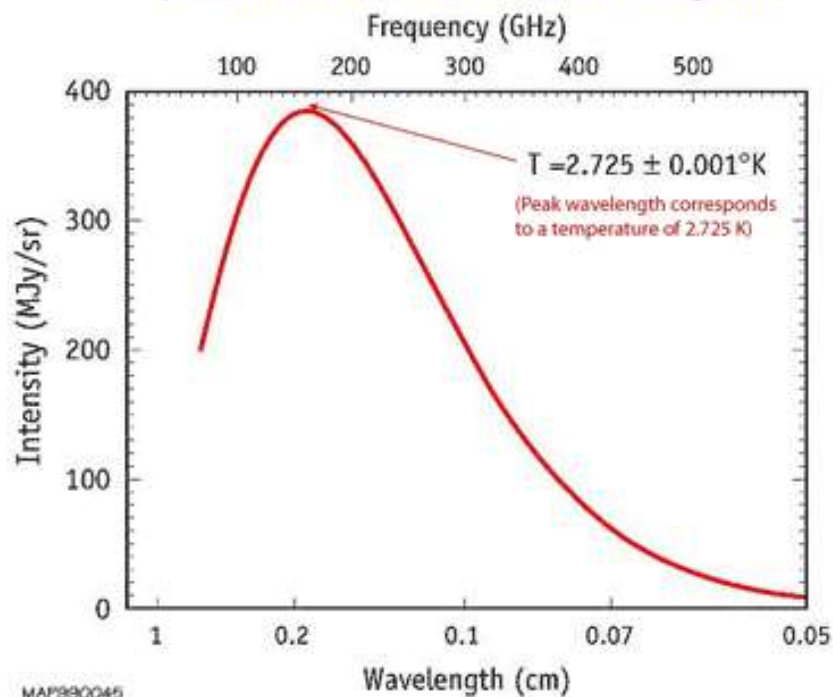


$$I_\lambda = B_\lambda(T) = \frac{2hc^2}{\lambda^5} \frac{1}{e^{(hc/\lambda kT)} - 1}$$



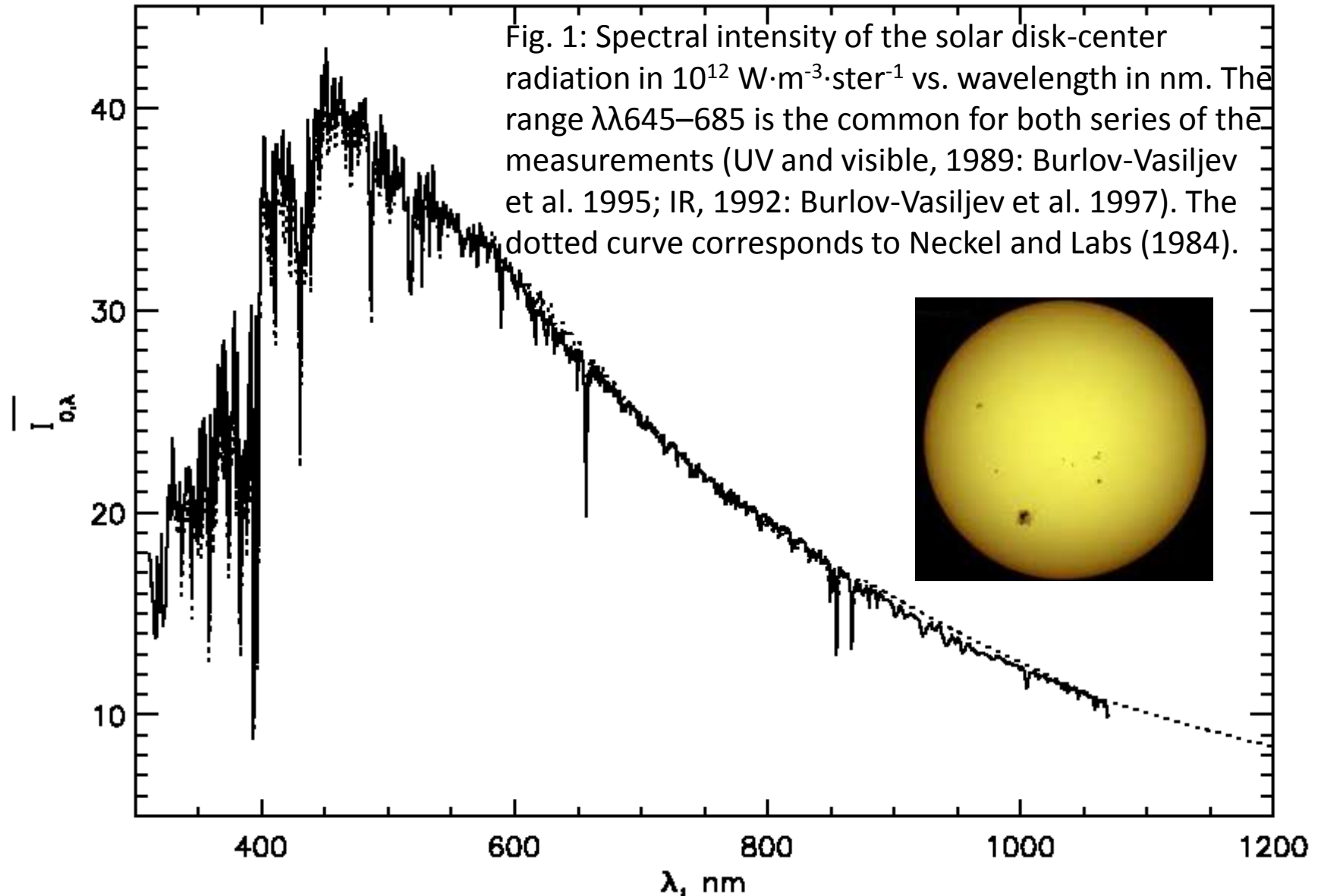
CMB: black body *quase perfeito*

Spectrum of the Cosmic Microwave Background

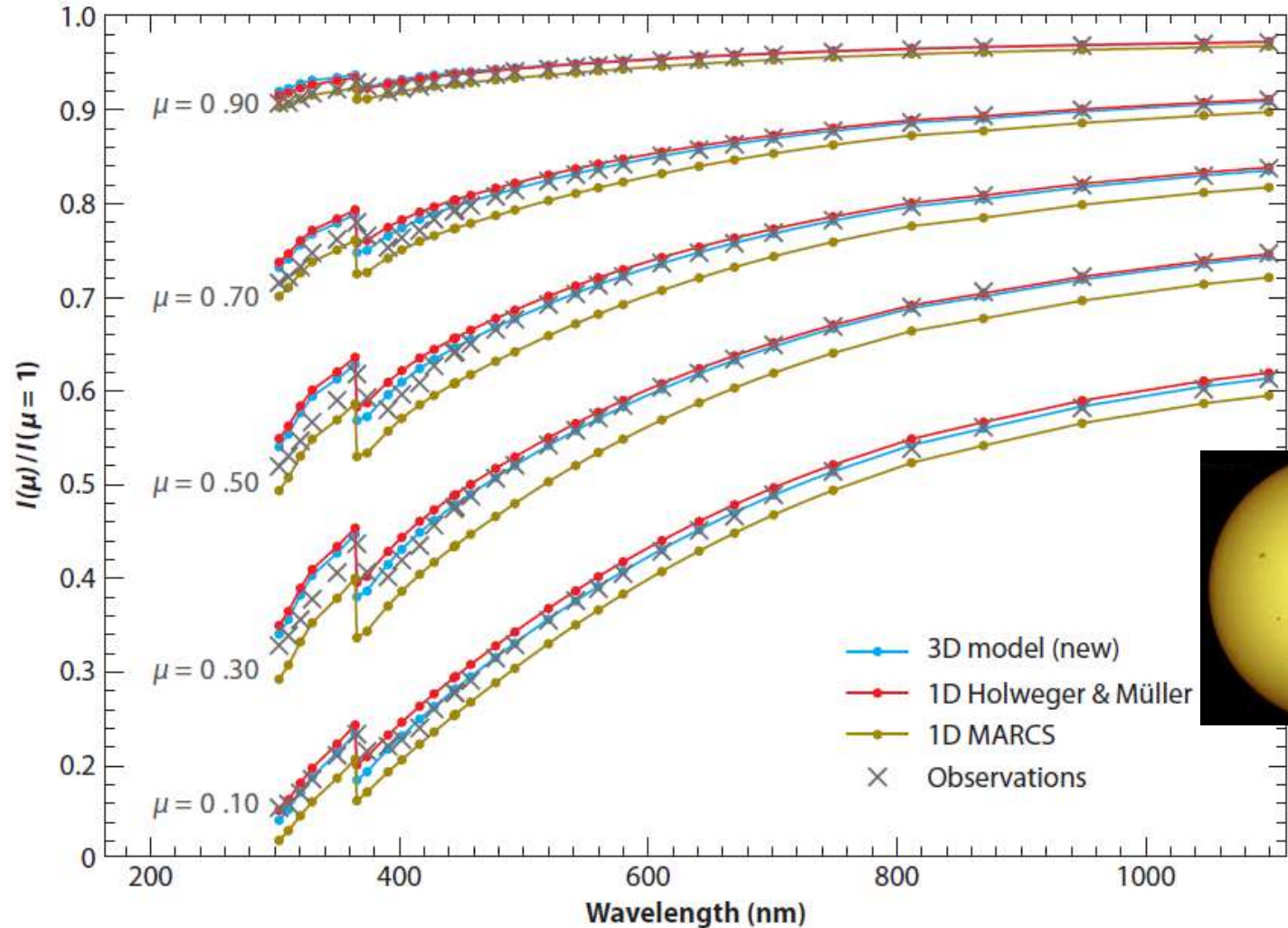


$$I_{\lambda} = B_{\lambda}(T) = \frac{2hc^2}{\lambda^5} \frac{1}{e^{(hc/\lambda kT)} - 1}$$

