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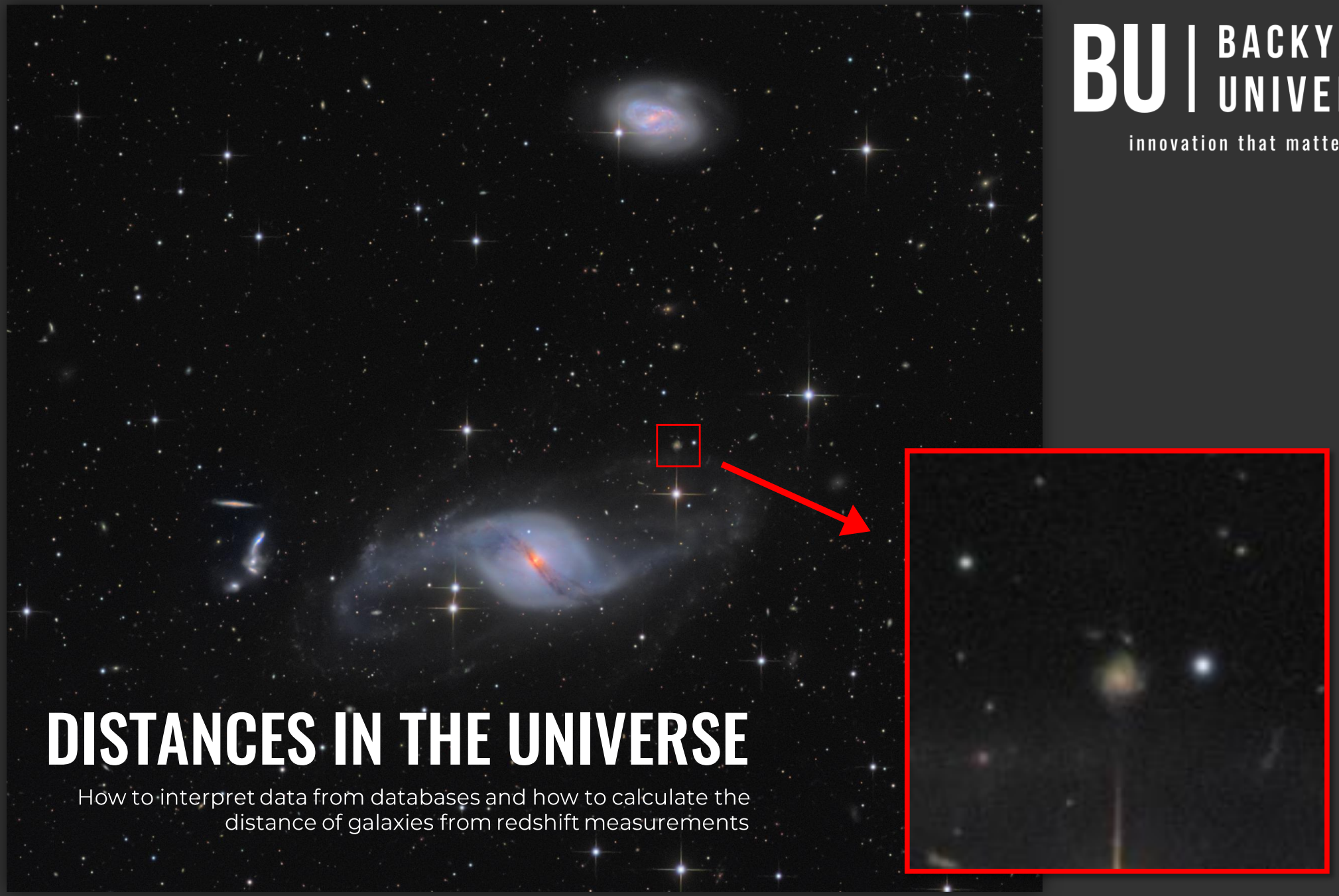

DISTANCES IN THE UNIVERSE

How to interpret data from databases and how to calculate the distance of galaxies from redshift measurements

