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Extragalactic Astrophysics

L2: General Concepts Review

Outline of the course

1. **History**
2. General concepts review
3. Galaxies in our local Universe
4. Galaxies kinematics and scaling relations
5. Star formation
6. Interstellar Medium
7. Distances and redshift
8. High redshift Universe
9. Final remarks and open debate

2. General Concepts review

Starting Point

What is the observable?

photon: a quantum of electromagnetic radiation.

from Greek phōs, phōt- ‘light’. Used for the first time in December 1926 by Gilbert N. Lewis.

electromagnetic radiation: waves of the electromagnetic field propagating through space, carrying electromagnetic radiant energy.

The energy of a photon is related to its frequency:

$$E = h\nu$$

ν = frequency

h = Planck’s Constant

$$h\nu = \frac{hc}{\lambda}$$

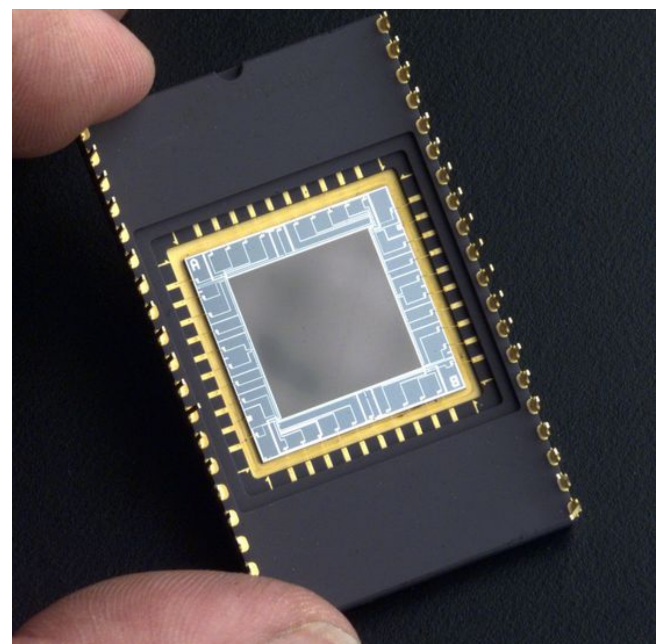
What is the observable?

Since the observable is the photon the scientific quests are:

1. To count the number of photons: aka **flux**
2. Measure the frequency of the photon received: aka **photometry** (or spectroscopy, depending on the technique used)
3. Understand the physical conditions that produced the observed photons in terms of frequency and flux: aka **actual physics**

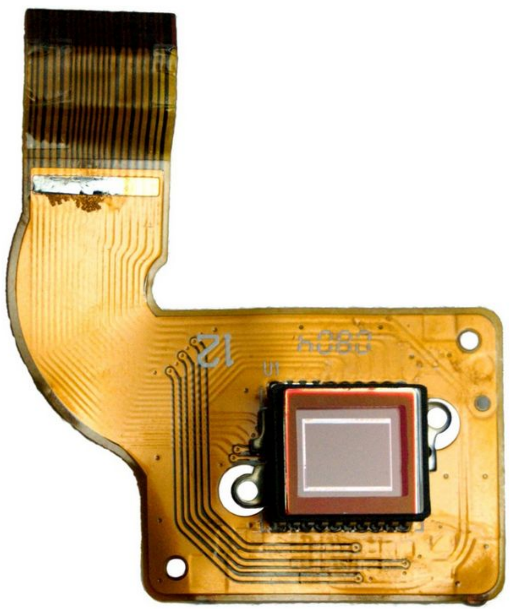
Count the number of photons

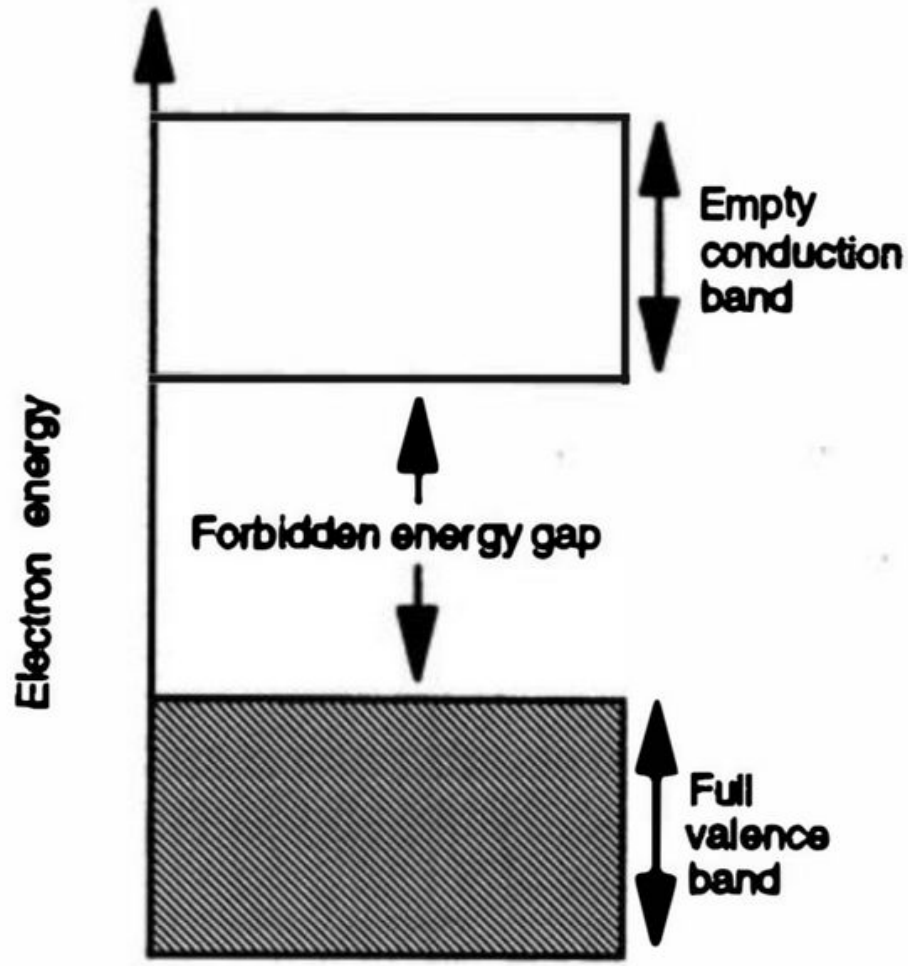
According to the wavelengths observed the method used to count the photons change. Here we focus in a device widely used in the range between Ultraviolet and Optical: the CCD.



Count the number of photons

MOS detector



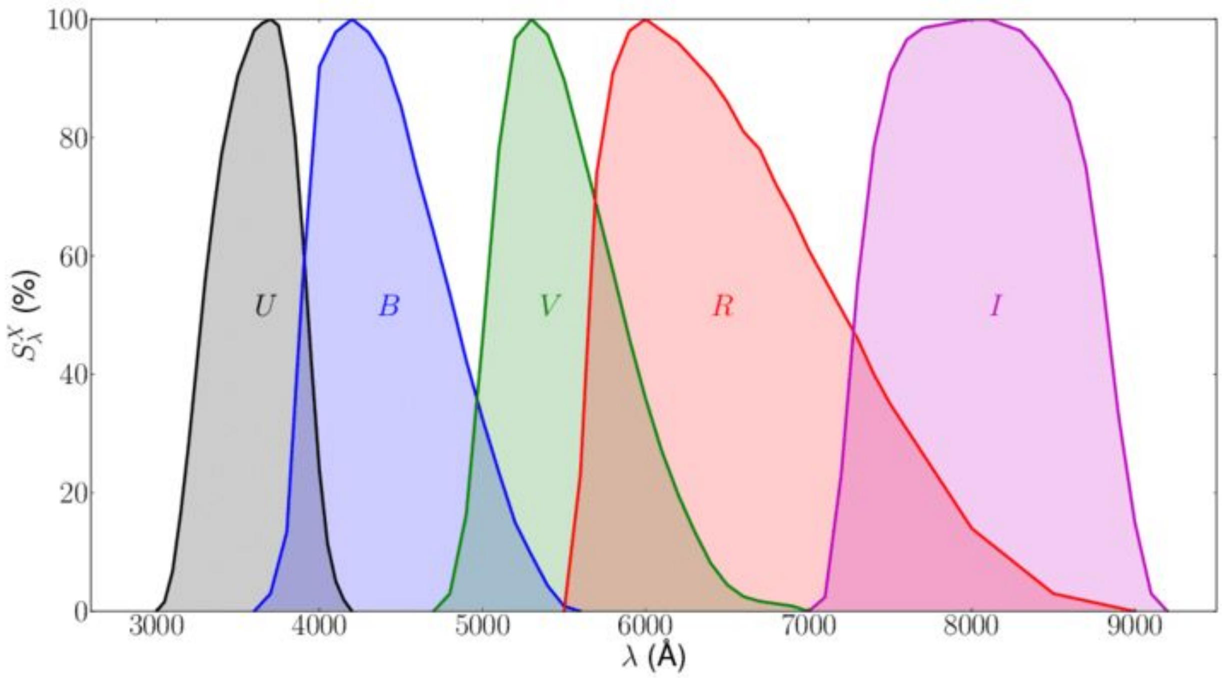


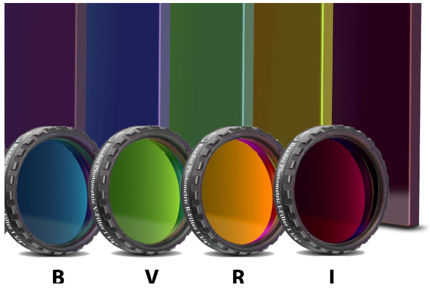
Semiconductor energy bands at low temperature.