Sun: center of the disk

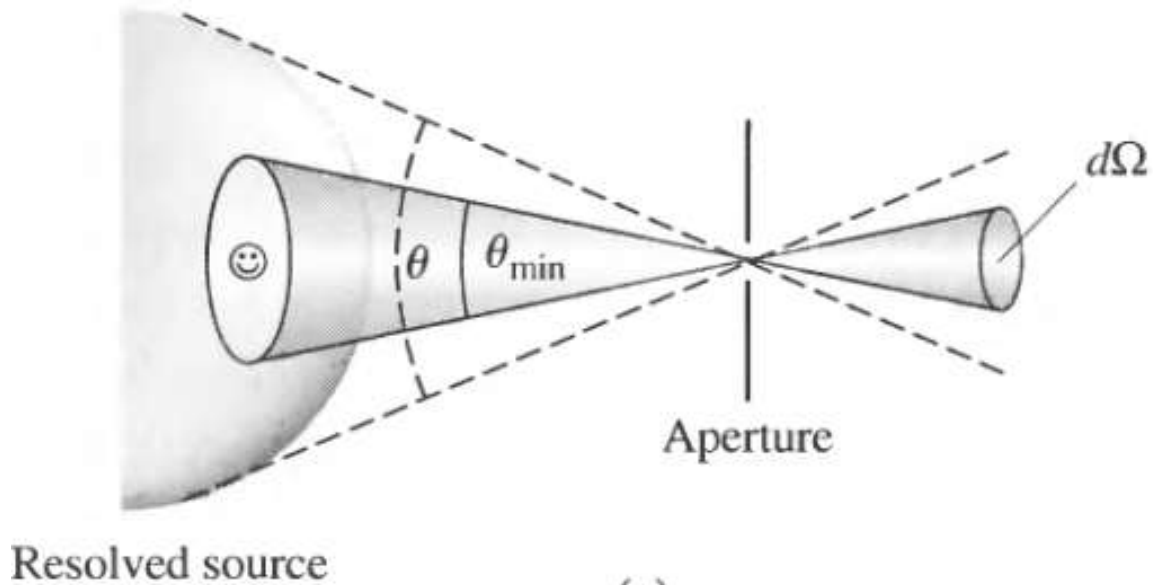


Sun center-disk variation

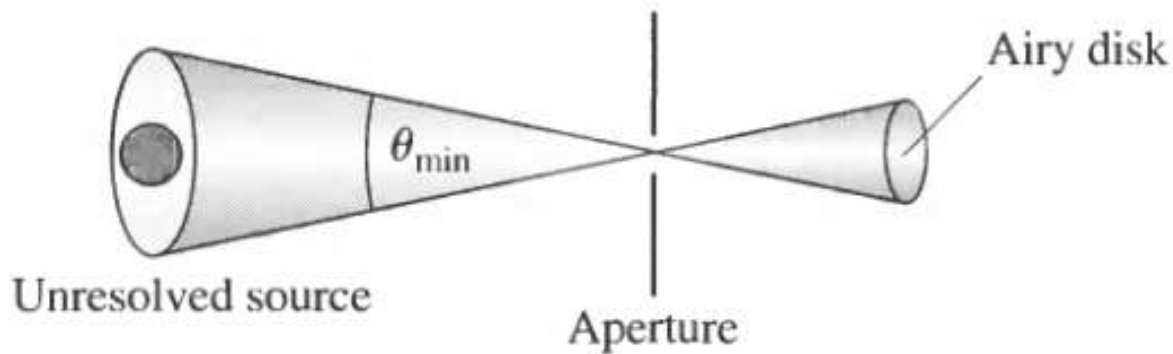


Comparison of the predicted continuum center-to-limb variation as a function of wavelength for different solar model atmospheres against observations (Neckel & Labs 1994). The results for five different viewing angles μ are shown from near disk center ($\mu = 0.9$) to close to the limb ($\mu = 0.1$). All intensities are normalized to the corresponding disk-center intensities. The 3D hydrodynamical model (Trampedach et al., in preparation) used in this review outperforms even the Holweger & Müller (1974) semiempirical model, which was designed to satisfy this diagnostic (Pereira et al., in preparation). As for all 1D theoretical model atmospheres, the MARCS (Gustafsson et al. 2008) model has a too steep temperature gradient, which manifests itself in a poor agreement with the center-to-limb variation.

Fonte resolvida: medida de **intensidade específica**



Fonte não-resolvida: medida de **fluxo**



Fluxo F_λ

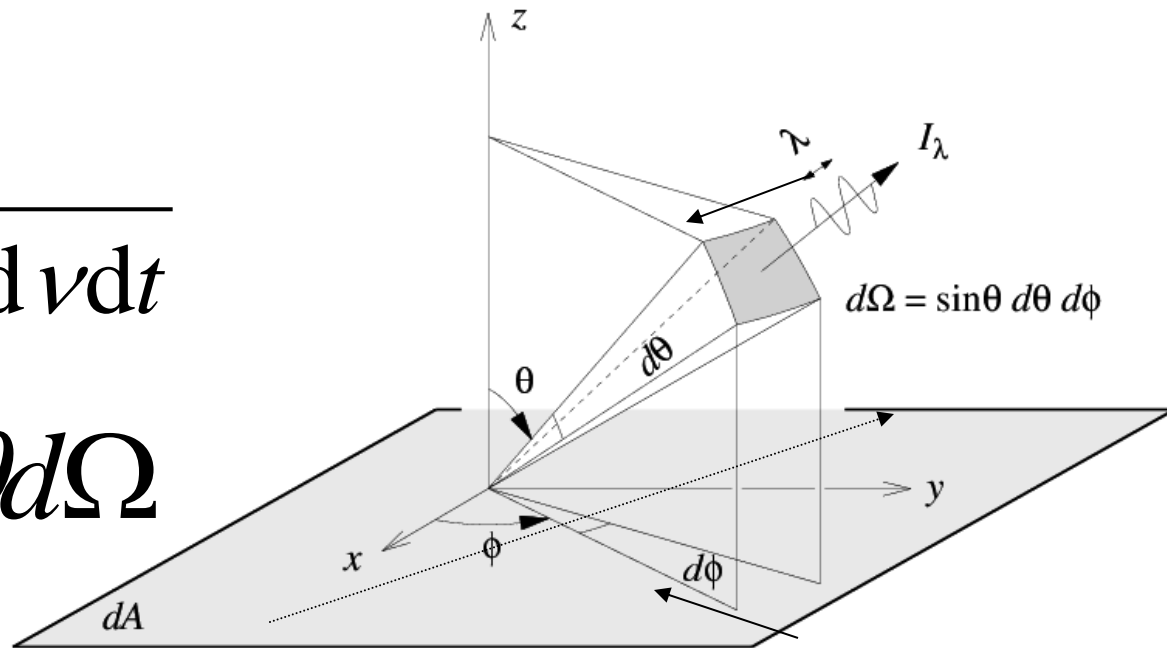
$$F_\lambda = \frac{\sum \Delta E_\lambda}{dA d\lambda dt}$$

F_λ : energia que atravessa uma área (dA), por unidade de comprimento de onda ($d\lambda$), por unidade de tempo (dt).

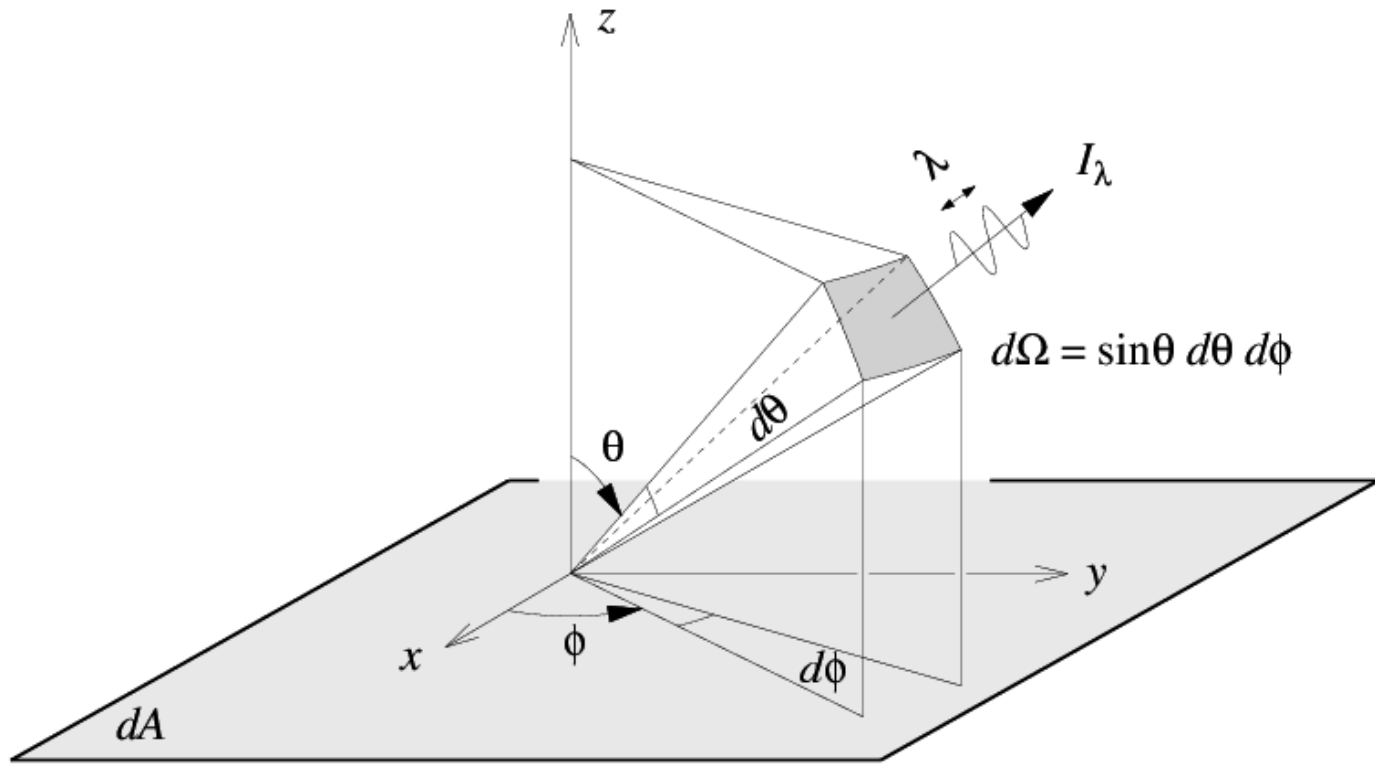
F_ν ($\text{erg cm}^{-2} \text{ Hz}^{-1} \text{ s}^{-1}$), F_λ ($\text{erg cm}^{-2} \text{ \AA}^{-1} \text{ s}^{-1}$)

