# Topical Lectures Cosmology

March 20-22, 2019

*Marieke Postma*
*Dorothea Samtleben*
*Paul de Jong*

Please sign attendance sheet

and evaluation sheet Friday; suggest topics for future lectures!

# Topical Lectures "Cosmology"

**from Wednesday, 20 March 2019 at 09:30 to Friday, 22 March 2019 at 17:00 (Europe/Amsterdam)**
**at Nikhef ( H331 )**

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## Wednesday, 20 March 2019

| | | |
|---|---|---|
| 10:00 - 10:30 | Introduction *30'* | Speaker: Paul de Jong |
| 10:30 - 11:15 | Lecture *45'* | Speaker: Jan Willem v. Holten |
| 11:15 - 11:30 | Coffee break | |
| 11:30 - 12:15 | Lecture *45'* | Speaker: Jan Willem v. Holten |
| 12:15 - 13:30 | Lunch | |
| 13:30 - 14:15 | Lecture *45'* | Speaker: Jan Willem v. Holten |
| 14:15 - 17:00 | Exercises/Project *2h45'* | |

## Thursday, 21 March 2019

| | |
|---|---|
| 09:30 - 10:15 | Lecture *45'*<br>Speaker: Dr. Jan Pieter Van der Schaar (Universiteit van Amsterdam) |
| 10:15 - 10:25 | short break |
| 10:25 - 11:15 | Lecture *50'* |
| 11:15 - 11:30 | Coffee break |
| 11:30 - 12:15 | Cosmology and Gravitational Waves *45'*<br>Speaker: Dr. Samaya Nissanke (Universiteit van Amsterdam) |
| 12:15 - 14:00 | Lunch |
| 14:00 - 17:00 | Exercises/Project *3h0'* |

## Friday, 22 March 2019

| | |
|---|---|
| 09:30 - 10:15 | Lecture *45'* |
| 10:15 - 10:25 | Short break |
| 10:25 - 11:15 | Lecture *50'* |
| 11:15 - 11:30 | Coffee break |
| 11:30 - 12:15 | Lecture: Observational Cosmology *45'*<br>Speaker: Prof. Henk Hoekstra (Universiteit Leiden) |
| 12:15 - 13:30 | Lunch |
| 13:30 - 16:00 | Exercises/Project *2h30'* |
| 16:00 - 17:00 | Closing *1h0'* |

“There is a theory which states that if ever anyone discovers exactly what the Universe is for and why it is here, it will instantly disappear and be replaced by something even more bizarre and inexplicable.”

*D. Adams, The Hitch Hiker’s Guide to the Galaxy*

“There is another theory which states that this has already happened.”

*D. Adams, The Hitch Hiker’s Guide to the Galaxy*

# Cosmology

Cosmos= Universe, Order, beauty
-logy= study

Greek!

Study of the Universe as a whole
Aim at getting an understanding of:

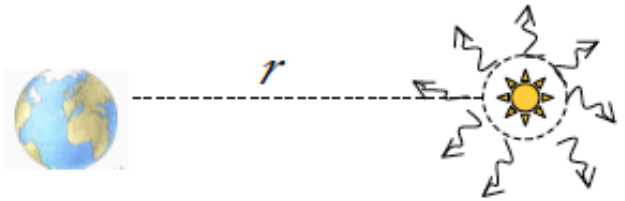
- its origin
- its structure and composition
(where do galaxies, stars, planets, people come from?)
- its evolution
- its fate

*Slides from Licia Verde, Barcelona*

# Olbers' paradox

How bright would the night sky be if the distribution of stars was infinite?

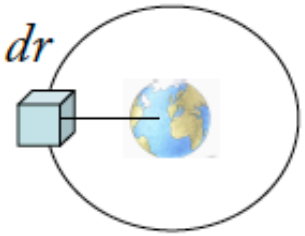
**Flux from a star** $f = \frac{L}{4\pi r^2}$




**Intensity of radiation form a shell of stars per sterradiant**

$$dJ = \frac{L}{4\pi r^2} n r^2 dr$$

*Density, for simplicity assume constant*




**If the Universe is infinite:** $J = \int_{r=0}^{r=\infty} dJ = \frac{nL}{4\pi} \int_0^\infty = \infty$

Olbers: "but… the night sky is actually dark!"