Measure the frequency of the photon received

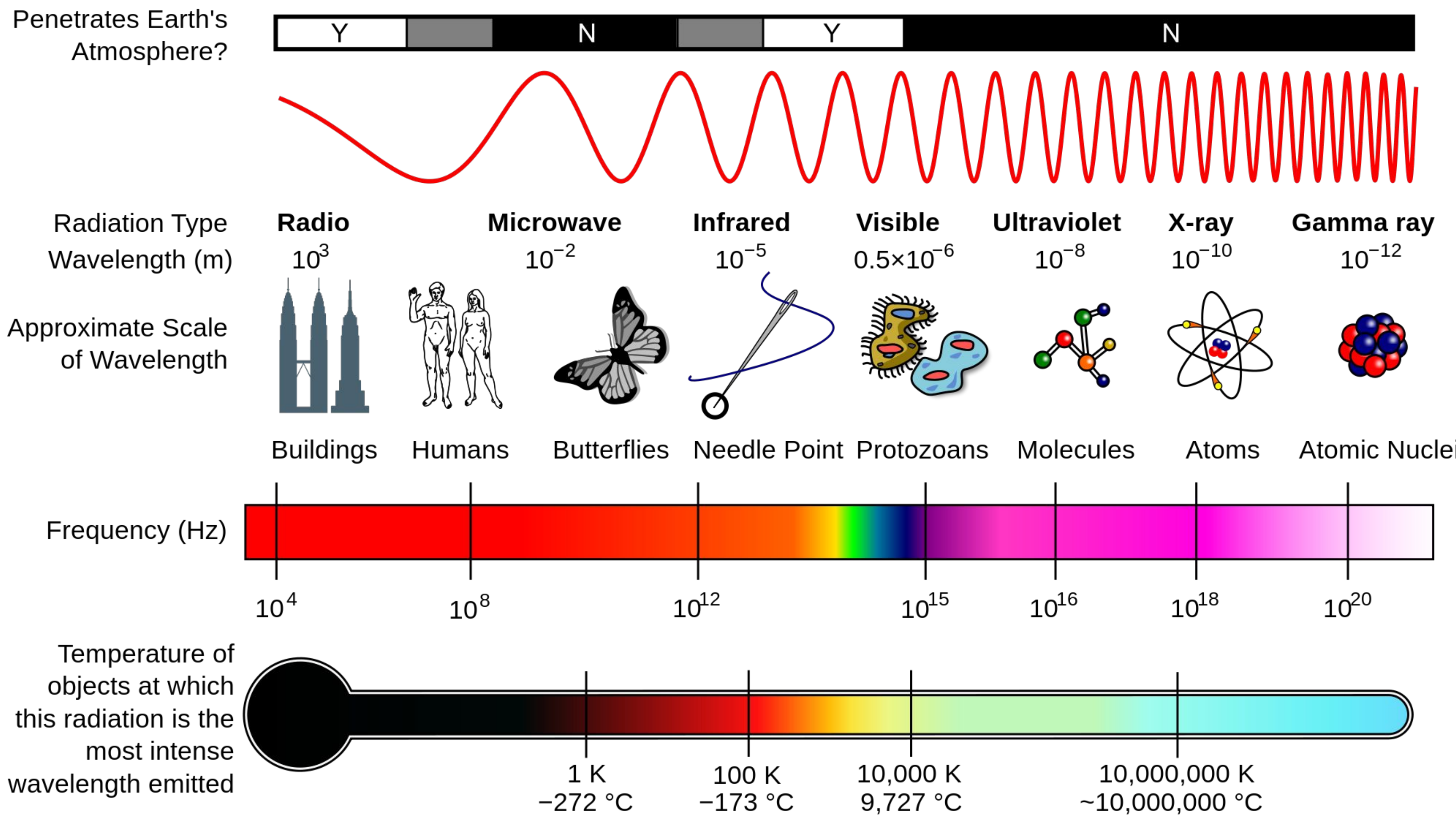
The energy of photons receives by CCDs spans a wide range of values. This means that the sentence ‘one CCD to rule them all’ is not applicable in this case.

We need a photometric filter



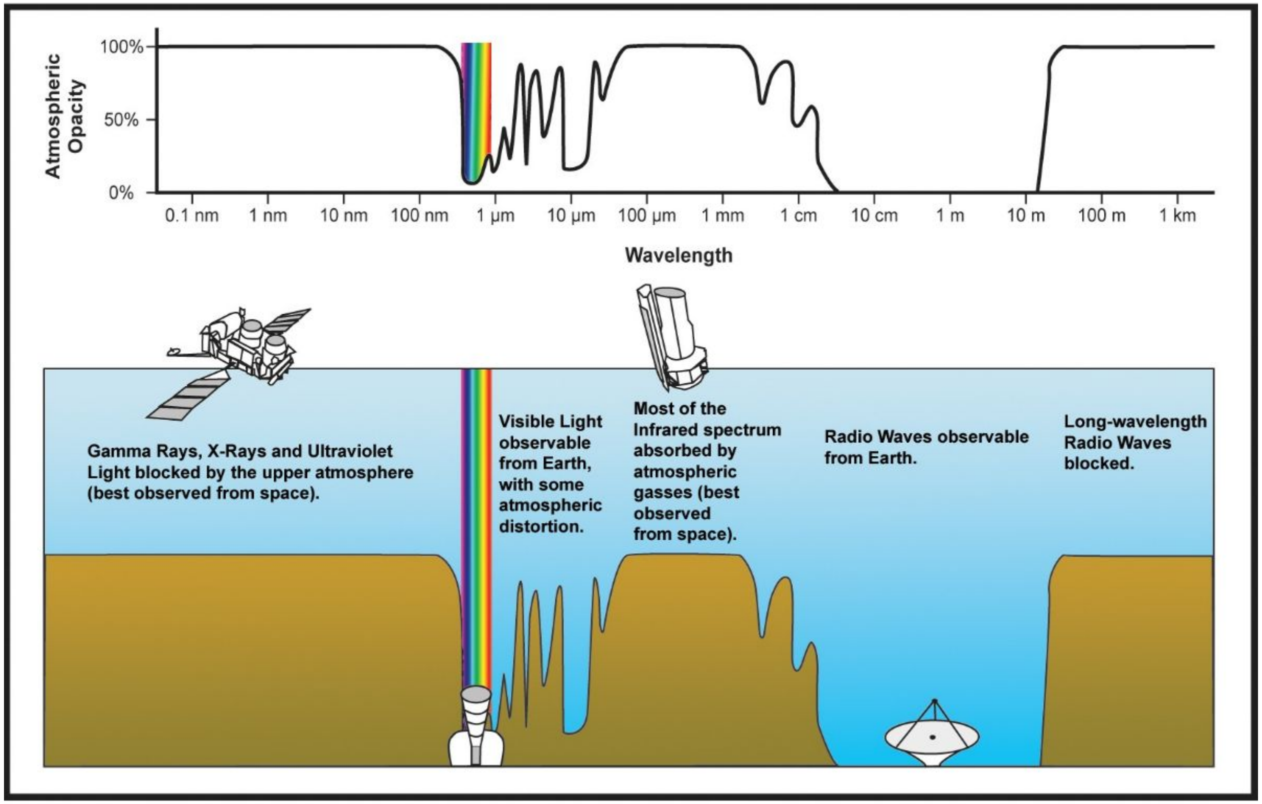


Electromagnetic spectrum



Electromagnetic spectrum

- Optical, Near infrared (IR), and Radio are accessible
- Other wavelengths require satellites
    1) Absorption scattering
    2) Airglow (recombination of atoms ionized during the day)
    3) Thermal emission



Atmospheric absorption percentages throughout the electromagnetic spectrum. Image Credit: NASA

Counting photons

Luminosity: energy emitted per unit of time. Unit:

CGS = erg/s - SI = Joule/s = Watt

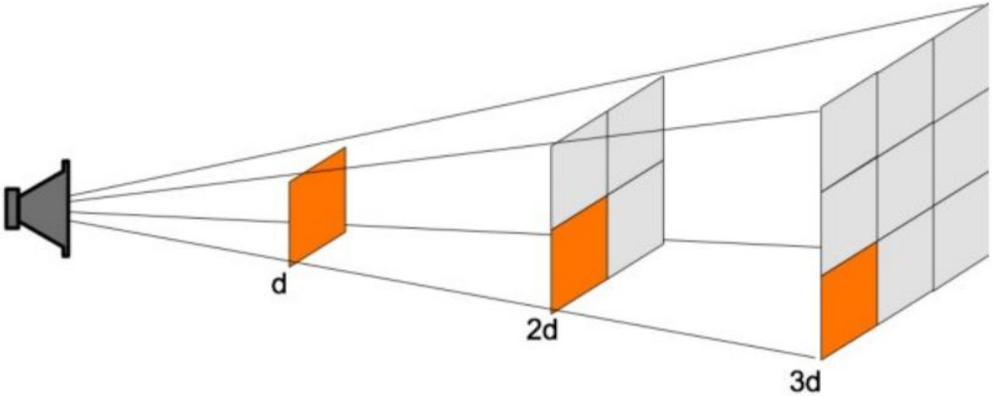
Astronomy: Solar Luminosity – $L_{sol} = 3.83 \times 10^{26}$ W

This is the amount of energy that is emitted isotropically in all directions.

Flux: energy received by the observer per unit area and seconds. Unit: CGS = erg/s/cm^2 - SI = W/m^2

FLUX IS DISTANCE DEPENDENT, LUMINOSITY IS NOT

$$f = L / 4\pi d^2$$



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Counting photons

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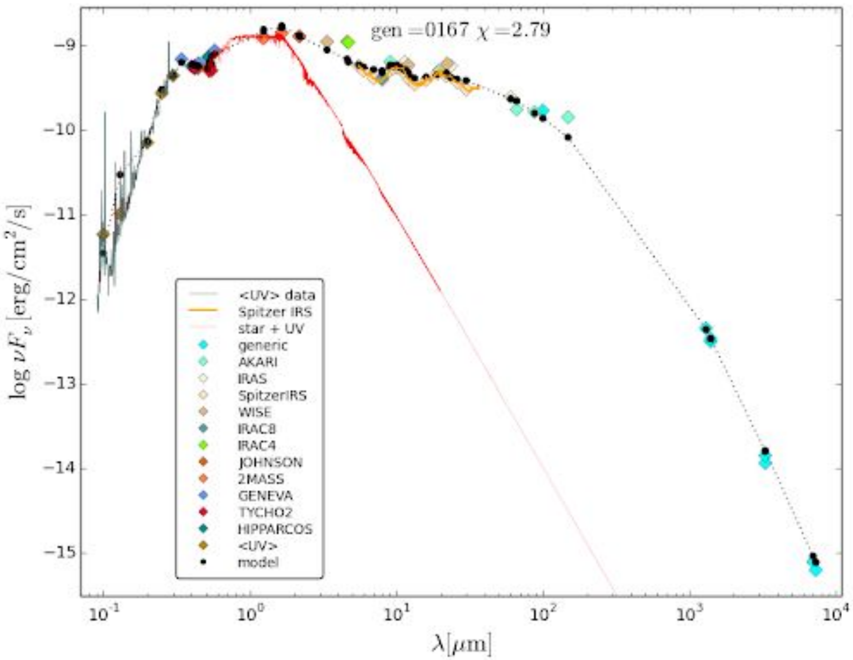
Flux density: energy emitted per unit of time, unit area, at a specific frequency. Unit: $[F_\nu] = [W/m^2/Hz]$

Flux: since flux is energy emitted per unit of time and unit area, to convert flux density into flux is sufficient to multiply for the frequency the measured flux density, at a specific frequency.

$$f = \nu f_\nu \quad \text{or} \quad f = \lambda f_\lambda$$



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Spectral Energy Distribution