$$I_\nu = \frac{\Delta E_\nu}{\cos \theta dA d\Omega d\nu dt}$$

$$F_\lambda = \int I_\lambda \cos \theta d\Omega$$



$$F_\lambda = \int I_\lambda \cos \theta d\Omega = \int_{\phi=0}^{2\pi} \int_{\theta=0}^{\pi} I_\lambda \cos \theta \sin \theta d\theta d\phi$$



$$F_\lambda = \int_{\phi=0}^{2\pi} \int_{\theta=0}^{\pi/2} I_\lambda \cos \theta \sin \theta d\theta d\phi \quad + \quad \int_{\phi=0}^{2\pi} \int_{\theta=\pi/2}^{\pi} I_\lambda \cos \theta \sin \theta d\theta d\phi$$

sai

entra = 0 ←

Considerando apenas a radiação de dentro para fora:

$$F_{\lambda} = \int_{\phi=0}^{2\pi} \int_{\theta=0}^{\pi/2} I_{\lambda} \cos \theta \sin \theta d\theta d\phi$$

Se I_{λ} não tem dependência com o ângulo azimutal (ϕ):

$$F_{\lambda} = \int_{\phi=0}^{2\pi} d\phi \int_{\theta=0}^{\pi/2} I_{\lambda} \cos \theta \sin \theta d\theta$$

$$F_{\lambda} = 2\pi \int_{\theta=0}^{\pi/2} I_{\lambda} \cos \theta \sin \theta d\theta$$

E se I_{λ} é independente do ângulo θ : **$F_{\lambda} = \pi I_{\lambda}$**

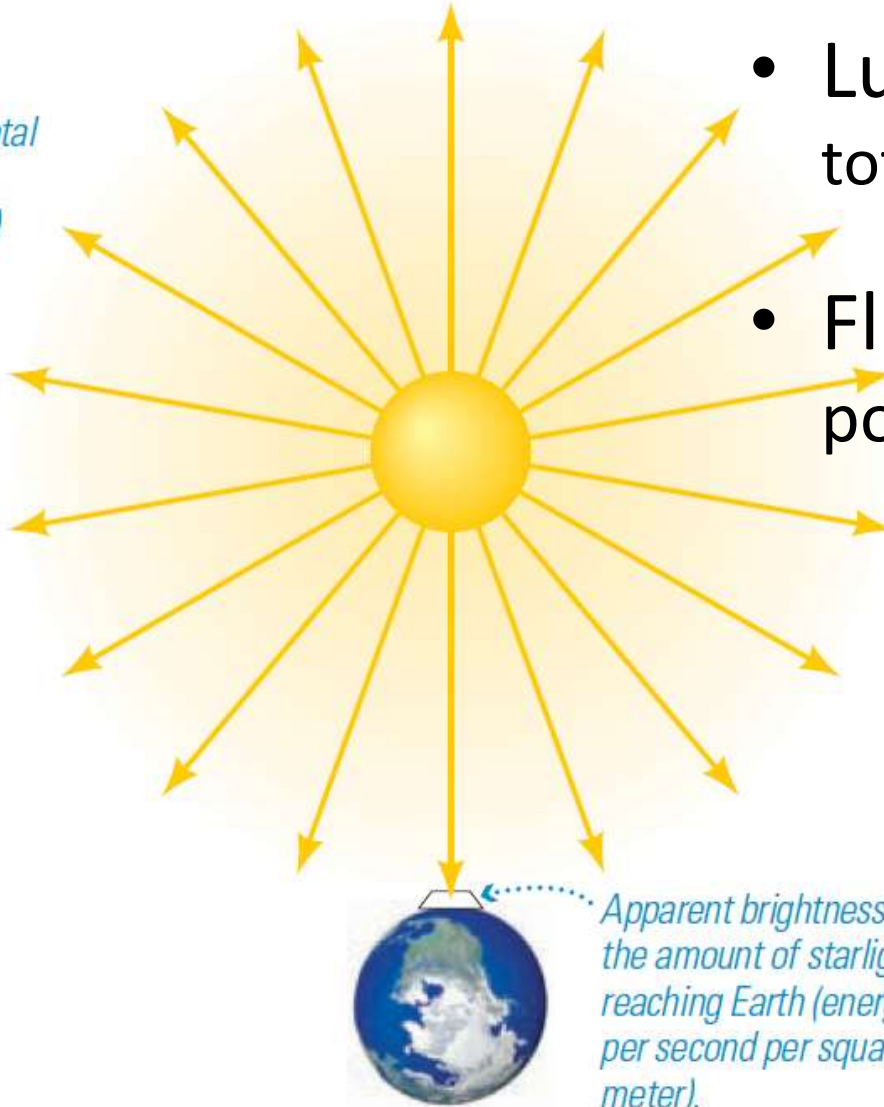
Aproximando uma estrela por um corpo negro, $I_{\lambda} = B_{\lambda}$

Isto é, podemos aproximar o fluxo emitido na superfície da estrela por:

$$**F_{\lambda} = \pi B_{\lambda}**$$

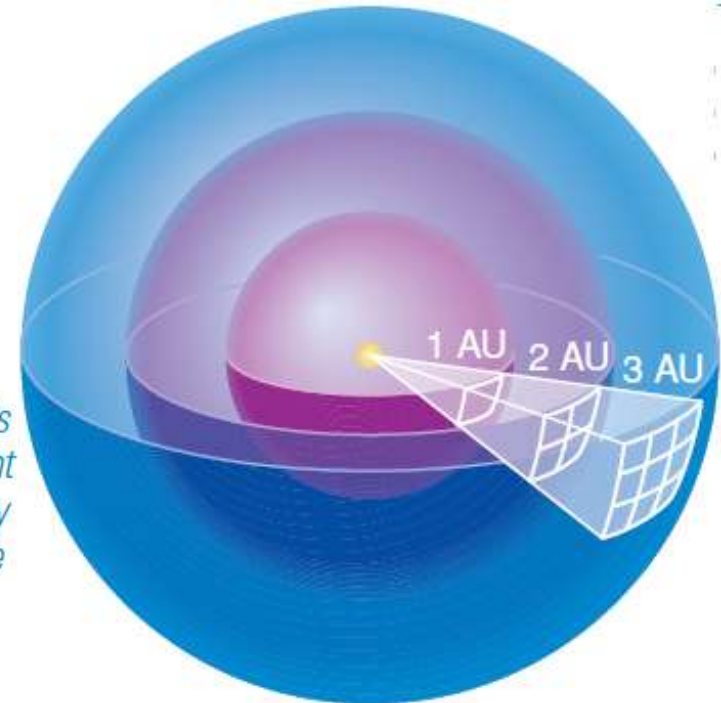
Fluxo e Luminosidade

Luminosity is the total amount of power (energy per second) the star radiates into space.

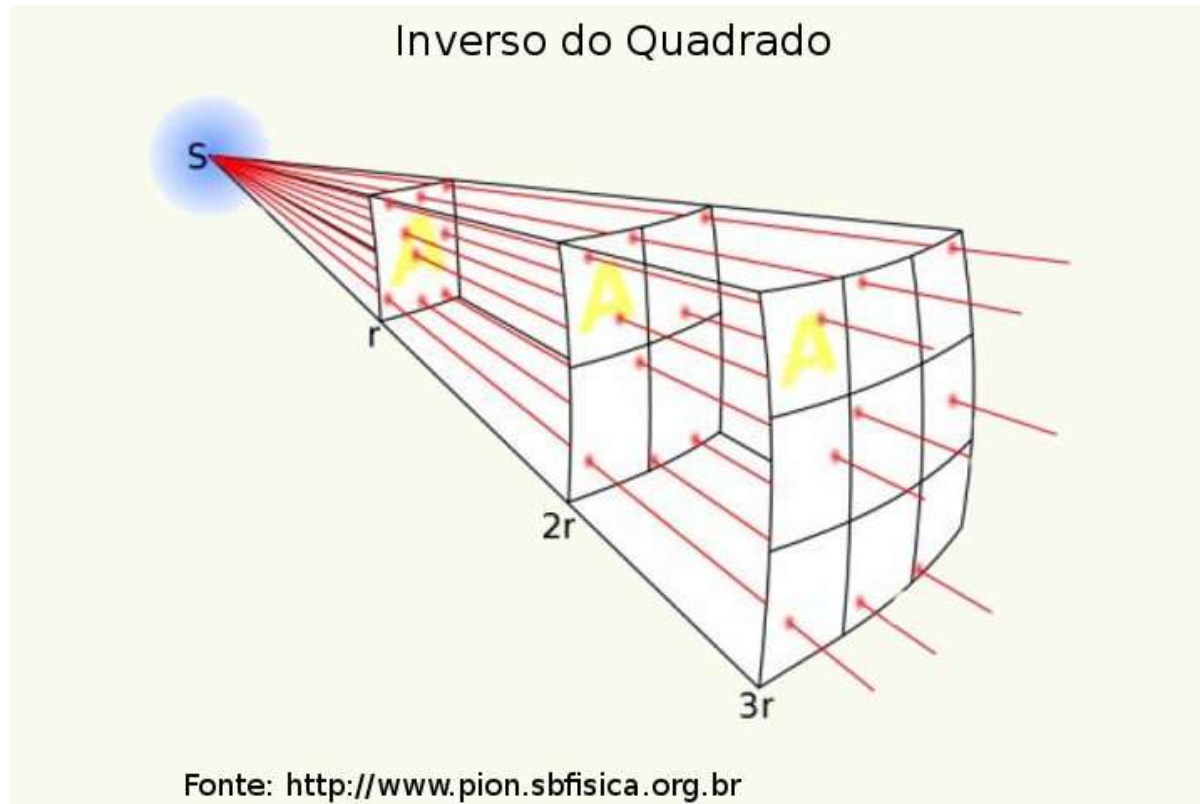


Not to scale!