**Woops!**

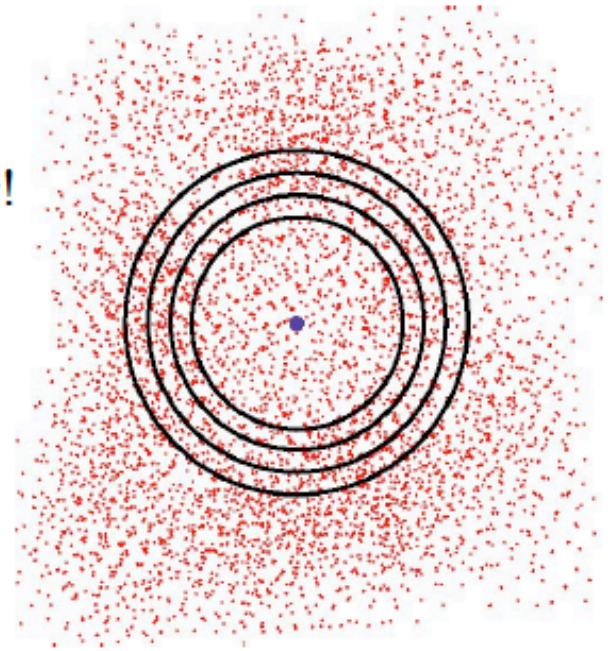
# “Solutions” to Olber’s Paradox

-The brightness of stars goes down as $1/r^2$.

- BUT…The number of stars goes UP by $r^2$!

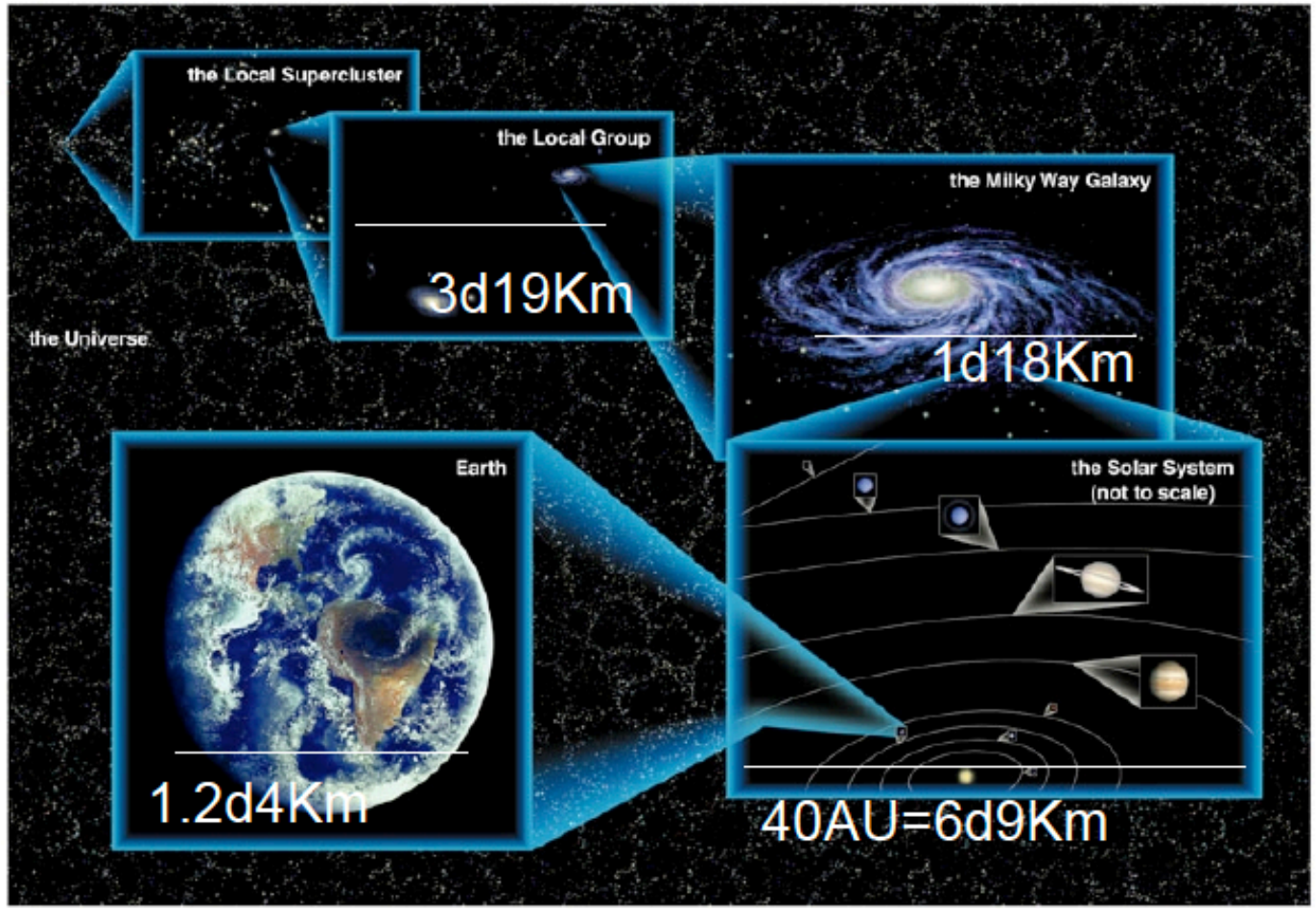
- Dust clouds obscure the light from distant stars/galaxies.