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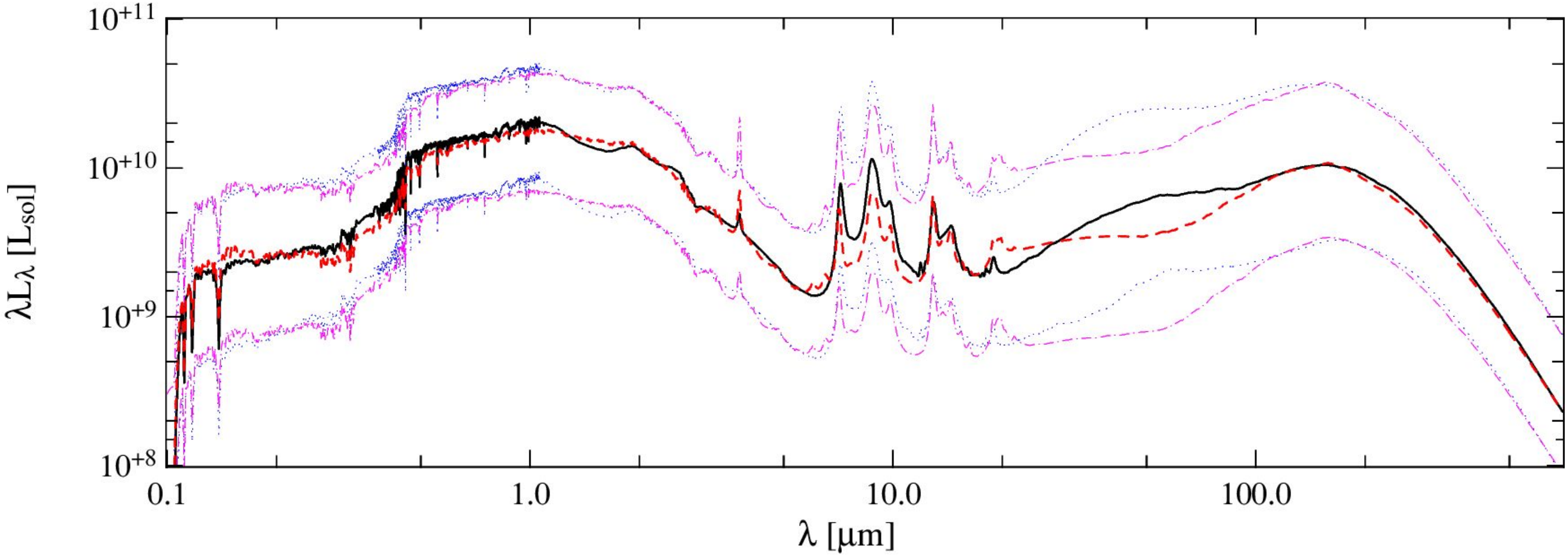
The energy emitted from a source as a function of wavelength/frequency



Magnitudes

The magnitude measures the apparent brightness of astronomical objects

If two objects emit fluxes f_1 and f_2, than their magnitude m_1 and m_2 is:

$$m_1 – m_2 = -2.5 \log_{10}(f_1/f_2)$$

We can write also (with a little bit of algebra):

$$f_1/f_2 = 10^{-0.4(m_1 - m_2)}$$

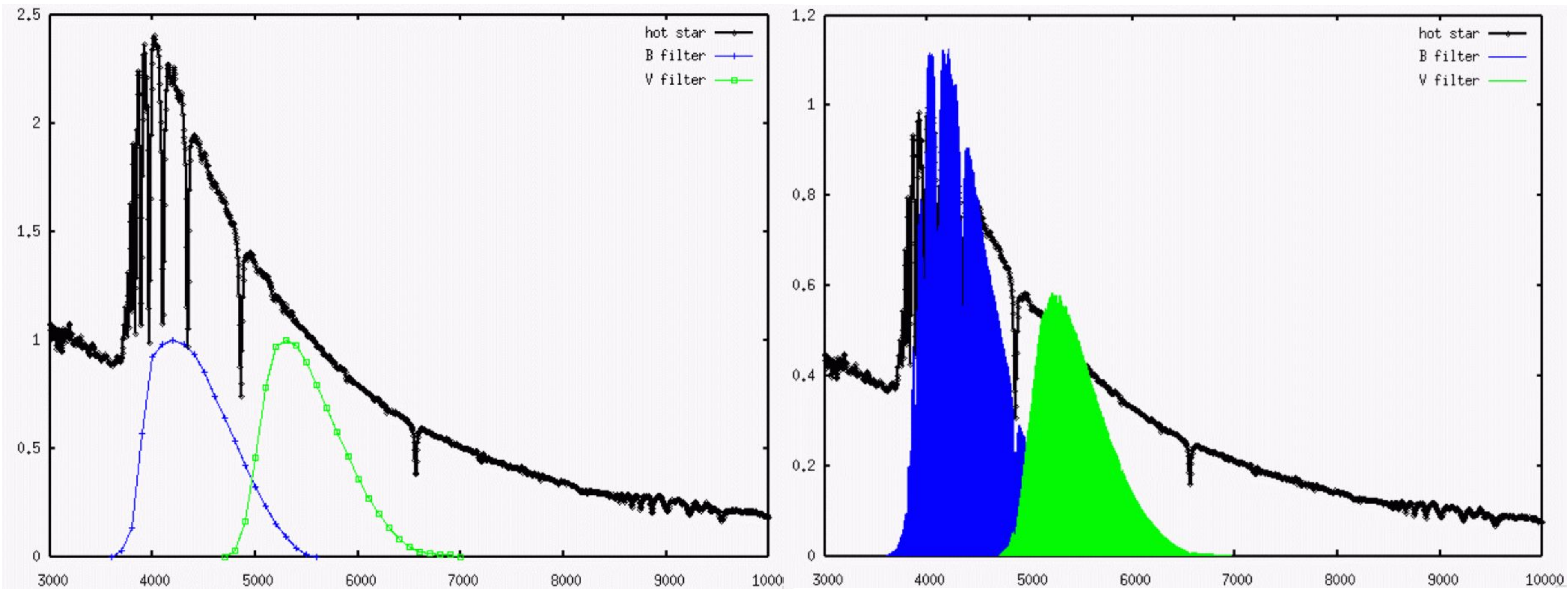
NOTE

- 1 mag corresponds to $f_1/f_2 = 2.5$
- 5 mag corresponds to $f_1/f_2 = 100$
- the lower the magnitude, the brighter the object

Colors

The difference in mags measured in 2 different filters.

$$A-B = -2.5 \log_{10}(f_A/f_B) + Const$$



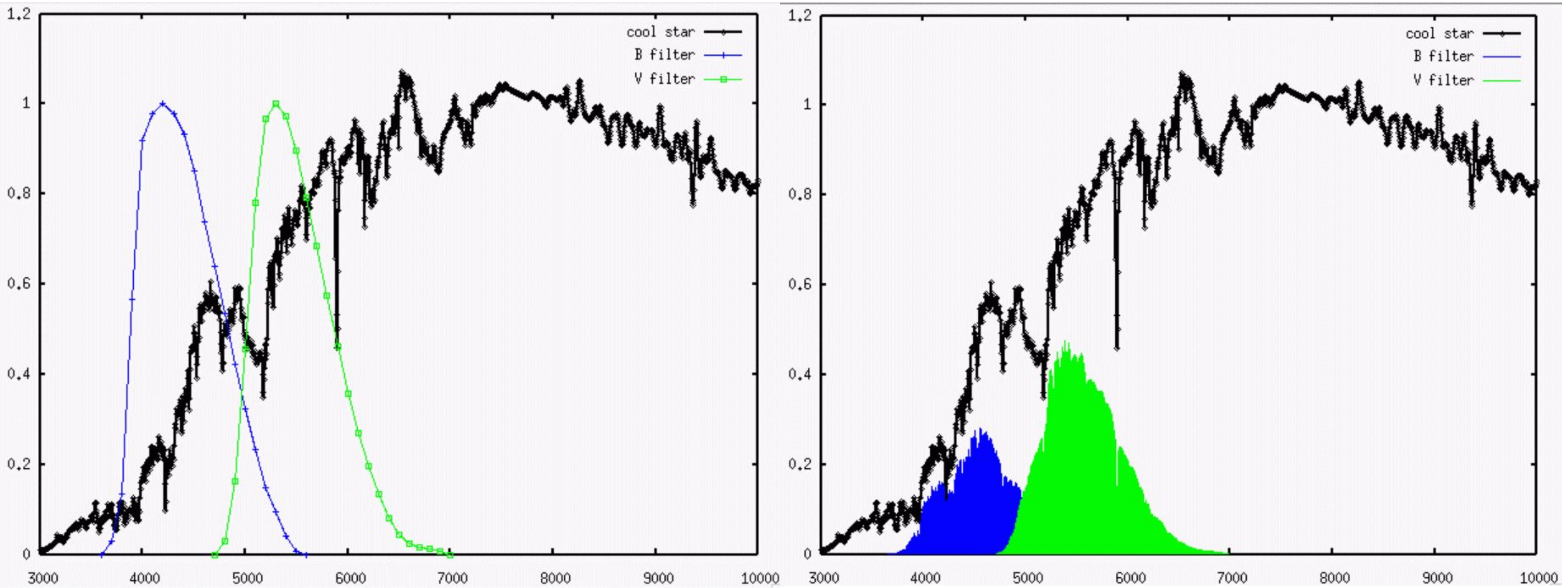
If we are considering Vega B-V = 0

If B-V < 0 the star considered will be bluer (younger age and hotter temperature)

Colors

The difference in mags measured in 2 different filters.