LOCALIZING THE OBJECT OF INTEREST

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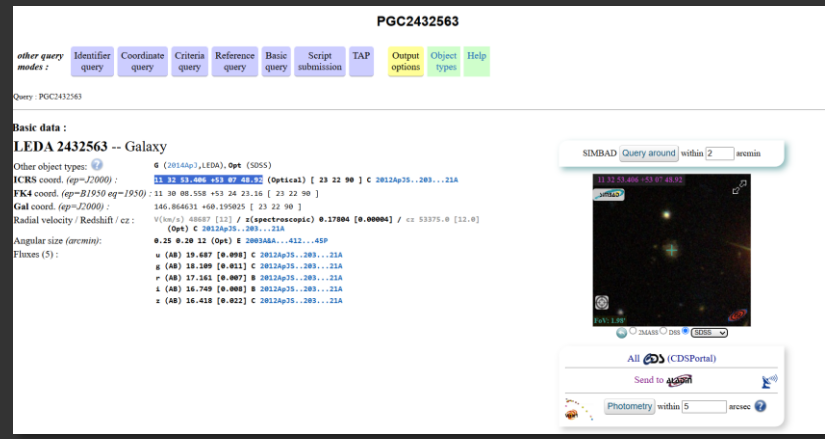
PGC2432563

(Name of the object, from PixInsight Annotation)

+ some additional Deconvolution & Denoising

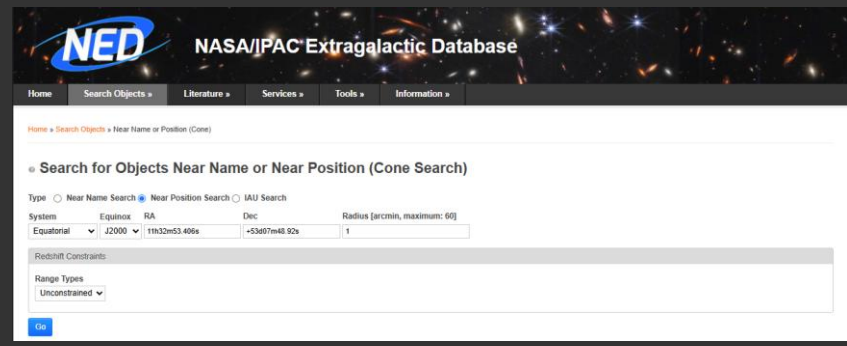
SimBAD search to get the coordinates

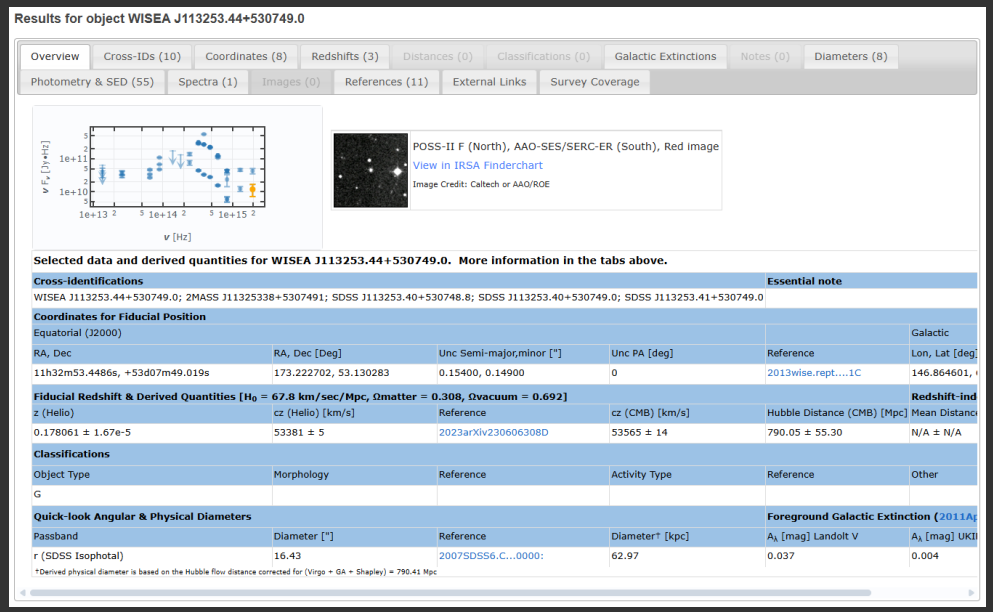
https://simbad.cds.unistra.fr/simbad/



NED search to get information about the object

https://ned.ipac.caltech.edu/





OBJECT DATA from NED

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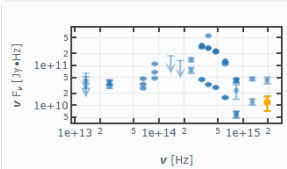
What are derived quantities???