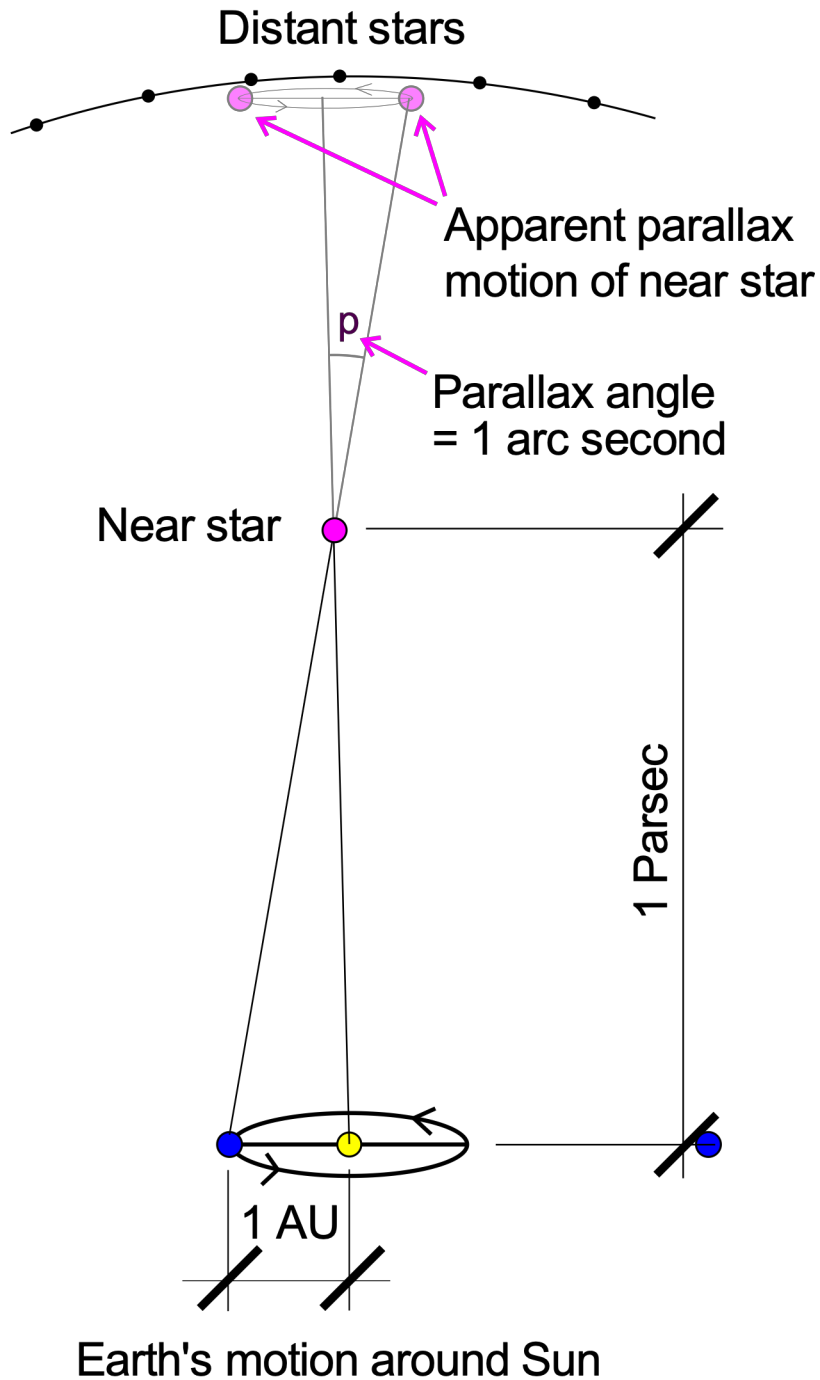
- BUT…Those clouds would heat up…and we would see THEM!



Something has to GIVE: Either the Universe is not INFINITE OR the Universe is not STATIC.