- Luminosidade : energia total por unidade de tempo
- Fluxo : Luminosidade por unidade de área

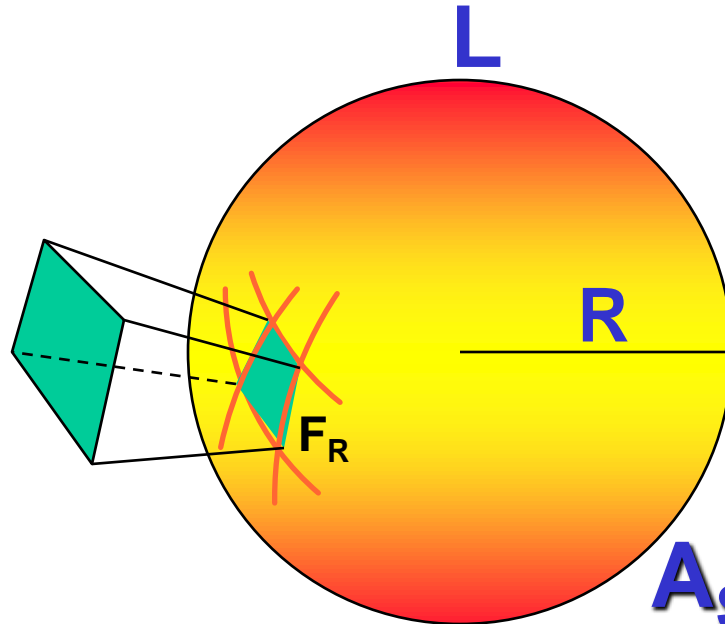


O Fluxo (energia/área) não é constante: inversamente proporcional ao quadrado da distância



Fluxo Solar Superficial

É a potência emitida
por unidade de área do Sol.

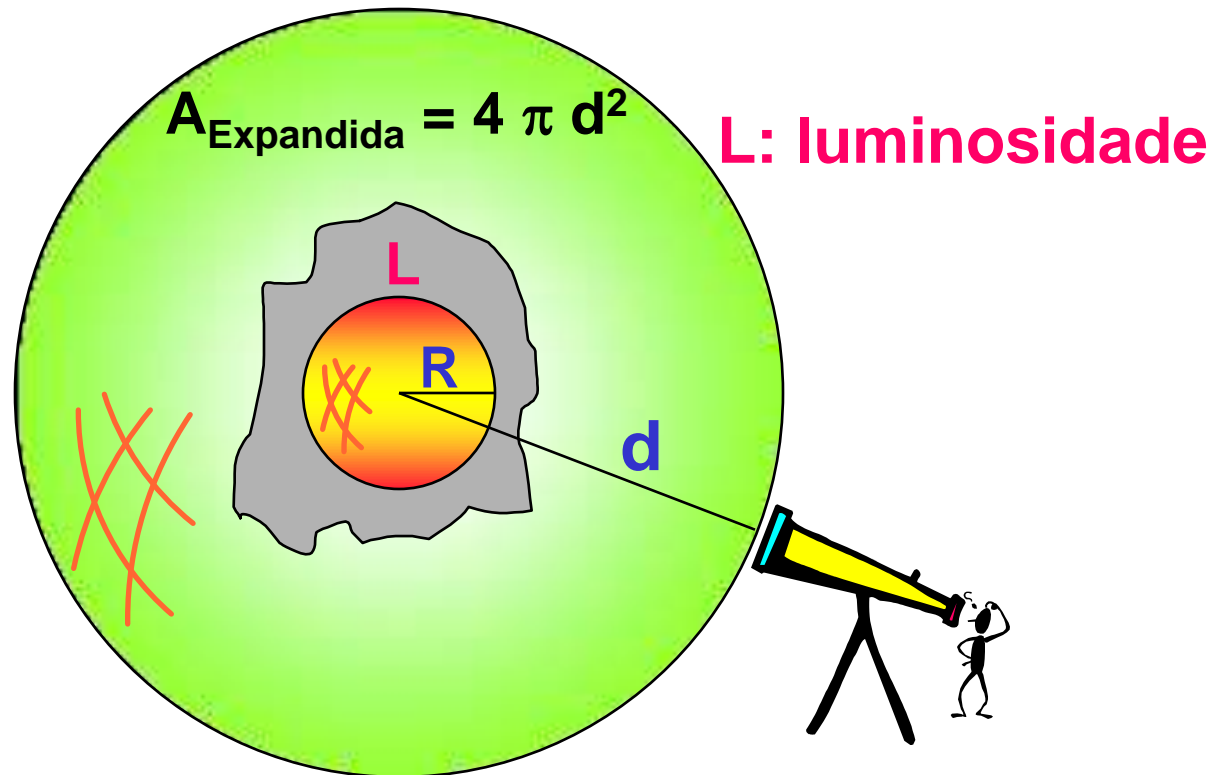


$$A_{\text{Superficial}} = 4 \pi R^2$$

$$F_R = L / (4 \pi R^2)$$

Fluxo Solar à distância d

É a potência medida por unidade de área a uma distância d do centro do Sol.



$$F = F_d = L / (4\pi d^2)$$

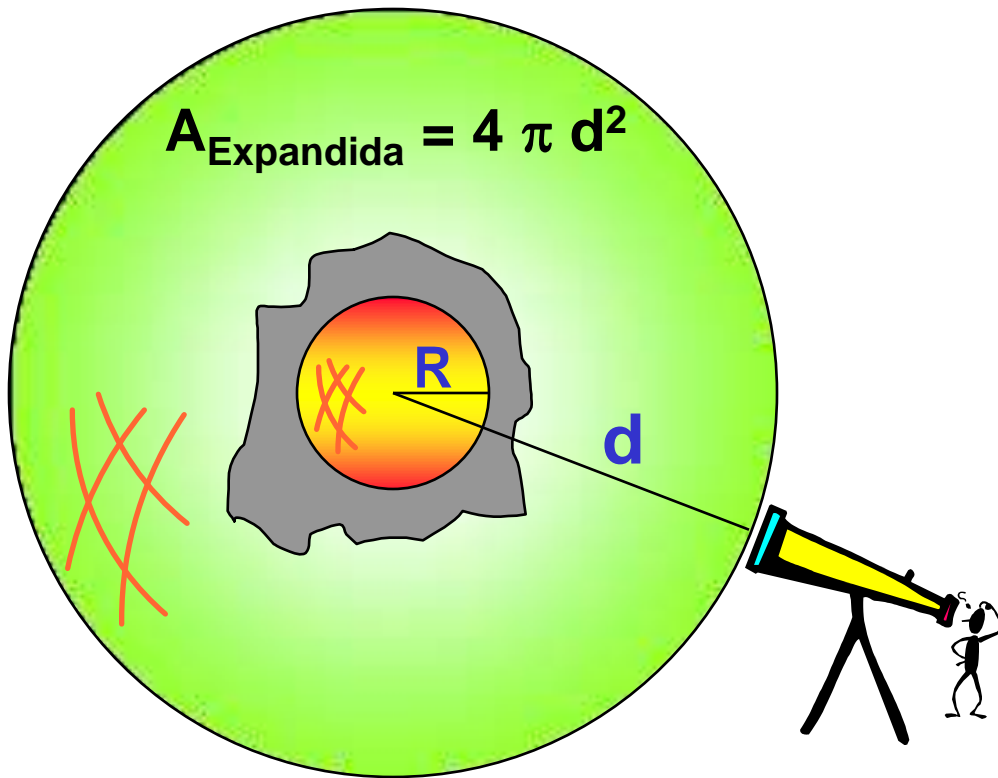
Variação do Fluxo em função da distância d

$$F_d = L / (4\pi d^2)$$

$$F_R = L / (4\pi R^2)$$

$$F_d / F_R = R^2 / d^2$$

$$F_d \cdot d^2 = F_R \cdot R^2$$



Aproximando uma estrela por um corpo negro, $I_\lambda = B_\lambda$

Ou seja, o fluxo emitido na superfície da estrela (raio R): $F_\lambda = \pi B_\lambda$

Então, o fluxo f_λ a uma distância d :

$$f_\lambda = (R/d)^2 F_\lambda = (R/d)^2 \pi B_\lambda$$

Exemplo.