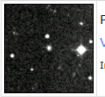
What the hell does all these numbers mean?

PGC2432563 / WISEA J113253.44+530749.0

Results for object WISEA J113253.44+530749.0

Overview | Cross-IDs (10) | Coordinates (8) | Redshifts (3) | Dis… | …sifications (0) | Galactic Extinctions | Notes (0) | Diameters (8)
Photometry & SED (55) | Spectra (1) | Images (0) | References (1… | Survey Coverage





POSS-II F (North), AAO-SES/SERC-ER (South), Red image
View in IRSA Finderchart
Image Credit: Caltech or AAO/ROE

Selected data and derived quantities for WISEA J113253.44+530749.0. More information in the tabs above.

Cross-identifications				**Essential note**	
WISEA J113253.44+530749.0; 2MASS J11325338+5307491; SDSS J113253.40+530748.8; SDSS J113253.40+530749.0; SDSS J113253.41+530749.0					
Coordinates for Fiducial Position					
Equatorial (J2000)					Galactic
RA, Dec	RA, Dec [Deg]	Unc Semi-major,minor ["]	Unc PA [deg]	Reference	Lon, Lat [deg]
11h32m53.4486s, +53d07m49.019s	173.222702, 53.130283	0.15400, 0.14900	0	2013wise.rept....1C	146.864601,
Fiducial Redshift & Derived Quantities [H_0 = 67.8 km/sec/Mpc, Ωmatter = 0.308, Ωvacuum = 0.692]					**Redshift-ind**
z (Helio)	cz (Helio) [km/s]	Reference	cz (CMB) [km/s]	Hubble Distance (CMB) [Mpc]	Mean Distanc
0.178061 ± 1.67e-5	53381 ± 5	2023arXiv230606308D	53565 ± 14	790.05 ± 55.30	N/A ± N/A
Classifications					
Object Type	Morphology	Reference	Activity Type	Reference	Other
G					
Quick-look Angular & Physical Diameters				**Foreground Galactic Extinction (2011Ap**	
Passband	Diameter ["]	Reference	Diameter† [kpc]	A_λ [mag] Landolt V	A_λ [mag] UKI
r (SDSS Isophotal)	16.43	2007SDSS6.C...0000:	62.97	0.037	0.004

†Derived physical diameter is based on the Hubble flow distance corrected for (Virgo + GA + Shapley) = 790.41 Mpc

EXPLANATION OF THE NED TABLE DATA

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Cross-identifications	Essential note
WISEA J113253.44+530749.0; 2MASS J11325338+5307491; SDSS J113253.40+530748.8; SDSS J113253.40+530749.0; SDSS J113253.41+530749.0	

Cross-identifications = *WISEA J113253.44+530749.0*

A list of alternative names or catalog entries for the same astronomical object across different surveys and databases

Coordinates for Fiducial Position					
Equatorial (J2000)					Galactic
RA, Dec	RA, Dec [Deg]	Unc Semi-major,minor ["]	Unc PA [deg]	Reference	Lon, Lat [deg]
11h32m53.4486s, +53d07m49.019s	173.222702, 53.130283	0.15400, 0.14900	0	2013wise.rept....1C	146.864601,

Coordinates for Fiducial Position

The Fiducial Position refers to the reference sky coordinates used to define the exact location of an object in the sky — usually given in a standard celestial coordinate system (Equatorial J2000)

RA, Dec = *11h32m53.4486s, +53d07m49.019s*
Right Ascension (RA) and Declination (DEC) Coordinates

UNC Semi-major, minor = *0.15400, 0.14900*
Uncertainties of the measured size and shape – specifically its ellipse-like shape.