$$A\text{-}B = -2.5 \log_{10}(f_A/f_B) + \text{Const}$$



If we are considering Vega B-V = 0

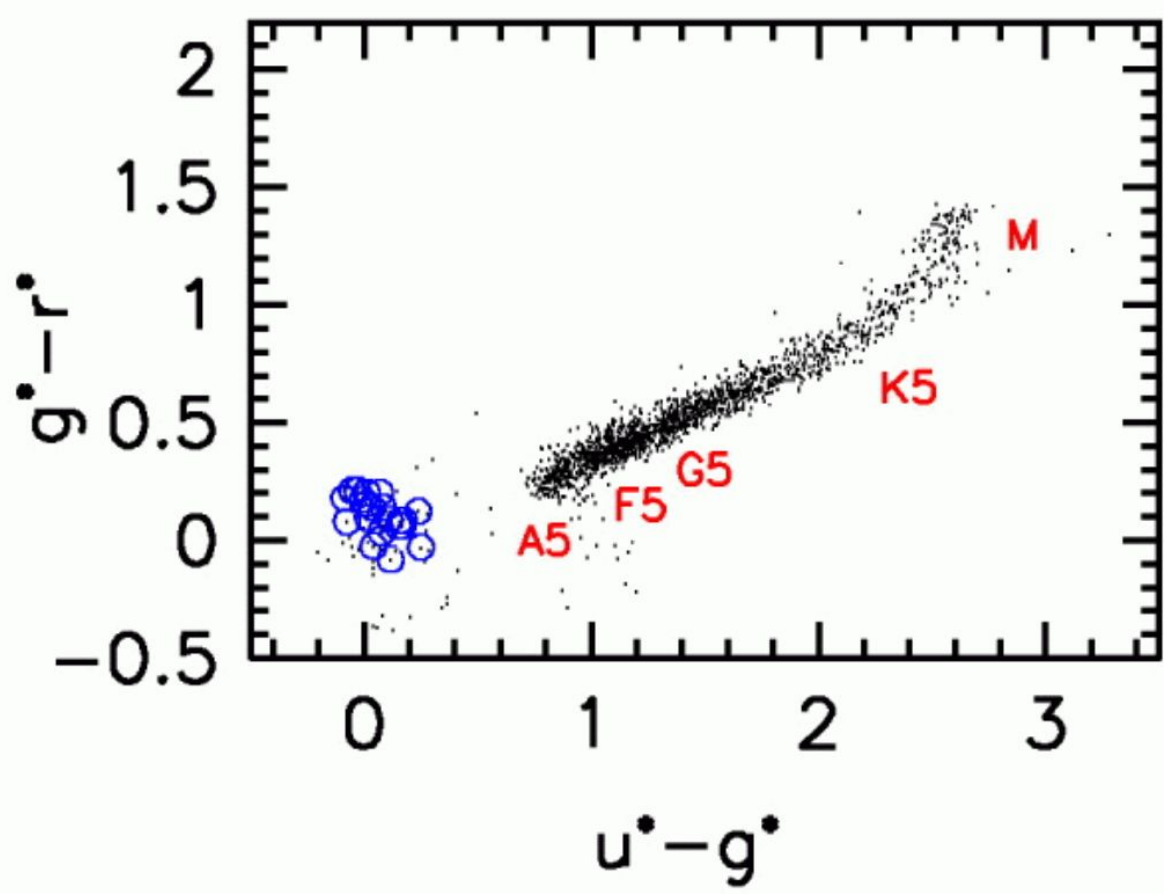
If B-V > 0 the star considered will be redder (older age and colder temperature)

Colors

The difference in mags measured in 2 different filters.

$$A\text{-}B = -2.5 \log_{10}(f_A/f_B) + \text{Const}$$

This then translate into a diagram, giving information about the evolution of the objects observed and their physical condition



Absolute Magnitude

If at a distance **D** the flux of an object is F, then at a distance **d** the flux measured will be:

$$f = (D/d)^2 F$$

Absolute Magnitude: is the apparent magnitude a source would have at a standard distance D = 10 pc:

$$M = m - 5 \log_{10}(d_{pc}) + 5$$

Galaxies bi-modality

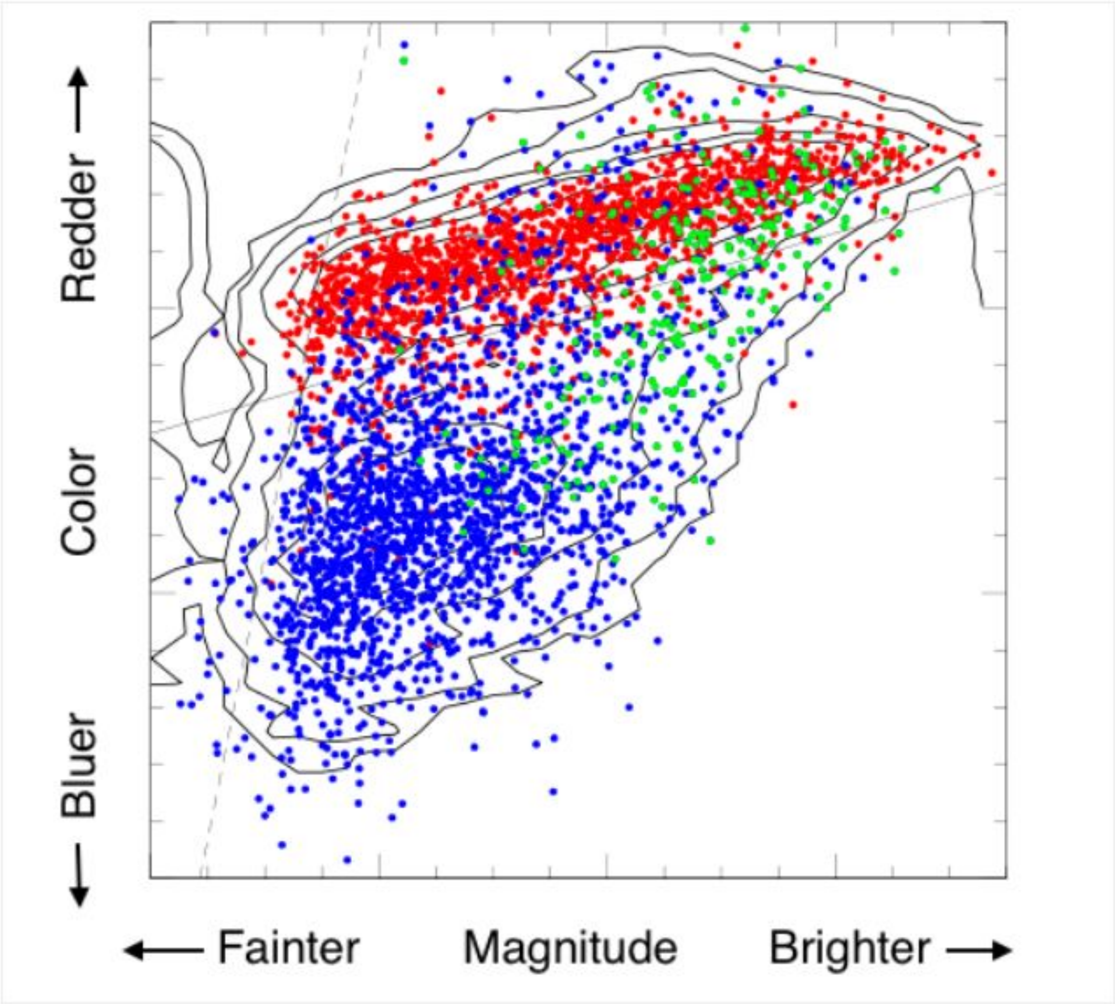
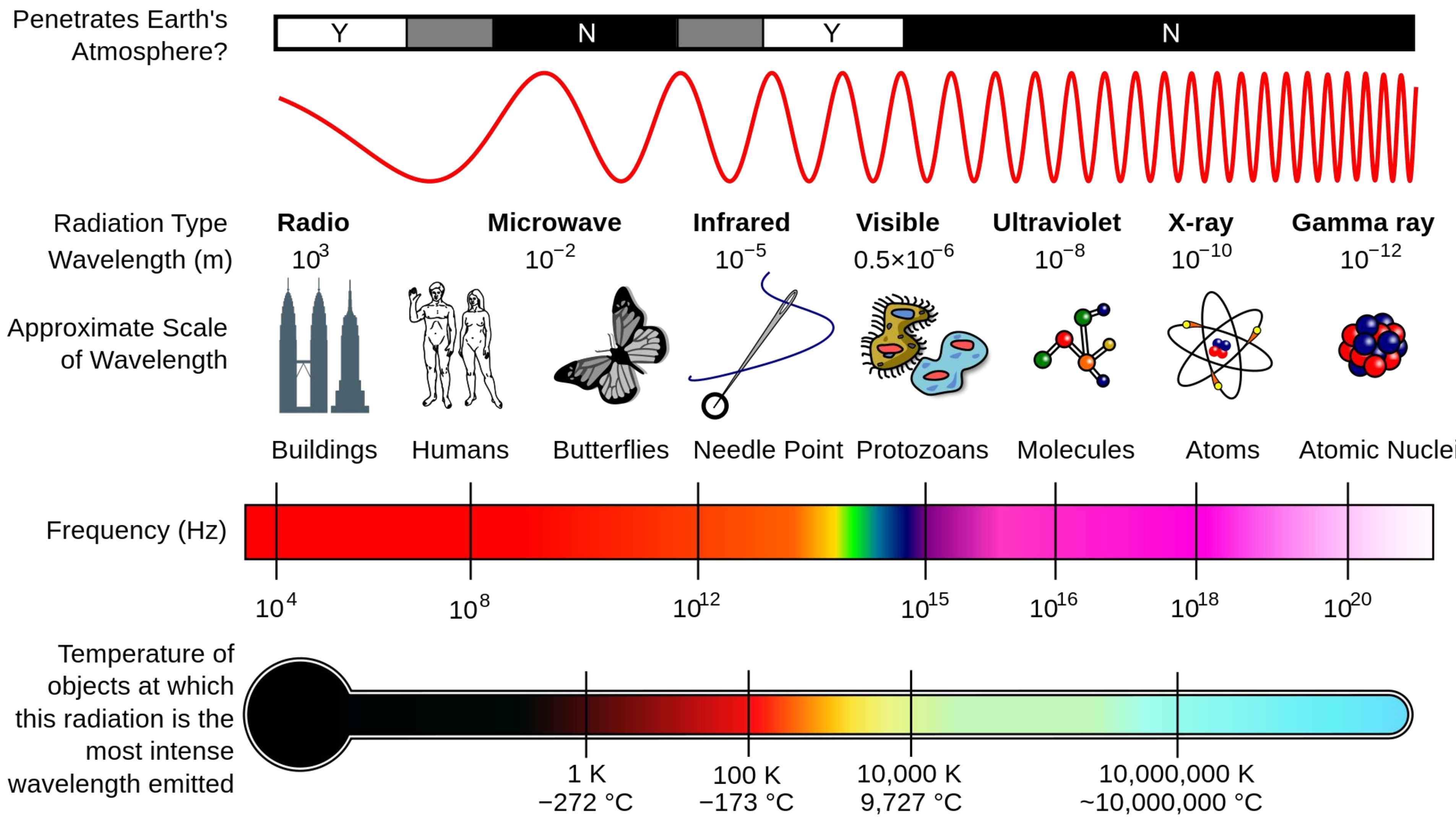


Figure 1: An example of a Color-Magnitude Diagram, using galaxies in the Sloan Great Wall (adapted from Figure 3 of Gavazzi et al. 2010). Spiral galaxies (blue points) tend to be fainter and bluer, while ellipticals (red points) lie in the relatively-tight "red sequence".