Fluxo emitido na superfície do Sol (5777K):

$$F_{\lambda} = \pi B_{\lambda}$$

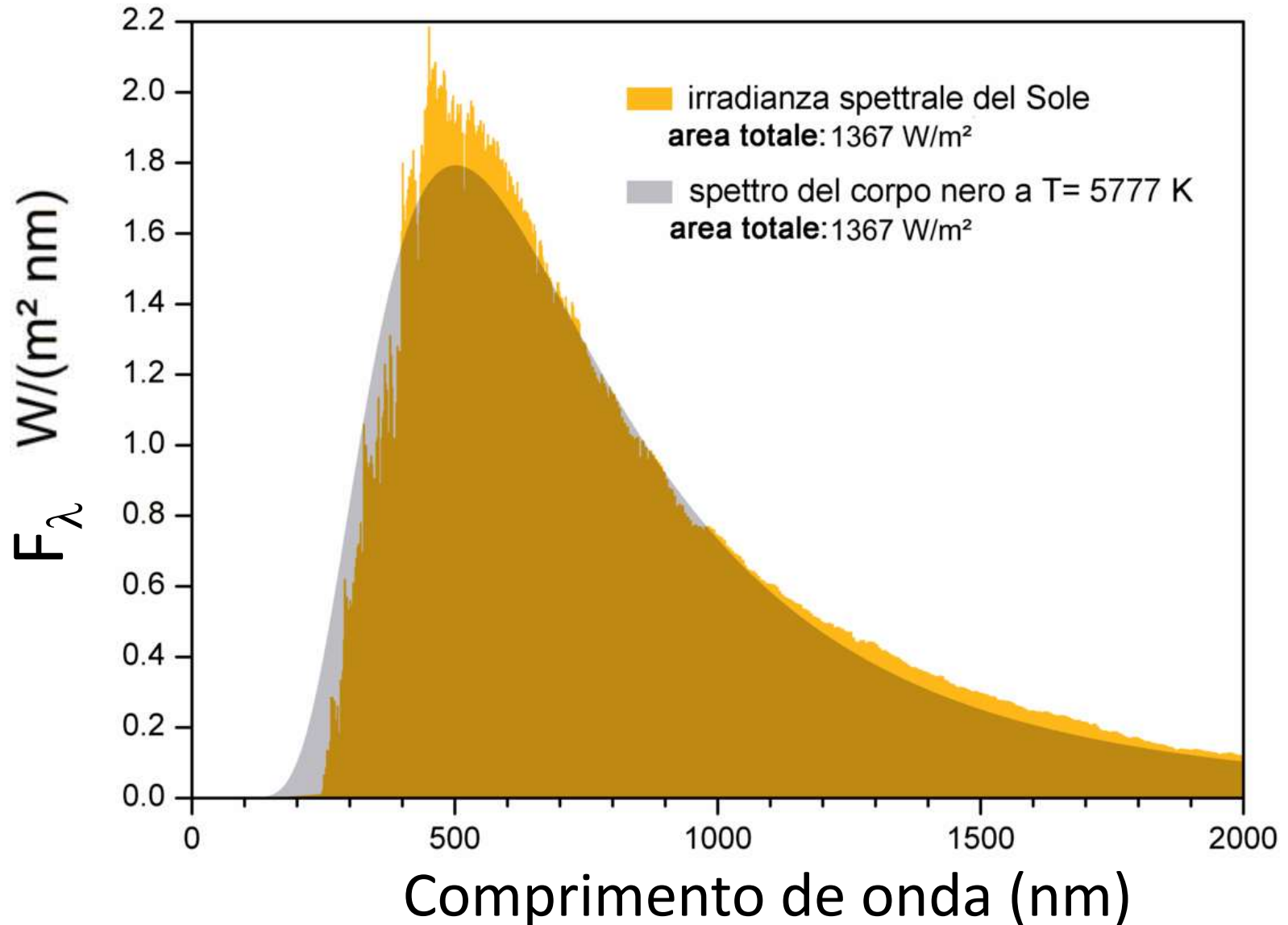
$$B_{\lambda}(T) = \frac{2hc^2}{\lambda^5} \frac{1}{e^{(hc/\lambda kT)} - 1}$$

*Fluxo na
superfície
do Sol*

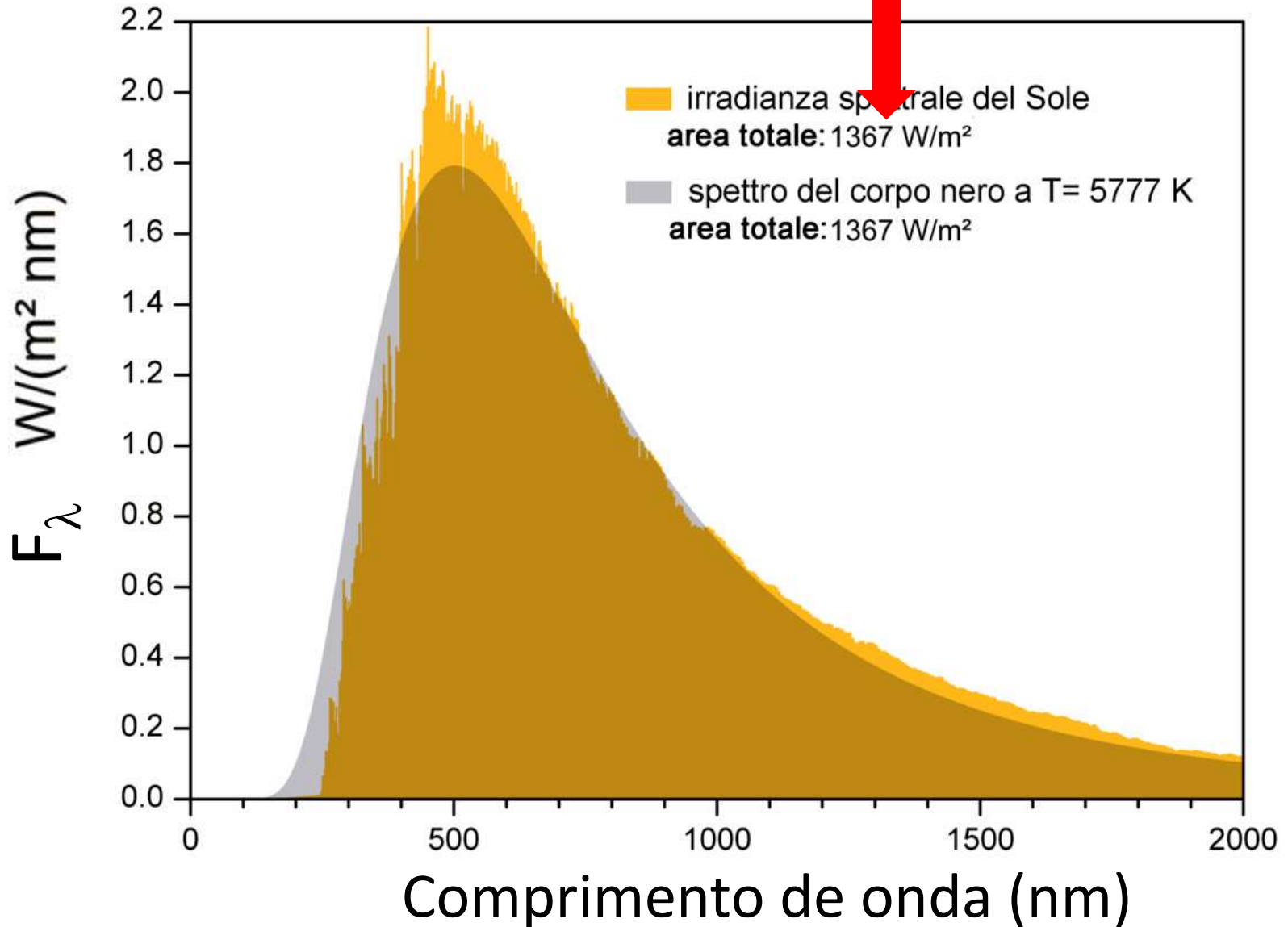
*Fluxo a 1 U.A.
(irradiância espectral)*

Lambda[Å]	$\pi * B_{\lambda}$ [erg/(cm ² .s.Å)]	Sun 1UA [erg/(cm ² .s.Å)]	Sun 1UA [Watts / (m ² .nm)]
3660	6323208,5	1,36E+02	1,361
4380	7902337,7	1,70E+02	1,701
5450	8147305,8	1,75E+02	1,754

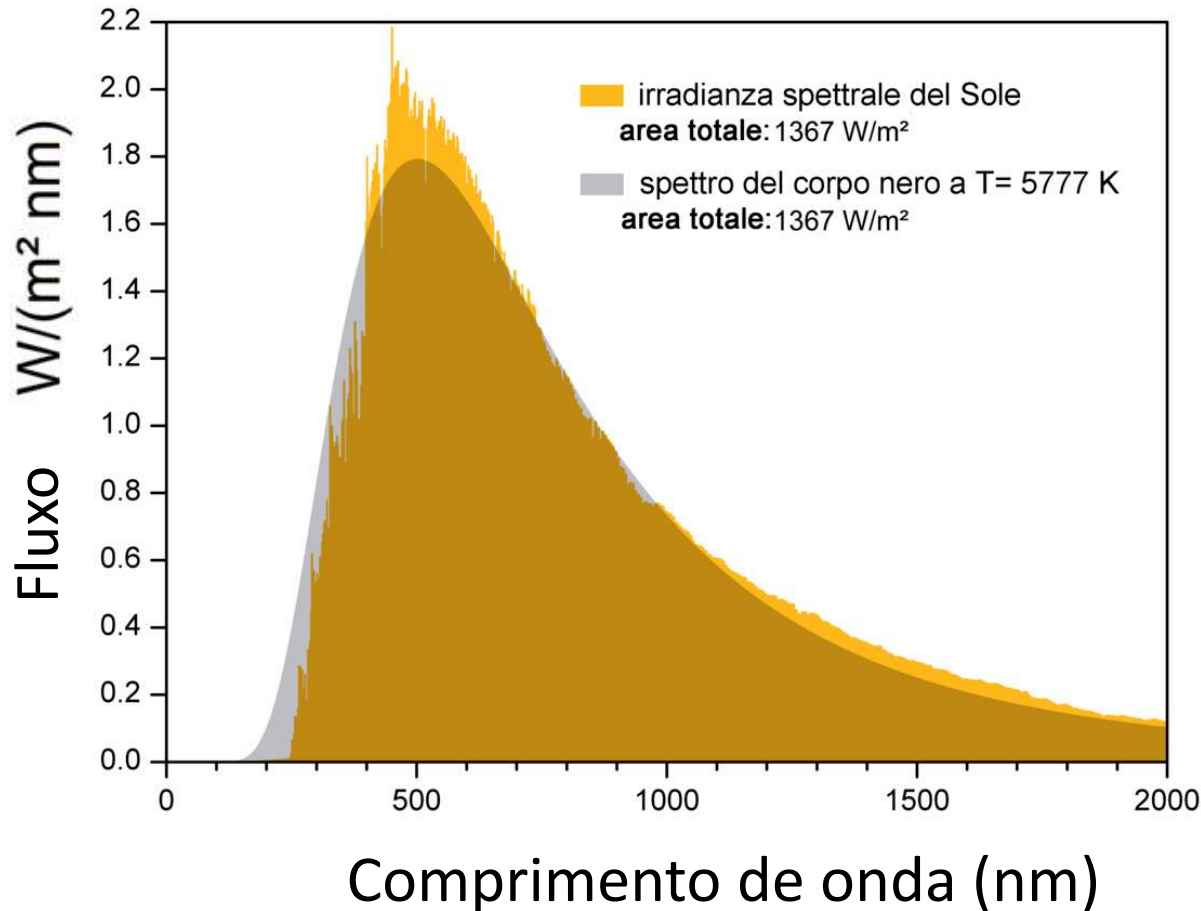
Fluxo do Sol a 1 U.A. (irradiância espectral)