RA, Dec [Deg] = *173.222702, +53.130283*
Coordinates on the celestial sphere

Example

$$24h = 360°, \rightarrow 1h = 15°$$

$$RA\ (Deg) = 11 \cdot 15° + \frac{32}{60} \cdot 15° + \frac{53.4486}{3600} \approx 173.2227°$$

EXPLANATION OF THE NED TABLE DATA

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Fiducial Redshift & Derived Quantities [H_0 = 67.8 km/sec/Mpc, Ωmatter = 0.308, Ωvacuum = 0.692]					Redshift-ind
z (Helio)	cz (Helio) [km/s]	Reference	cz (CMB) [km/s]	Hubble Distance (CMB) [Mpc]	Mean Distanc
0.178061 ± 1.67e-5	53381 ± 5	2023arXiv230606308D	53565 ± 14	790.05 ± 55.30	N/A ± N/A

Fiducial Redshift & Derived Quantities [H_0 = 67.8 km/sec/Mpc, Ω_{matter} = 0.308, Ω_{vacuum} = 0.692]

*z-Helio = 0.178061 ± 1.67e-5 (**Measured!!**)*

The redshift of the galaxy relative to the Sun (heliocentric frame). Measures how much the light was stretched by the expansion of the Universe.

*c_z (Helio) [km/s] = 53381 ± 5 (**calculated**)*

Recession velocity (in km/s), calculated by multiplicate the speed of light with the measured redshift, relative to the Sun

Example

$$c_z = 299792.458 \frac{km}{s} \cdot 0.178061 \approx 53381 \frac{km}{s}$$

Reference = 2023arXiv230606308D

The paper or catalog where this redshift measurement was published.

*cz (CMB) [km/s] = 53565 ± 14 (**calculated**)*

Velocity of the galaxy relative to the cosmic microwave background (CMB).cz(CMB) is a corrected version of cz(Helio), compensating for the motion of the Earth and Solar System relative to the CMB.

*Hubble Distance (CMB) [Mpc] = 790.05 ± 55.30 (**calculated**)*

The comoving distance is derived from the Friedmann–Lemaitre–Robertson–Walker (FLRW) metric by integrating over redshift using a cosmological model with specified parameters (e.g. H_0 , Ω_{matter} , Ω_{vacuum}). At low redshifts, this reduces to Hubble's law, which provides a good approximation when the expansion of the Universe hasn't changed significantly over time.

Hubble's law $D_c \approx \frac{c_z}{H_0}$

EXPLANATION OF THE NED TABLE DATA

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Classifications					
Object Type	Morphology	Reference	Activity Type	Reference	Other
G					

Classification = *G*

This is a broad classification indicating that the object is confirmed to be a galaxy — but no specific subtype (like spiral, elliptical, irregular, or AGN) is assigned (yet).

Quick-look Angular & Physical Diameters				Foreground Galactic Extinction (2011Ap	
Passband	Diameter ["]	Reference	Diameter† [kpc]	A_λ [mag] Landolt V	A_λ [mag] UKI
r (SDSS Isophotal)	16.43	2007SDSS6.C...0000:	62.97	0.037	0.004

†Derived physical diameter is based on the Hubble flow distance corrected for (Virgo + GA + Shapley) = 790.41 Mpc

Quick-look Angular & Physical Diameters

Angular Diameter = *16.43"*
tells you how big the object appears on the sky – measured in arcseconds (")

Physical Diameter = *62.97*
the true size of the galaxy – in kiloparsecs (kpc) – calculated from the angular size and the galaxy's distance using the angular diameter distance

$$D_{phys} = \theta \cdot D_a$$

Example

D_a=790Mpc (Hubble Distance), $D_{arcsec} = 16.43"$

$$\theta = \frac{\pi}{180} \cdot \frac{D_{arcsec}}{3600} = 7{,}96549 \cdot 10^{-5}$$

$$D_{phys} = 7{,}96549 \cdot 10^{-5} \cdot 790Mpc = 0{,}06292Mpc = 62.9kpc$$

HOW DISTANCES ARE CALCULATED

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Hubble's law is a simple linear relation used to estimate distances for nearby galaxies, where the expansion of the Universe hasn't changed significantly over time. The redshift should be small, typically < 0.1

Hubble's law	$D_c \approx \frac{c_z}{H_0}$

For galaxies at moderate to high redshifts, the Universe's expansion rate has changed significantly due to the influence of matter and dark energy. In this case, we use the **Comoving Distance Formula**, which is derived from the **Friedmann–Lemaître–Robertson–Walker (FLRW) metric** and a cosmological model.

The most commonly used model is the **Lambda-CDM model**, which will be described on the next slides

THE LAMBDA-CDM MODEL (ΛCDM)

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Key Assumptions of the ΛCDM

1. **The universe is homogeneous and isotropic on large scales**

Means, it looks the same in all directions and locations!