Electromagnetic spectrum



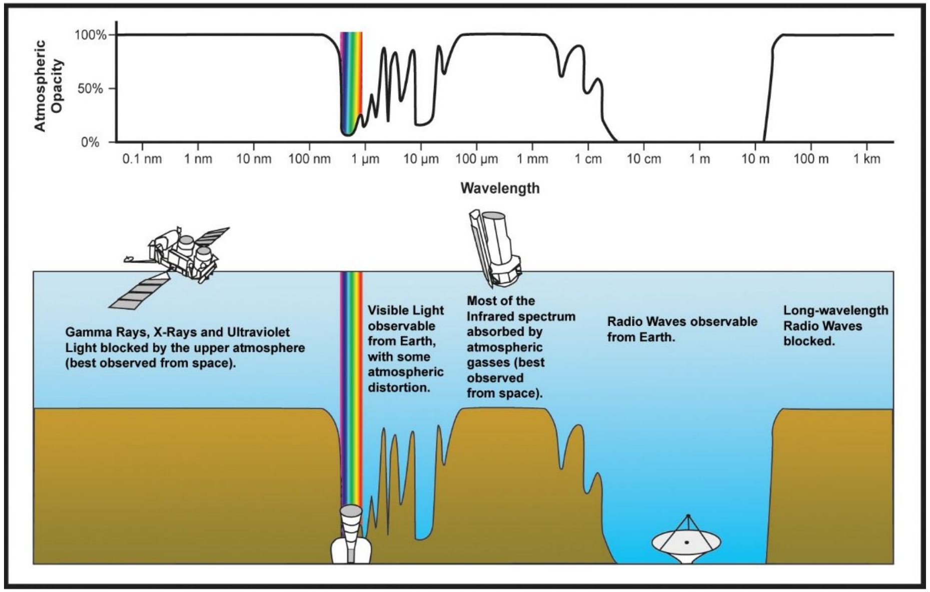
Radio

Wavelengths: > 1 mm
Frequency: < 300 GHz
Lowest-energy radiation in the universe

Origin:
- Synchrotron radiation: gyration of charged particles around magnetic field lines
- Free-free radiation: deceleration of charged particles in an electric field

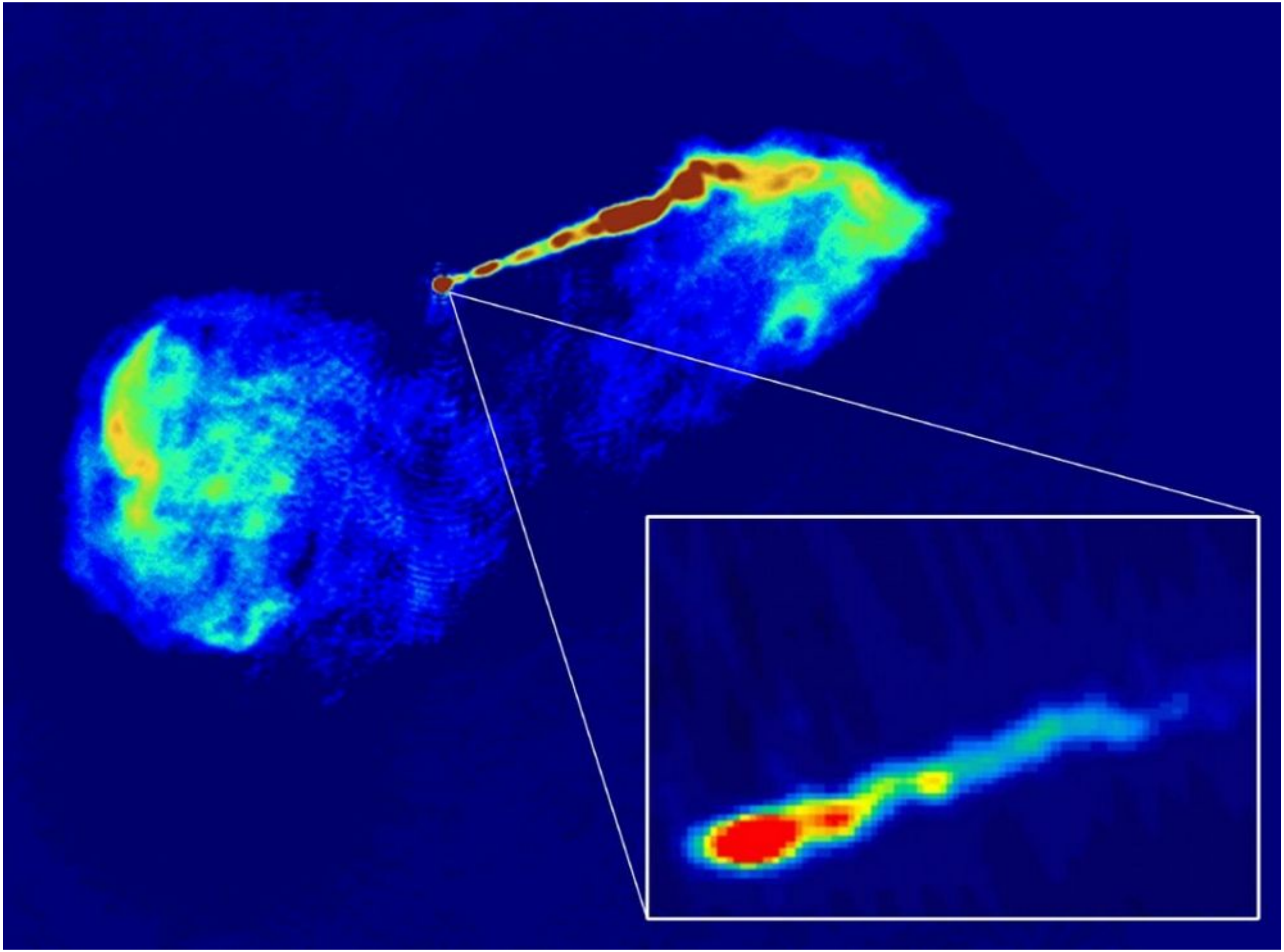
Sources:
a. Jets produced by active galactic nuclei (AGN) and gamma-ray bursts (GRBs)
b. Supernovae and tidal disruption events (TDEs) emit radio waves
c. HII regions (hot OB stars)

Technique:
- Single dish
- Interferometry



Atmospheric absorption percentages throughout the electromagnetic spectrum. Image Credit: NASA

M87 at 18 cm (VLA - VLBA)



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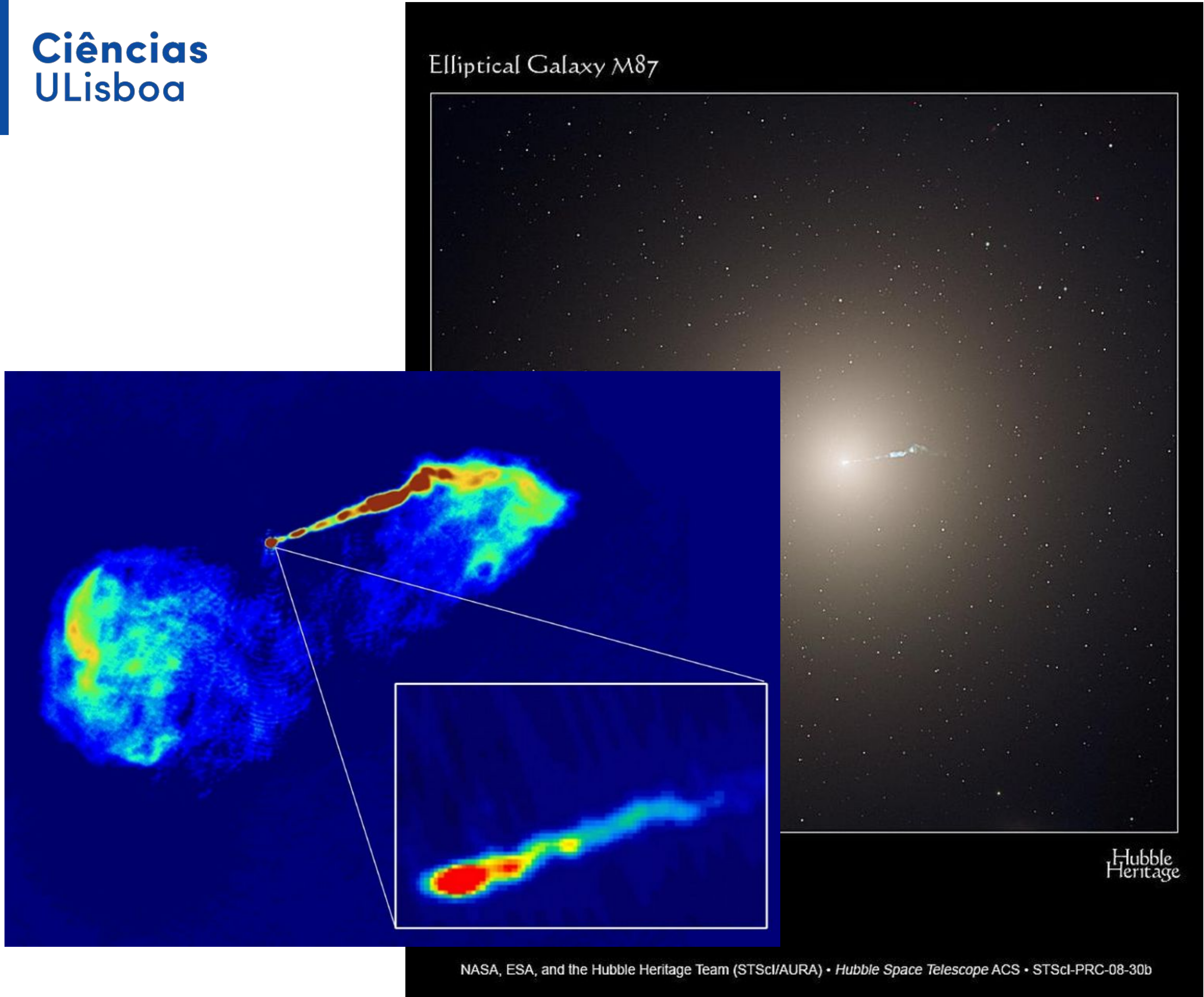