Flusso totale a 1 U.A. (costante solar)



Temperatura efetiva (T_{eff}): a temperatura correspondente a um corpo negro com o mesmo fluxo total F (na superficie da estrela)



$$F = \sigma T_{\text{eff}}^4$$

**Lei de Stefan–
Boltzmann para
um corpo negro**

Fluxo da estrela 56 Ari

A&A 509, A28 (2010)

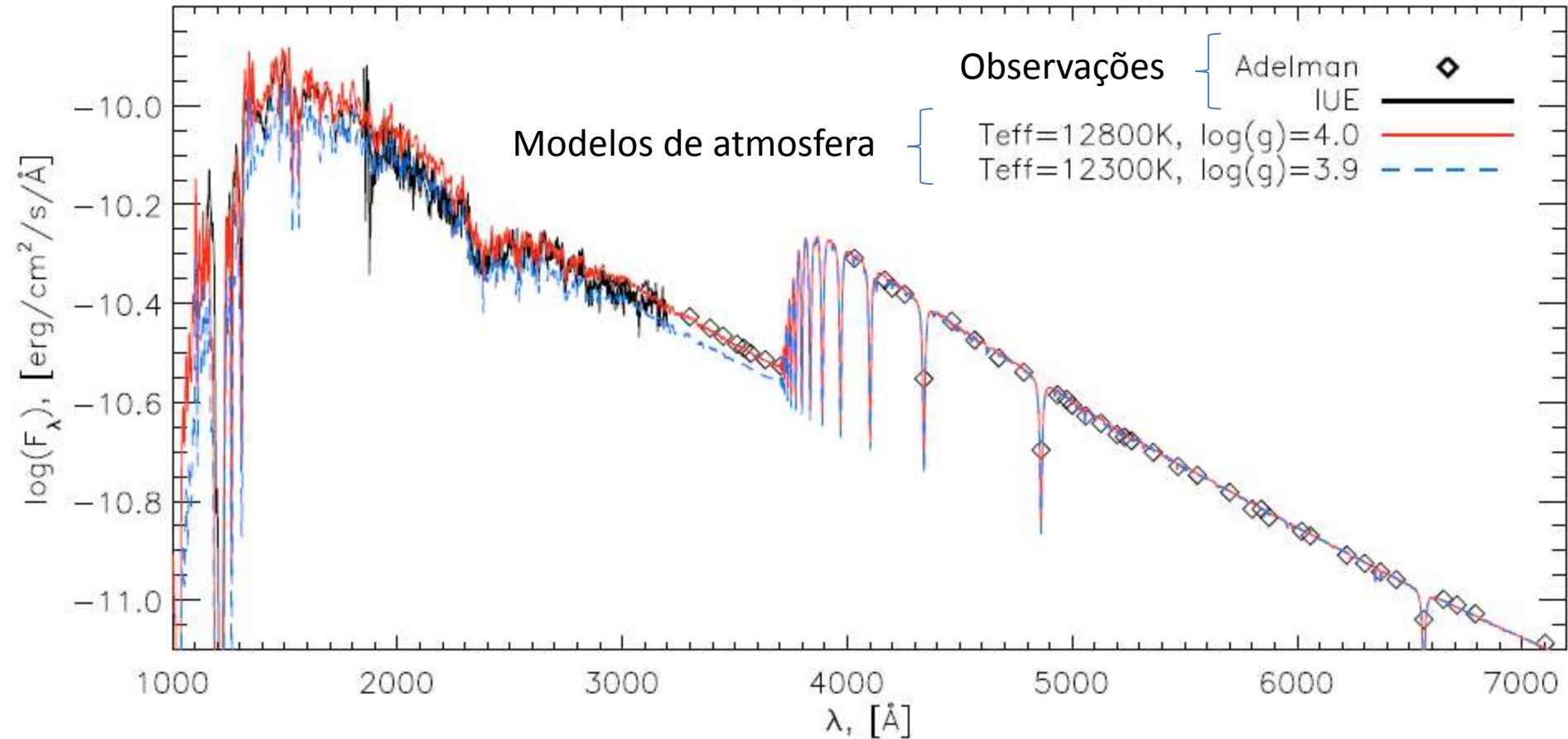


Fig. 1. Comparison of the observed and computed spectral energy distributions of 56 Ari. Theoretical models correspond to $T_{\text{eff}} = 12\,300\text{ K}$, $\log(g) = 3.9$ and $T_{\text{eff}} = 12\,800\text{ K}$, $\log(g) = 4.0$. The model fluxes have been convolved with an $FWHM = 10\text{ \AA}$ Gaussian kernel for a better view.

D. Shulyak¹, O. Kochukhov², G. Valyavin³, B.-C. Lee⁴, G. Galazutdinov⁵, K.-M. Kim⁴,
I. Han⁴, and T. Burlakova⁶

Polarização

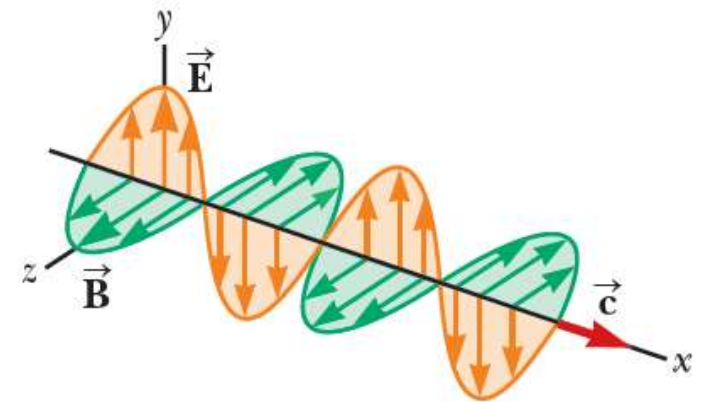
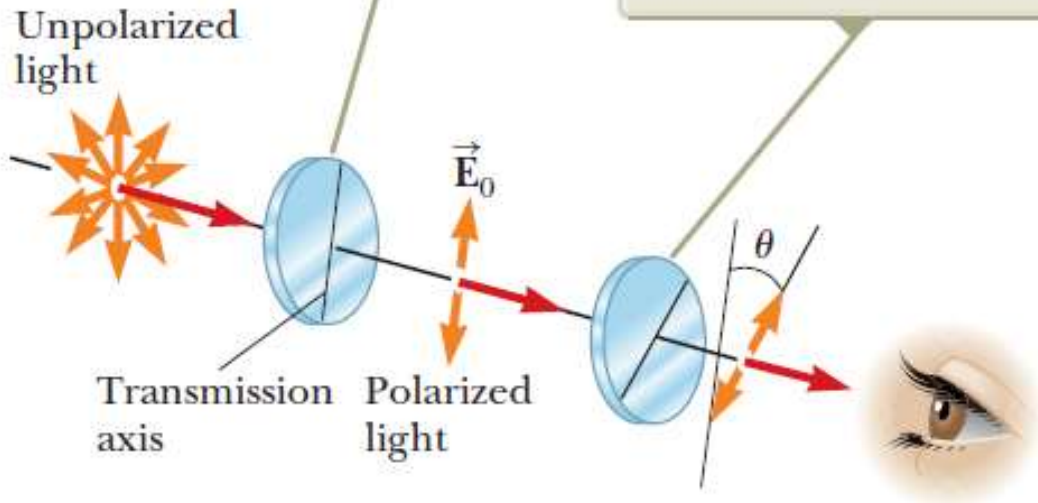