2. **The expansion and structure of the Universe is described by Einstein's field equations**

$$G_{\mu\nu} + \Lambda g_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu}$$

Tells spacetime how to curve
(Curvature of space time)

Descripes what is in it
(Matter and energy)

THE LAMBDA-CDM MODEL (ΛCDM)

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Key Assumptions of the ΛCDM – Part 2

3 **The geometry of the universe is flat**

That means, that the energy density parameter Ω is equal to **1**.

$$\Omega = \Omega_m + \Omega_r + \Omega_\Lambda = 1$$

Ω_m = Matter Density Parameter

Describes the fraction of the total energy density of the Universe made of matter

→ **Baryonic matter** like stars, gas, atoms

→ **Cold dark matter**

Ω_r = Radiation Density Parameter

Fraction of the Universe's total energy density made of radiation

→ **Photons from CMB (Comic Microwave Background)**

Ω_Λ = Dark Energy Density Parameter

Fraction of the Universe's total energy density made of dark energy

Measurements have shown that we live in a really flat universe!

$\Omega \approx 1.000 \pm 0.005$

Image by Christian Dorn from Pixabay

THE LAMBDA-CDM MODEL (ΛCDM)

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Key Assumptions of the ΛCDM – Part 3

4 **The Universe consists of**

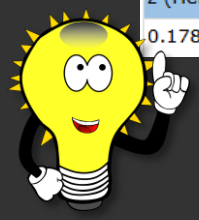
~5% Baryonic matter (normal matter like atoms, gases, matter like you and me)

~25% Cold dark Matter (**CDM**)

~70% Dark Energy (Λ)

Here, we can find the first parameters from our NED table !!!

Fiducial Redshift & Derived Quantities [H_0 = 67.8 km/sec/Mpc, Ωmatter = 0.308, Ωvacuum = 0.692]					Redshift-ind
z (Helio)	cz (Helio) [km/s]	Reference	cz (CMB) [km/s]	Hubble Distance (CMB) [Mpc]	Mean Distance
0.178061 ± 1.67e-5	53381 ± 5	2023arXiv230606308D	53565 ± 14	790.05 ± 55.30	N/A ± N/A



$$\Omega_{matter} = 0.308 = \Omega_{Baryonic} + \Omega_{CDM}$$

$$\Omega_{vacuum} = 0.692 = \Omega_{\Lambda}$$

$\Omega_r = 0.00005$ → negligible and not shown

THE LAMBDA-CDM MODEL (ΛCDM)

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Key Assumptions of the ΛCDM – Part 4

5 **Inflation –** The early Universe expanded extremely rapidly, and tiny quantum fluctuations during this phase became the seeds of all large-scale structures we observe today