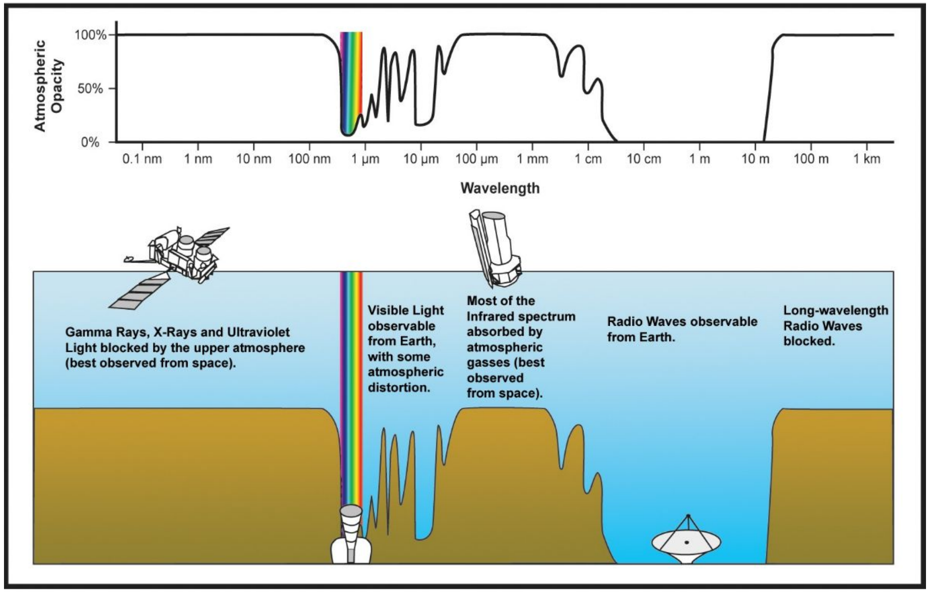
Microwave – Sub millimeter

Wavelengths: 300 microns - 1 mm
Frequency: 1THz - 300 GHz

Origin:
- Synchrotron radiation: gyration of charged particles around magnetic field lines
- Free-free radiation: deceleration of charged particles in an electric field
- Thermal emission

Sources:
a. Relativistic jets produced by neutron stars or black holes
b. Cold dust and gas in star-forming regions
c. CMB

Technique:
- Space Missions



Atmospheric absorption percentages throughout the electromagnetic spectrum. Image Credit: NASA

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Microwave – Sub millimeter

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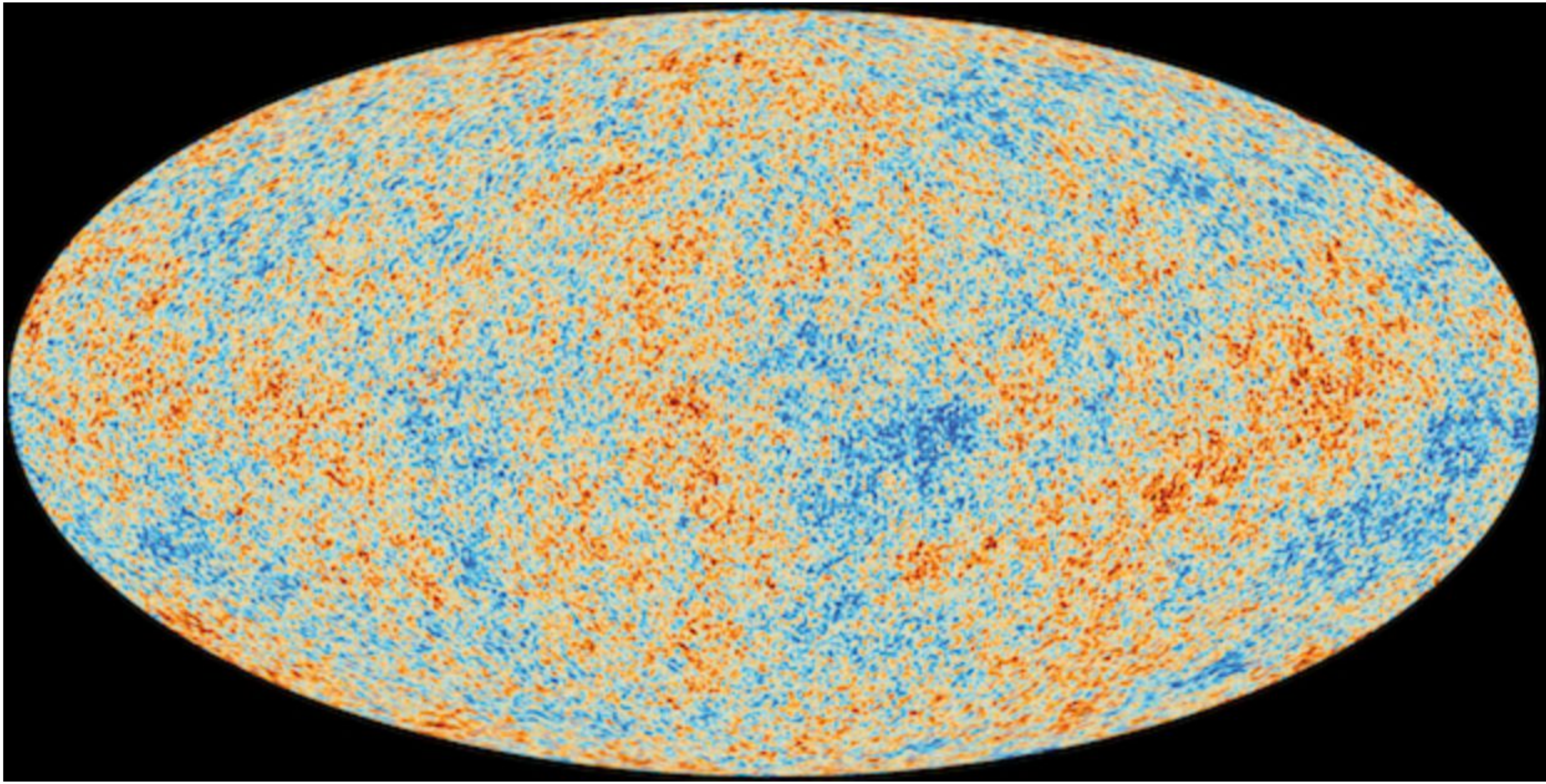
CMB map from Planck



Far Infrared

Wavelengths: 15-300 microns

Frequency: 20-1THz

Origin:

- Thermal emission. Interstellar dust absorbs the UV light and re-radiates it in the thermal IR.

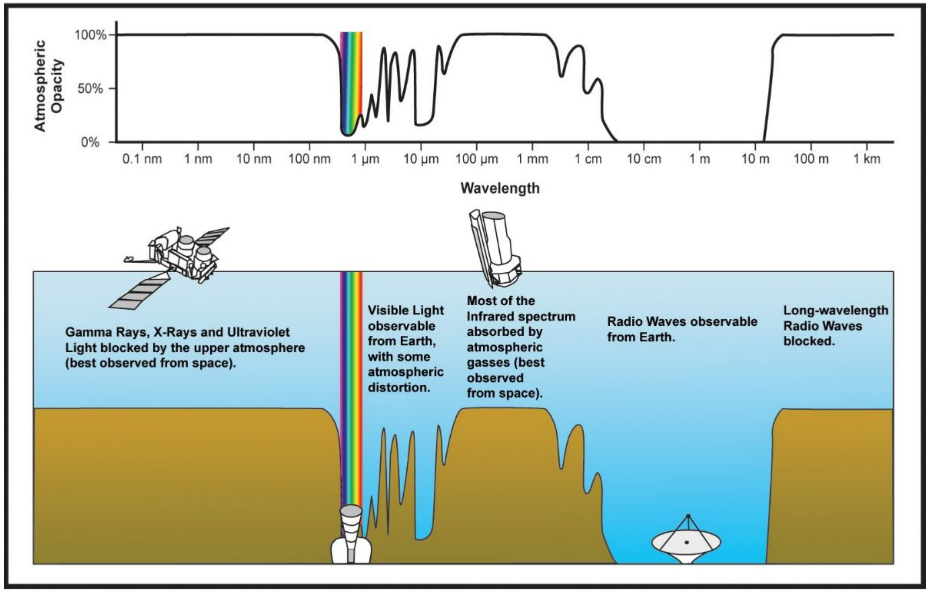
FIR emission of dusty starburst galaxies can be a sensitive tracer of young stellar populations

Sources:

a. Thermal emission from galaxies

Technique:

- Space Missions



Atmospheric absorption percentages throughout the electromagnetic spectrum. Image Credit: NASA

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M31 – Optical - FIR

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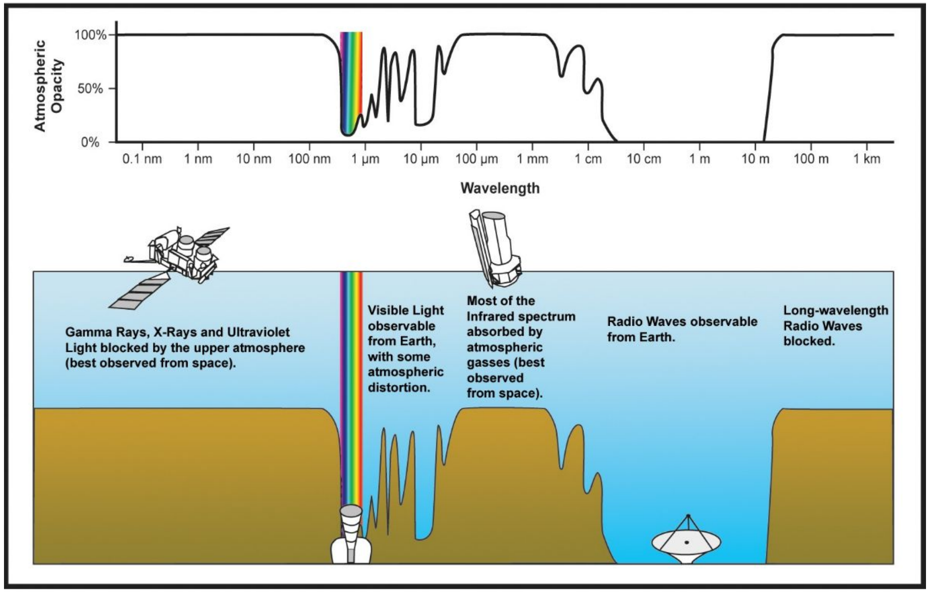
Mid Infrared