1669: Bartholinus discovers double refraction in calcite

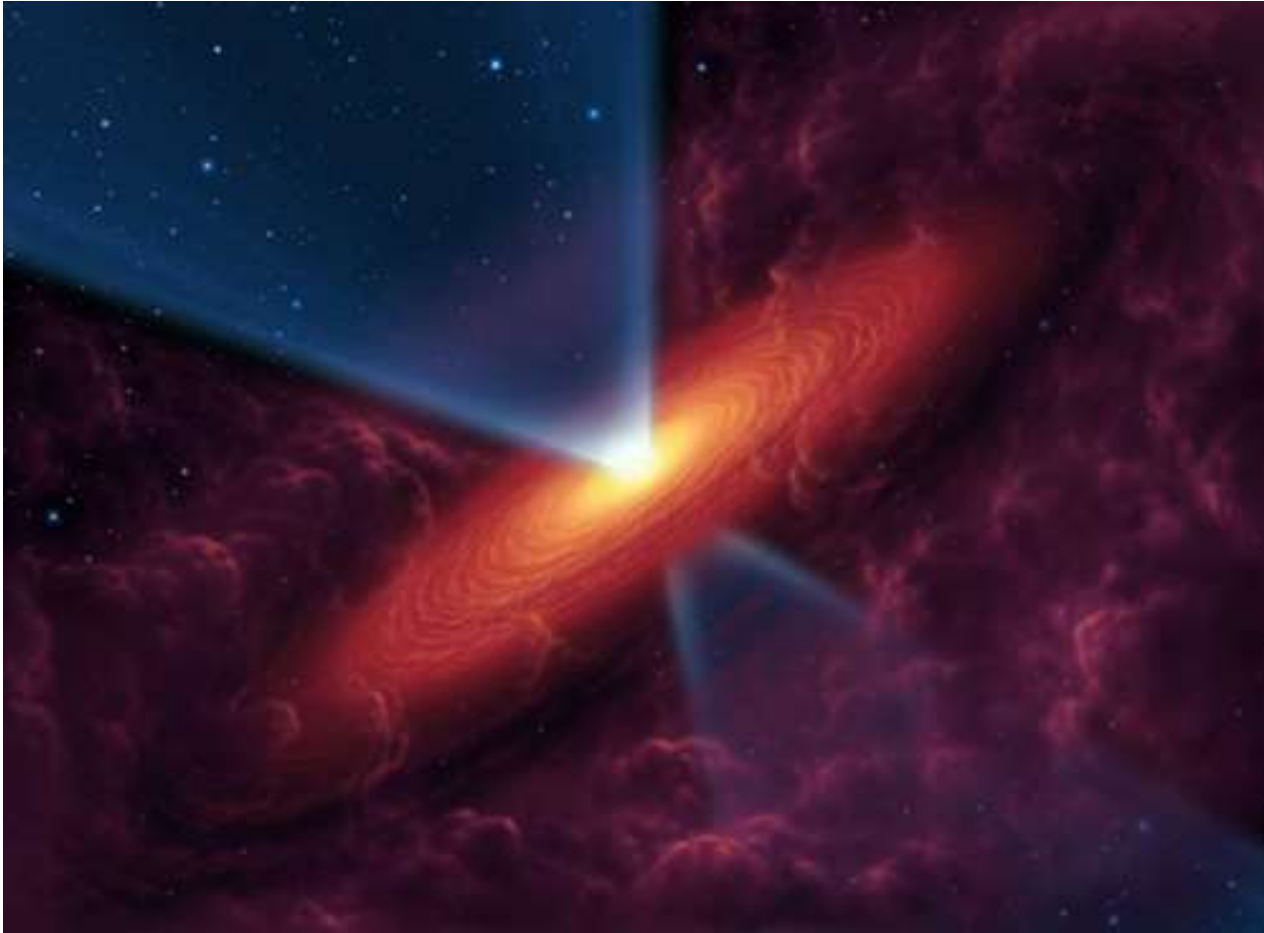


The polarizer polarizes the incident light along its transmission axis.

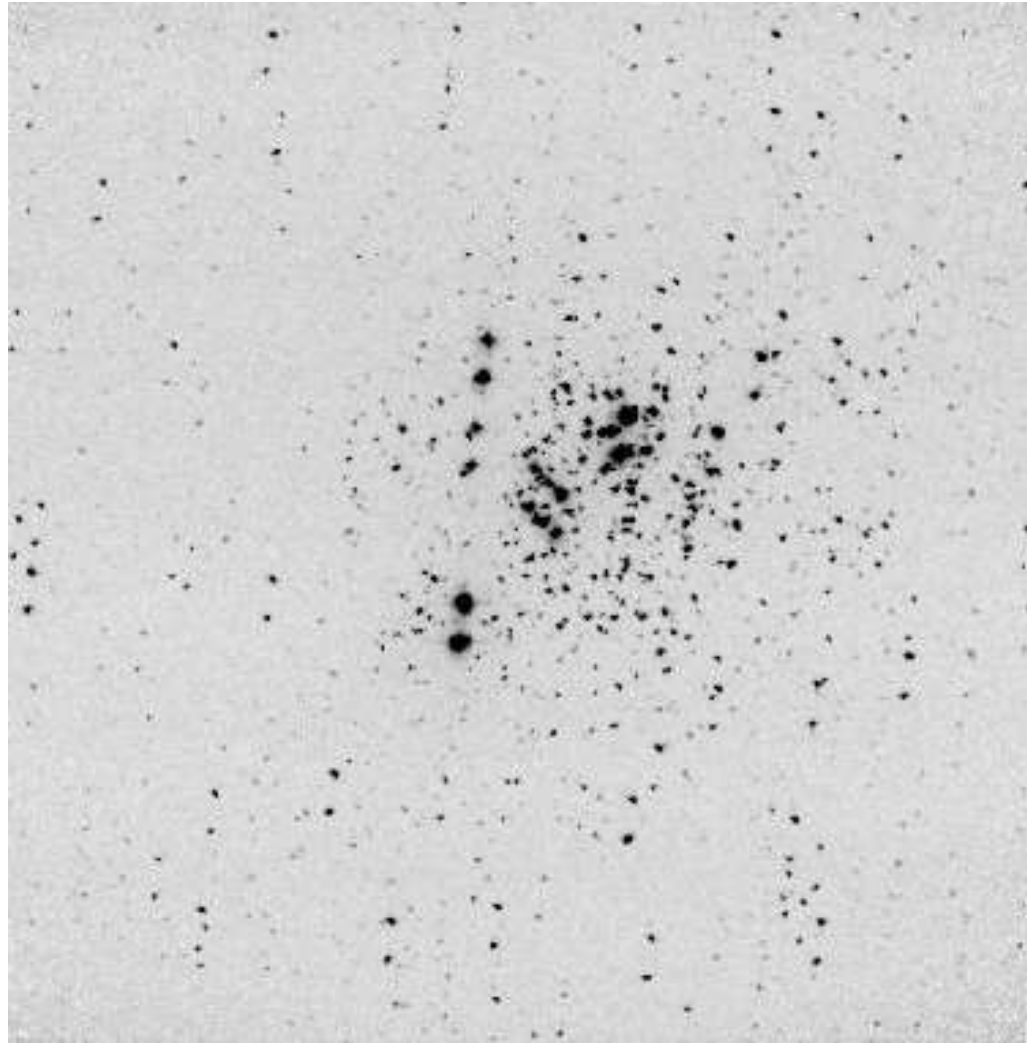
The analyzer allows the component of the light parallel to its axis to pass through.



Polarização devida a envoltórios ou discos



Aglomerado NGC 4755 observado com o polarímetro do IAG



Non-photon astronomy

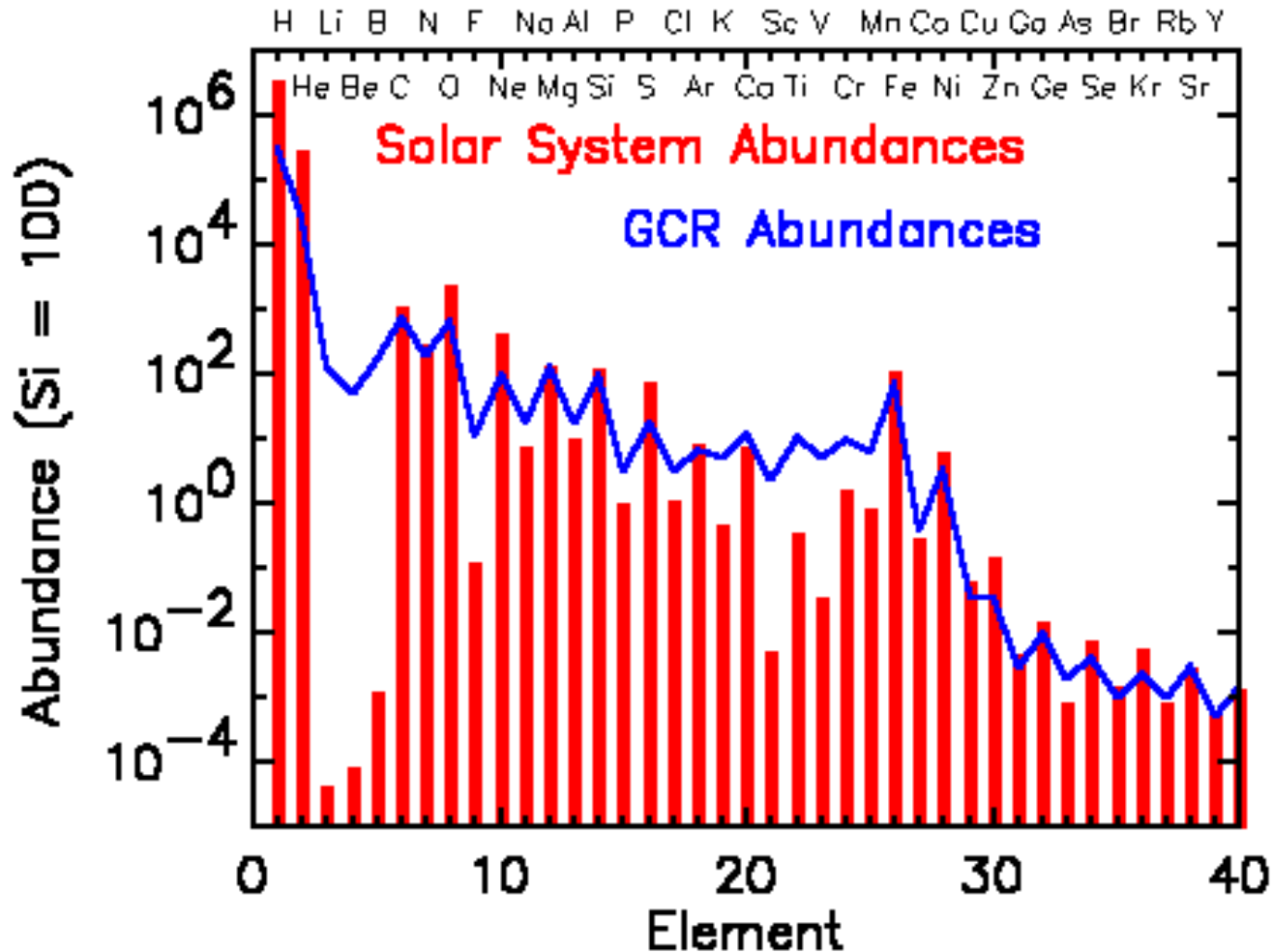
- **Cosmic rays**
- **Solar system bodies + pre-solar dust grains**
- **Neutrinos**
- **Gravitational waves**

Cosmic rays

- Matter (mostly p^+ and heavier atomic nuclei) at high energies $E = \frac{mc^2}{\sqrt{1 - v^2/c^2}}$
- Galactic CR change direction due to $F = q(\mathbf{v} \times \mathbf{B})$
- Some CR are very energetic (SN, AGN?)