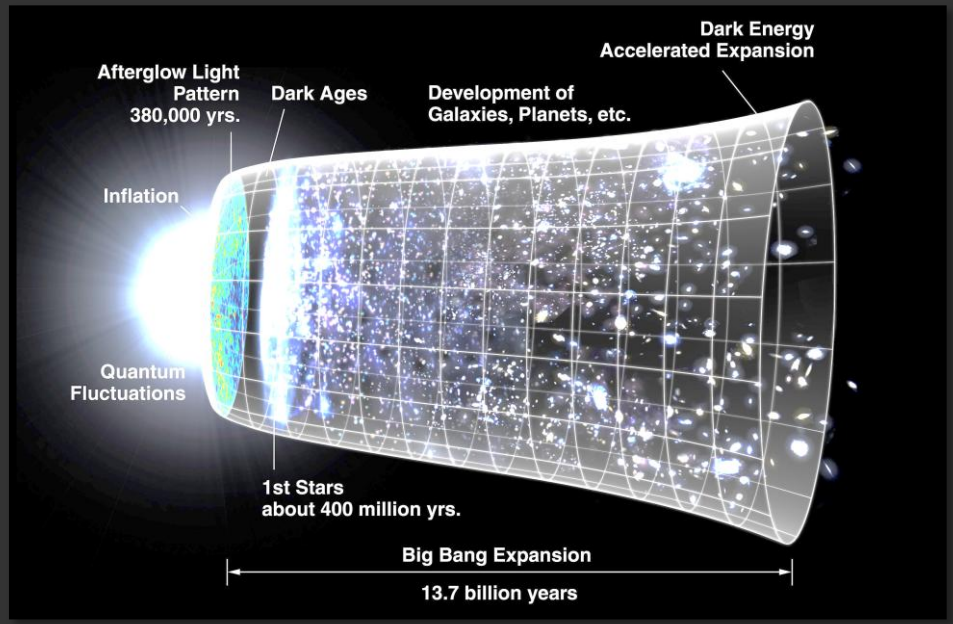

Image by WikiImages from Pixabay

CALCULATION OF THE DISTANCE

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The parameters shown in the **NED Table** can be used to calculate the distance and recession velocity

Fiducial Redshift & Derived Quantities [H_0 = 67.8 km/sec/Mpc, Ωmatter = 0.308, Ωvacuum = 0.692]		
z (Helio)	cz (Helio) [km/s]	Reference
0.178061 ± 1.67e-5	53381 ± 5	2023arXiv230605308D

$z = 0.178061 \pm 1.67e^{-5}$ (Red Shift measurement)

$H_0 = 67.8 \frac{km/s}{Mpc}$ (Hubble constant)

$\Omega_m = 0.308$ (Matter density)

$\Omega_\Lambda = 0.692$ (Dark energy density)

These parameters are used in the **Comoving Distance Integral** to calculate the distance to the galaxy

$$D_c(z) = \frac{c}{H_0} \int_0^z \frac{dz'}{E(z')}$$

(simplified Comoving Distance Formula)

CALCULATION OF THE DISTANCE

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The **Comoving Distance Formula** is an extraction derived from the **Friedmann–Lemaître–Robertson–Walker (FLRW) metric**

$$D_c(z) = \frac{c}{H_0} \int_0^z \frac{dz'}{E(z')}$$

with

$H_0 = 67.8 \frac{km/s}{Mpc}$ (Hubble constant)

$c = 299792.458 \frac{km}{s}$ (Speed of light)

$z =$ measured redshift

$E(z') =$ normalized Hubble parameter

Since we assume a flat Universe ($\Omega = 1$) and we negligible the energy density of radiation $E(z) = \sqrt{\Omega_m(1+z)^3 + \Omega_\Lambda}$

$$D_c(z) = \frac{c}{H_0} \int_0^z \frac{dz'}{\sqrt{\Omega_m(1+z)^3 + \Omega_\Lambda}}$$

Comoving Distance Formula

CALCULATION OF THE DISTANCE

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When we now calculate the Comoving Distance by using a little Python Script

Python Script to calculate the Comoving Distance

Example

```python
import numpy as np
from scipy.integrate import quad

# Constants
H0 = 67.8  # Hubble constant in km/s/Mpc
c = 299792.458  # Speed of light in km/s
Ωm = 0.308
ΩΛ = 0.692

# Define E(z) based on the Lambda-CDM model
def E(z):
    return np.sqrt(Ωm * (1 + z)**3 + ΩΛ)

# Define the integrand for the comoving distance integral
def integrand(z):
    return 1.0 / E(z)

# Upper limit of integration (redshift measurement)
z_max = 0.178061

# Perform the integration
integral, _ = quad(integrand, 0, z_max)

# Calculate comoving distance
D_C = (c / H0) * integral
D_C
```

$$D_c(z) = \frac{c}{H_0} \int_0^z \frac{dz'}{\sqrt{\Omega_m (1+z)^3 + \Omega_\Lambda}}$$

with

$H_0 = 67.8 \frac{km/s}{Mpc}$ (Hubble constant) $c = 299792.458 \frac{km}{s}$ (Speed of light)

z = 0.178061 (the redshift measurement from the NED Database)

Comoving Distance $D_c(z) = 754.03 Mpc$

SUMMARIZED IN SIMPLE WORDS

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1. We observe the light from a distant galaxy using a spectrometer and notice that it is redshifted – meaning the wavelength has been stretched due to cosmic expansion

2. The redshift tells us how long the light has been traveled – the higher the redshift, the farther away the galaxy is!

3. Due to the fact that the Universe hasn‘t expanded at a constant rate (→ *Inflation*), we need to account for how fast the Universe was expanding each moment in time.

4. We divide the light‘s journey into many small steps and calculate how far the light traveled in each step, based on the universe‘s expansion rate at that redshift.