Wavelengths: 2.5-15 microns
Frequency: 120-20 THz

Origin:
- Dust

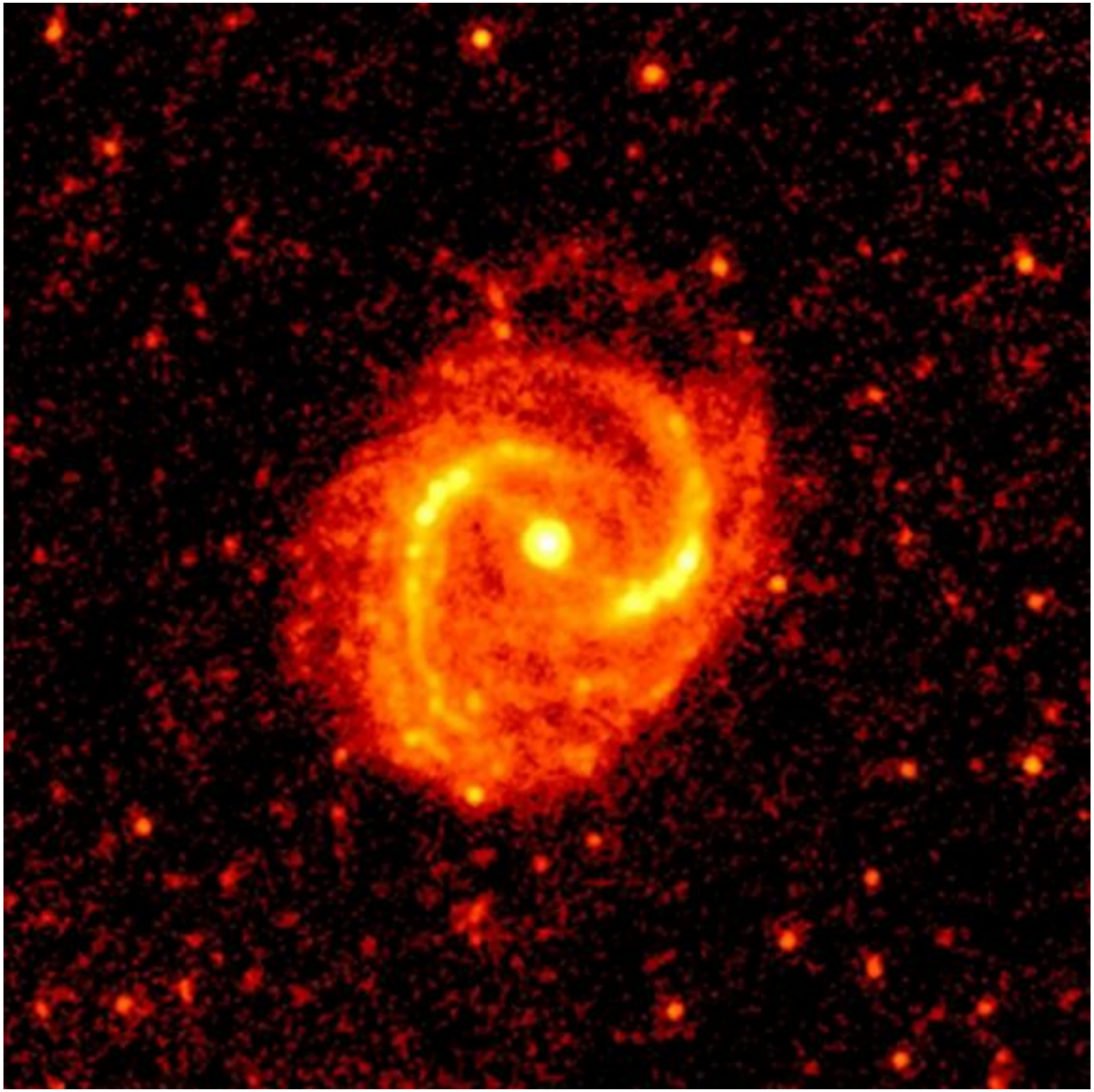
Sources:
a. Star formation
b. Dust in young stars

Technique:
- Space Missions (even if visible from the ground)



Atmospheric absorption percentages throughout the electromagnetic spectrum. Image Credit: NASA

M91 – Spitzer



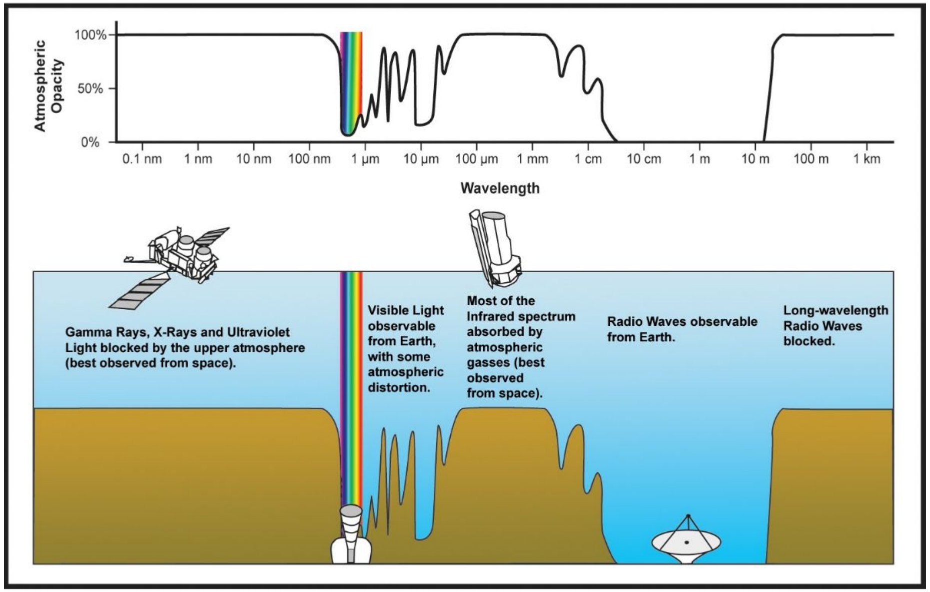
Near Infrared

Wavelengths: 0.8-2.5 microns
Frequency: 380-120 THz

Origin:
- Black body radiation

Sources:
a. Dominated by near-solar-mass evolved stars. It is a direct measurement of the galaxy mass

Technique:
- Telescopes from the ground



Atmospheric absorption percentages throughout the electromagnetic spectrum. Image Credit: NASA

M83

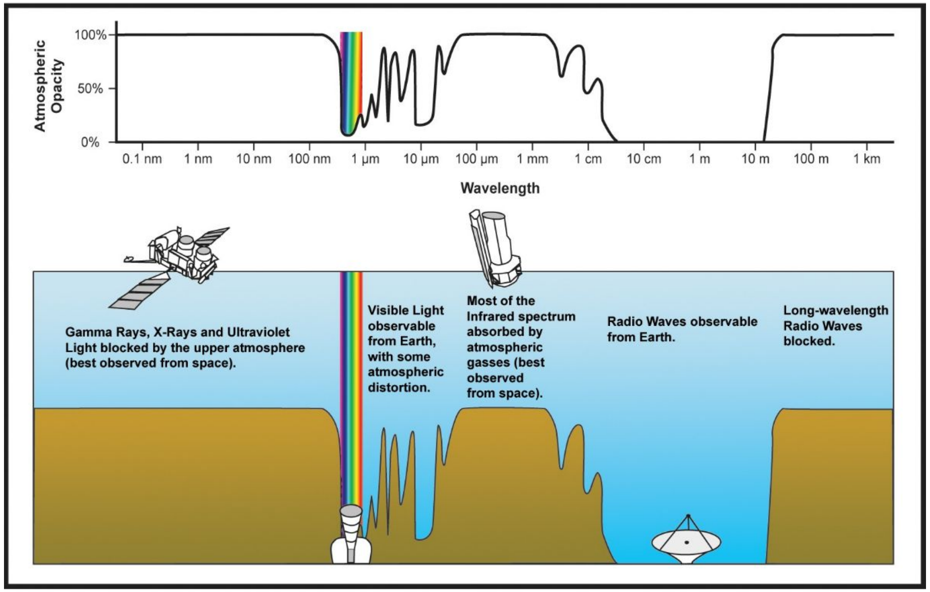
Optical

Wavelengths: 350-800 nm
Frequency: 860-380 THz

Origin:
- Black body radiation
- Free-free emission from ionized gas

Sources:
a. Thermal emission from stars
b. Emission lines from ionized gas

Technique:
- Telescopes from the ground



Atmospheric absorption percentages throughout the electromagnetic spectrum. Image Credit: NASA

NGC 1097

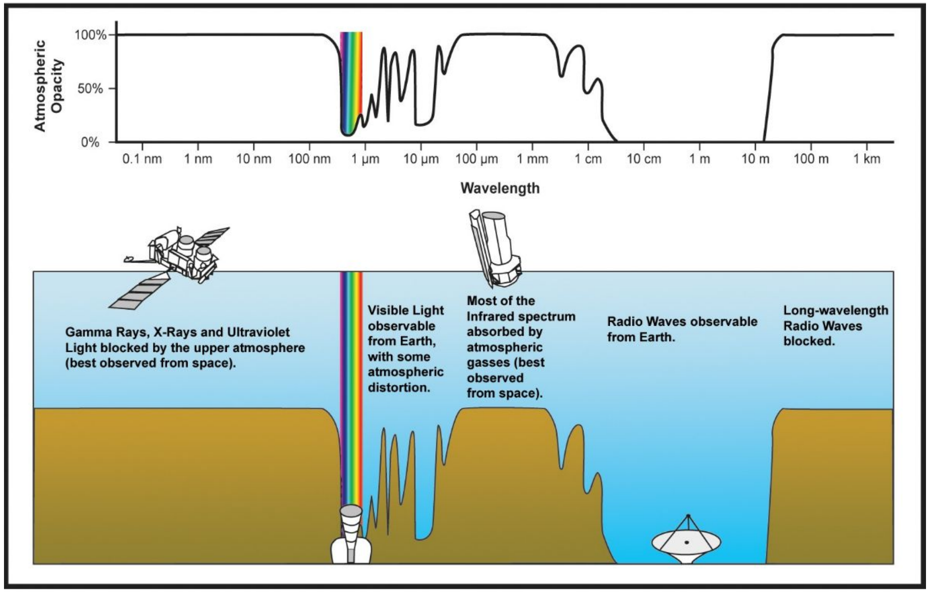
Ultraviolet

Wavelengths: 10-350 nm
Frequency: 3e16 Hz - 860 THz
Energy: 120-3.5 eV

Origin:
- Black body radiation from hot sources
- Non thermal emission from AGN

Sources:
a. Thermal emission from O-B stars. Dominated by short lived massive stars. It is a direct measurement of instantaneous star formation rate.
b. Continuum from AGN

Technique:
- Space Missions



Atmospheric absorption percentages throughout the electromagnetic spectrum. Image Credit: NASA

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M33

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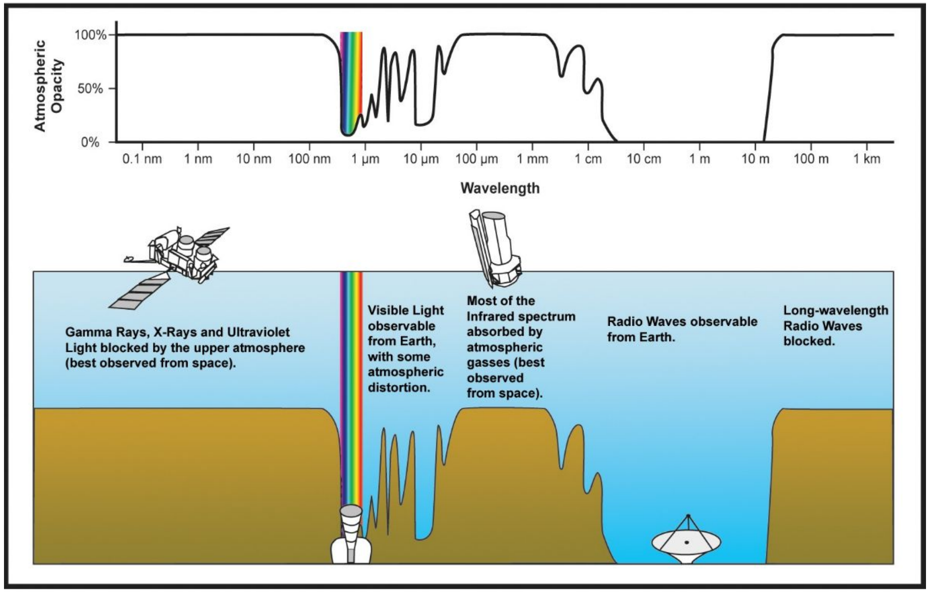
X-ray