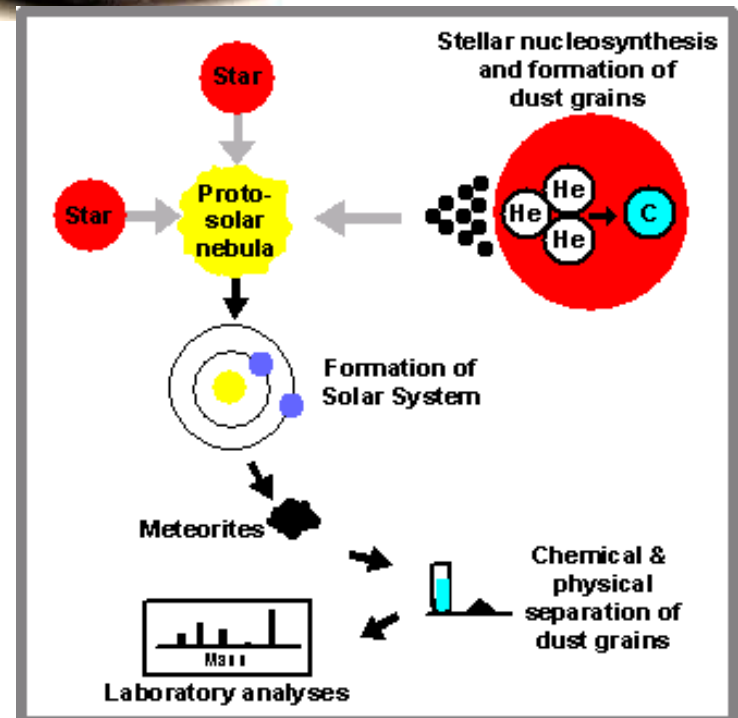
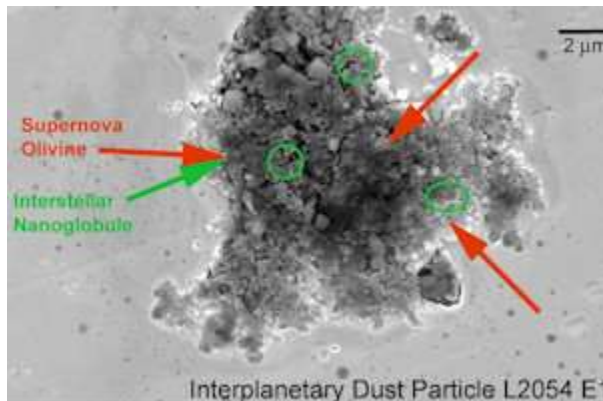
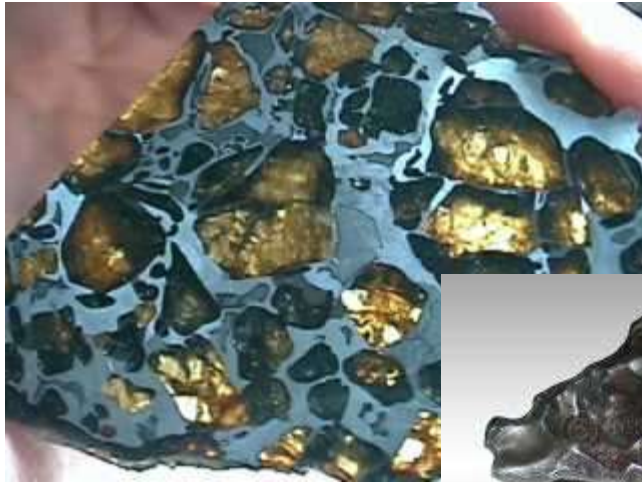


Cosmic rays composition



- Li, Be, B are originated in cosmic rays !!!

Solar system bodies (e.g. Meteorites) and pre-solar dust grains



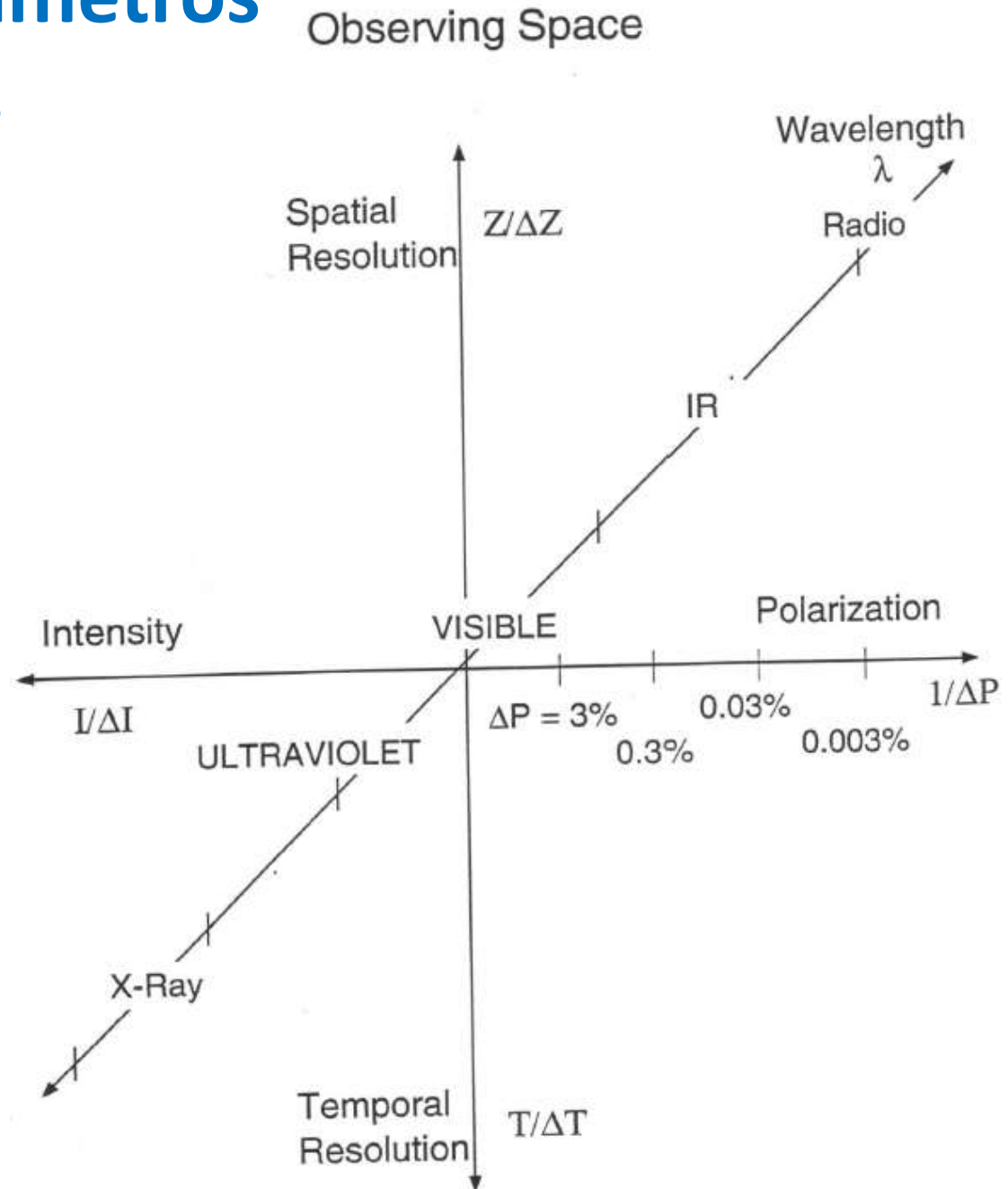
Aspectos das medidas

Fluxo, intensidade:

posição	movimento da fonte <i>(e.g. proper motions, planets, parallax)</i>
fotometria	absoluta e diferencial magnitudes <i>(e.g. temperatures, stellar Populations, photometric redshift)</i>
variabilidade temporal	explosões curvas de luz <i>(e.g., variable stars, microlensing, SN)</i>
resolução espacial	tamanho do instrumento comprimento de onda efeitos atmosféricos interferometria <i>(black hole @ Galactic center)</i>
cobertura/resolução espectral	atmosfera instrumentos <i>(aim is to achieve maximum coverage and in some cases max spectral resolut.)</i>
polarização	Parâmetros de Stokes <i>(important to study different physical processes and geometry)</i>

Espaço de parâmetros observacionais

- Wavelength coverage
(+ spectral resolution)
- Flux or Intensity
(absolute + relative)
- Spatial Resolution
(+ absolute positions)
- Temporal Resolution
(+ time series)
- Polarization



From Nordsieck (1996)