5. Finally, we add up all these little steps which gives us the comoving distance → the present-day distance to the galaxy accounting the expansion of the universe over time

SUMMARIZED IN SIMPLE WORDS

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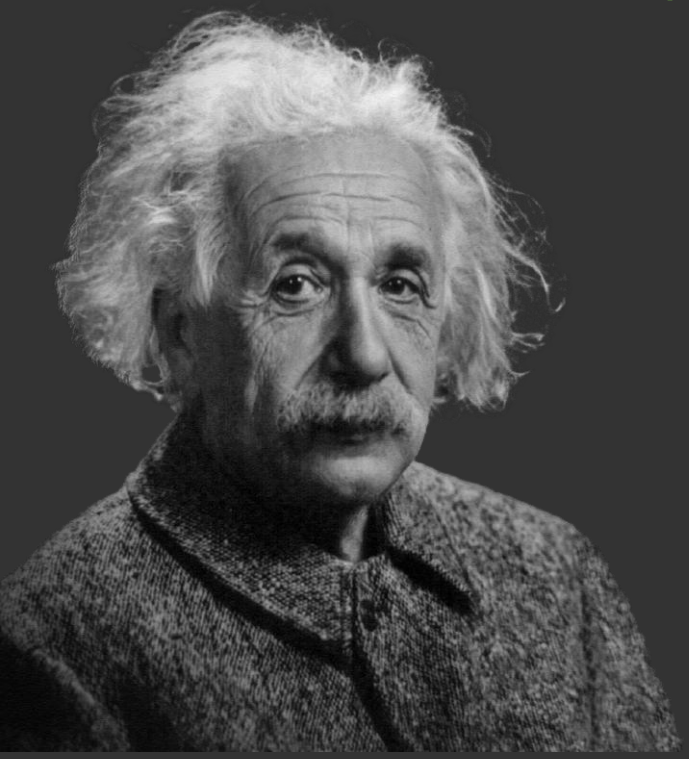
We calculate how far the light had to travel to reach us today, taking into account how the expansion of the Universe changed along the way



Thank you,

Albert Einstein

**14.03.1879 † 18. April 1955*

WHAT DOES THAT MEAN FOR OUR GALAXY?

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Name: *WISEA J113253.44+530749.0*

z-Helio = *0.178061 ± 1.67e-5*

c_z *(Helio) [km/s]* = *53381 ± 5*

$$c_{z,helio} = c \cdot z = 299792.458 \frac{km}{s} \cdot 0.178061 \approx 53381 \frac{km}{s}$$

c_z *(CMB) [km/s]* = *53565 ± 14*

$$c_{z,CMB} = c_{z,helio} + \vartheta_{corr} = 53381 \frac{km}{s} + 184 \frac{km}{s} \approx 53565 \frac{km}{s}$$

with

$$\vartheta_{corr} = V_\odot \cdot cos\theta$$
$$V_\odot \approx 370 km/s$$

θ = Angle between the direction of the CMB dipole and the direction to the object

Hubble Distance *(CMB) [Mpc]* = *790.05 ± 55.30*

$$D_c \approx \frac{c_{z,CMB}}{H_0} \approx \frac{53565 \frac{km}{s}}{67.8 \frac{\frac{km}{s}}{Mpc}} \approx 790{,}04\text{Mpc}$$

Comoving Distance *[Mpc]* $D_c(z)$ =*754.03*

Due to a redshift greater than 0.1, the **Comoving Distance Formula** based on the **FLRW metric** and the **ΛCDM model** provides more accurate results compared to the simple **Hubble approximation**.

WHAT DOES THAT MEAN FOR OUR GALAXY?

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Name: *WISEA J113253.44+530749.0*

Hubble Distance *(CMB) [Mpc] = 790.05 ± 55.30*

Distance based on Hubble Approx.
(NED Database value)

→ 2.58 billion light-years

Comoving Distance *[Mpc]* $D_c(z)$ *= 754.03*

Distance based on Comoving Distance

→ 2.46 billion light-years

2.46 billion light-years and we can still the **spiral structure of the galaxy**

LINKS

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Our website www.backyard-universe.de

SimBAD Astronomical Database https://simbad.cds.unistra.fr/simbad/

NASA Extragalactic Database (NED) *https://ned.ipac.caltech.edu/*