Wavelengths: 10 pm -10 nm
Frequency: 3e19 – 3e16 Hz
Energy: 120-0.12 keV

Origin:
- Black body radiation from hot sources
- Free-Free emission

Sources:
a. Thermal emission from neutron stars
b. Non thermal emission from hot gas in galaxy clusters
c. X-ray binaries
d. Accretion disks in AGN



Atmospheric absorption percentages throughout the electromagnetic spectrum. Image Credit: NASA

Technique:
- Space Missions

Whirlpool

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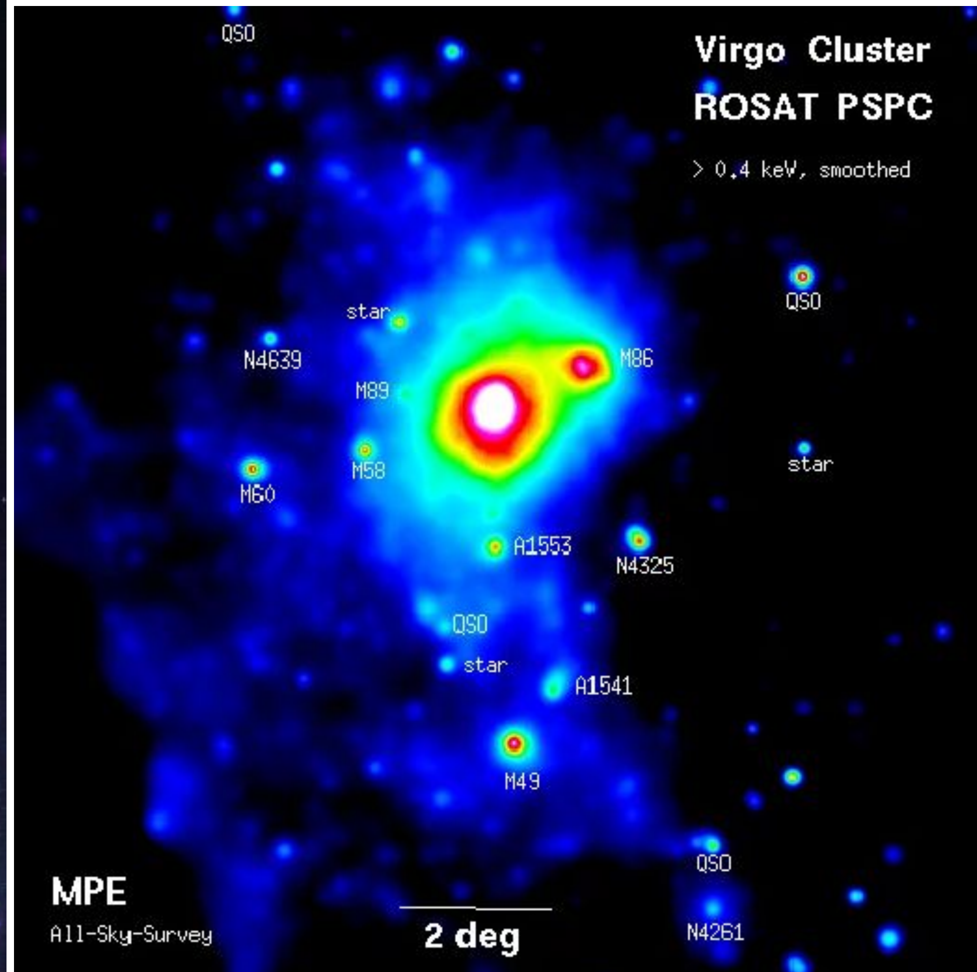


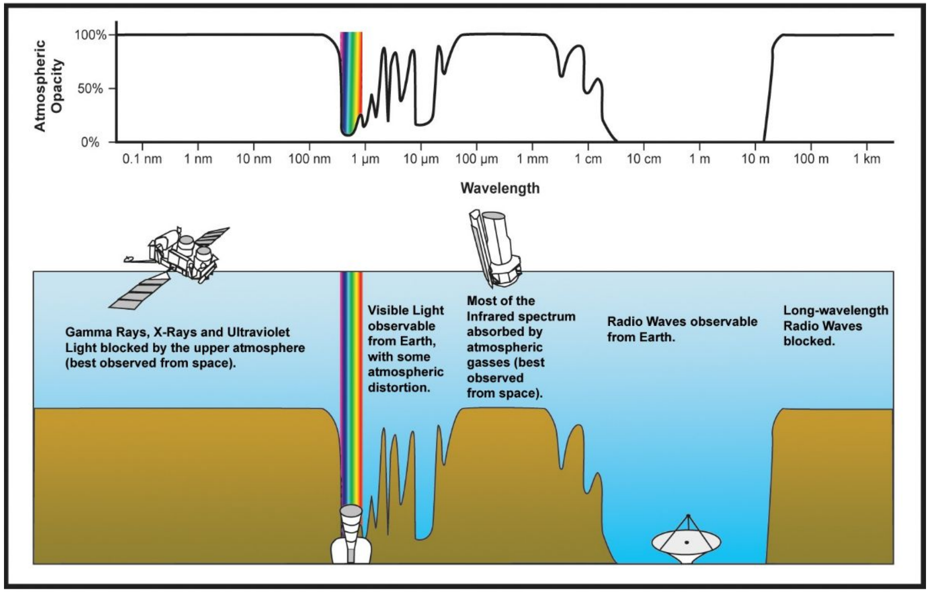
Gamma-ray

Wavelengths: > 10 pm
Frequency: > 3e19
Energy: > 120 keV

Origin:
- Nuclear Physics
- Shockwave
- Inverse Compton scattering

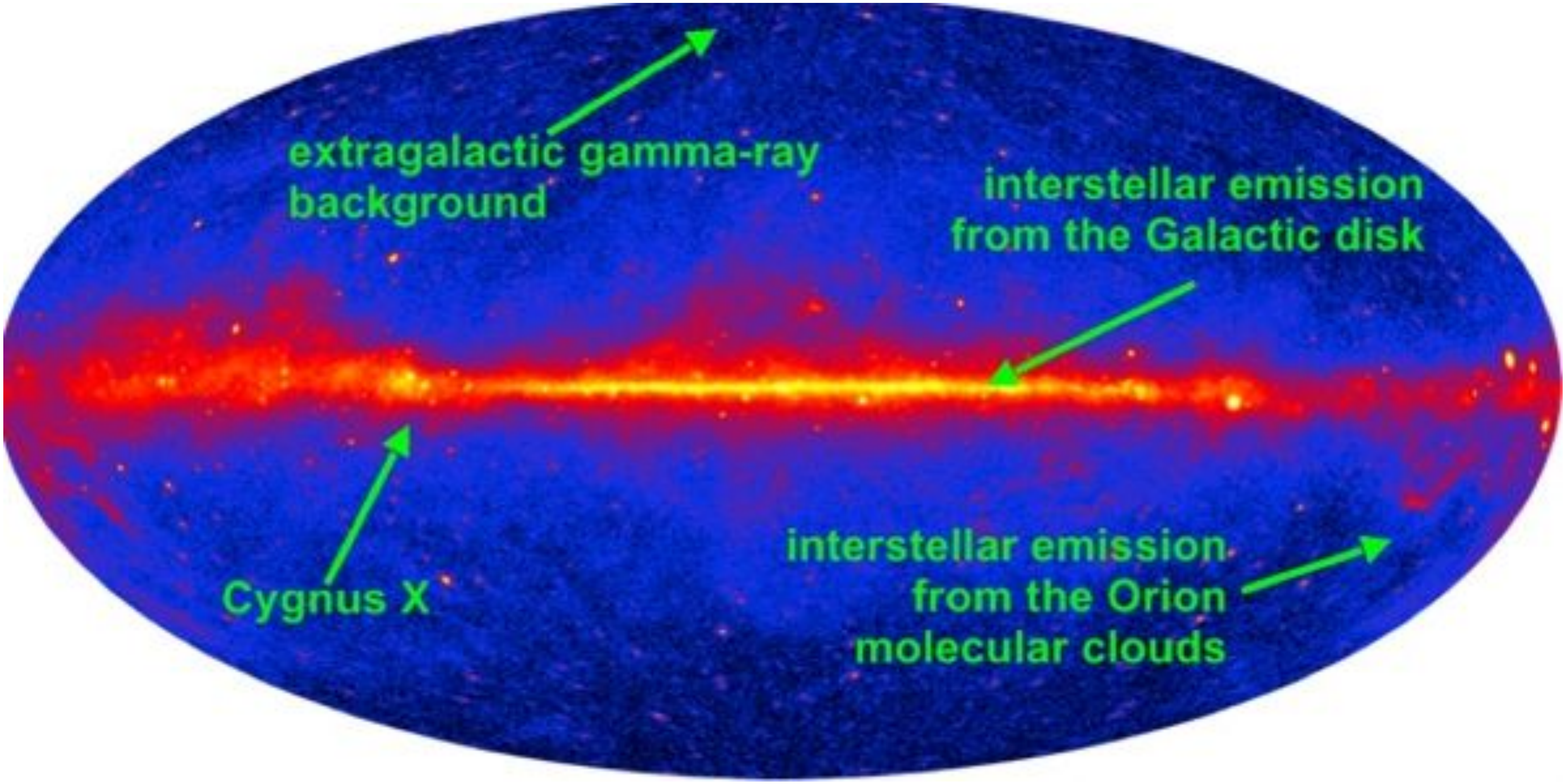
Sources:
a. Relativistic Jets in AGN
b. Gamma-ray binaries
c. Gamma-ray bursts

Technique:
- Space Missions



Atmospheric absorption percentages throughout the electromagnetic spectrum. Image Credit: NASA

Fermi Sky


extragalactic gamma-ray background
interstellar emission from the Galactic disk
Cygnus X
interstellar emission from the Orion molecular clouds

What did we learn?

1. The observable of Astrophysics is the ‘photon’
2. Methods to count the photons
3. Electromagnetic spectrum
4. Magnitude and colors
5. Science
6. Phenomenological approach