# Scales involved!




Distant stars
Apparent parallax
motion of near star
p
Parallax angle
= 1 arc second
Near star
1 Parsec
1 AU
Earth's motion around Sun

# New units of measure

For distance, we use pc, Kpc & Mpc

$$1\ \mathrm{pc} = 3.086 \times 10^{16}\mathrm{m}$$

= 3.26 lightyear

$$1\ \mathrm{Mpc} = 3.086 \times 10^{22}\mathrm{m}$$

For comparison, mean Earth-Sun distance (Astronomical Unit):

$$1\ \mathrm{AU} = 1.496 \times 10^{11}\mathrm{m}$$

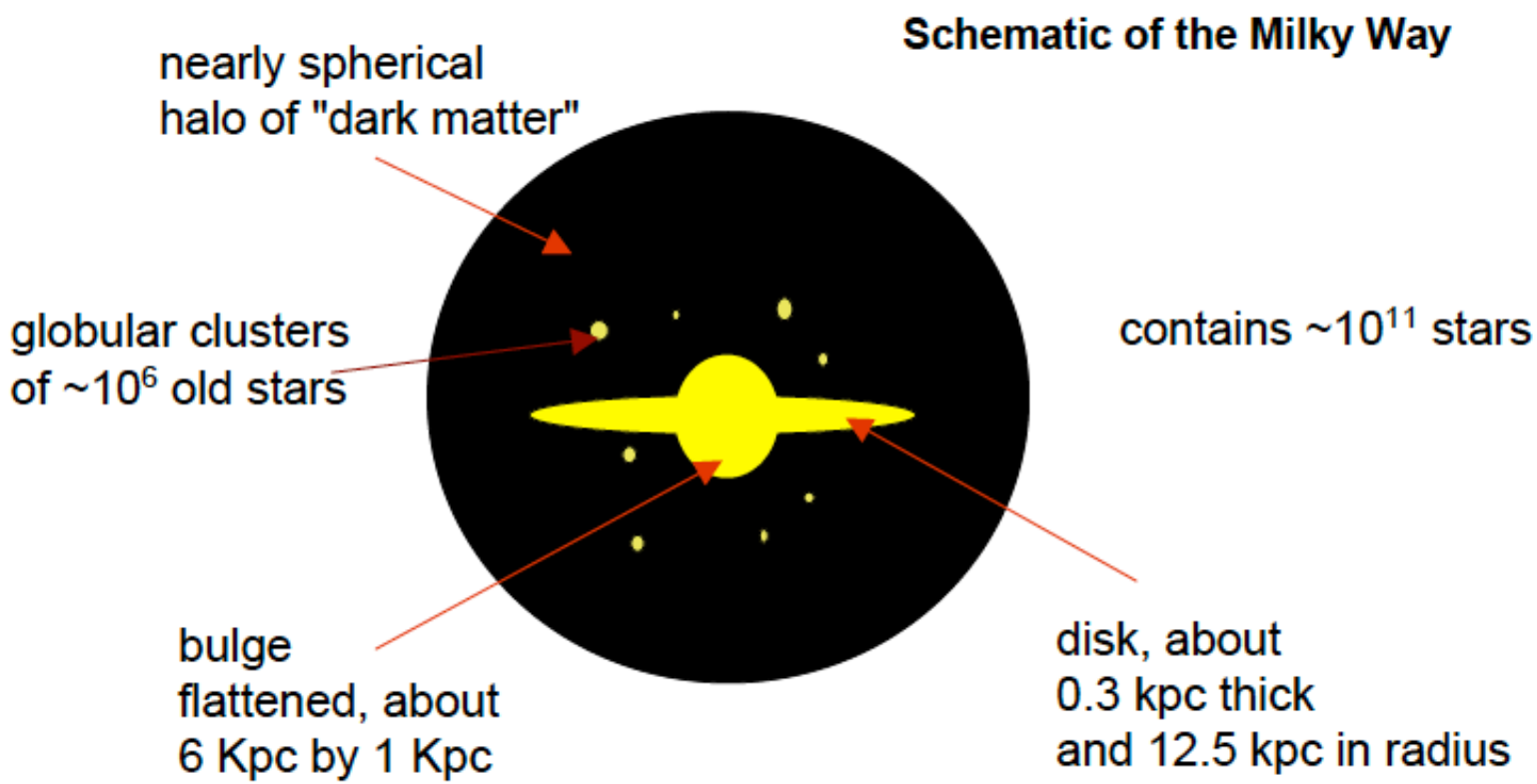
$$1\ \mathrm{pc} = 2.1 \times 10^{5}\mathrm{AU}$$

- Cosmologists often express masses
- in units of the solar mass:

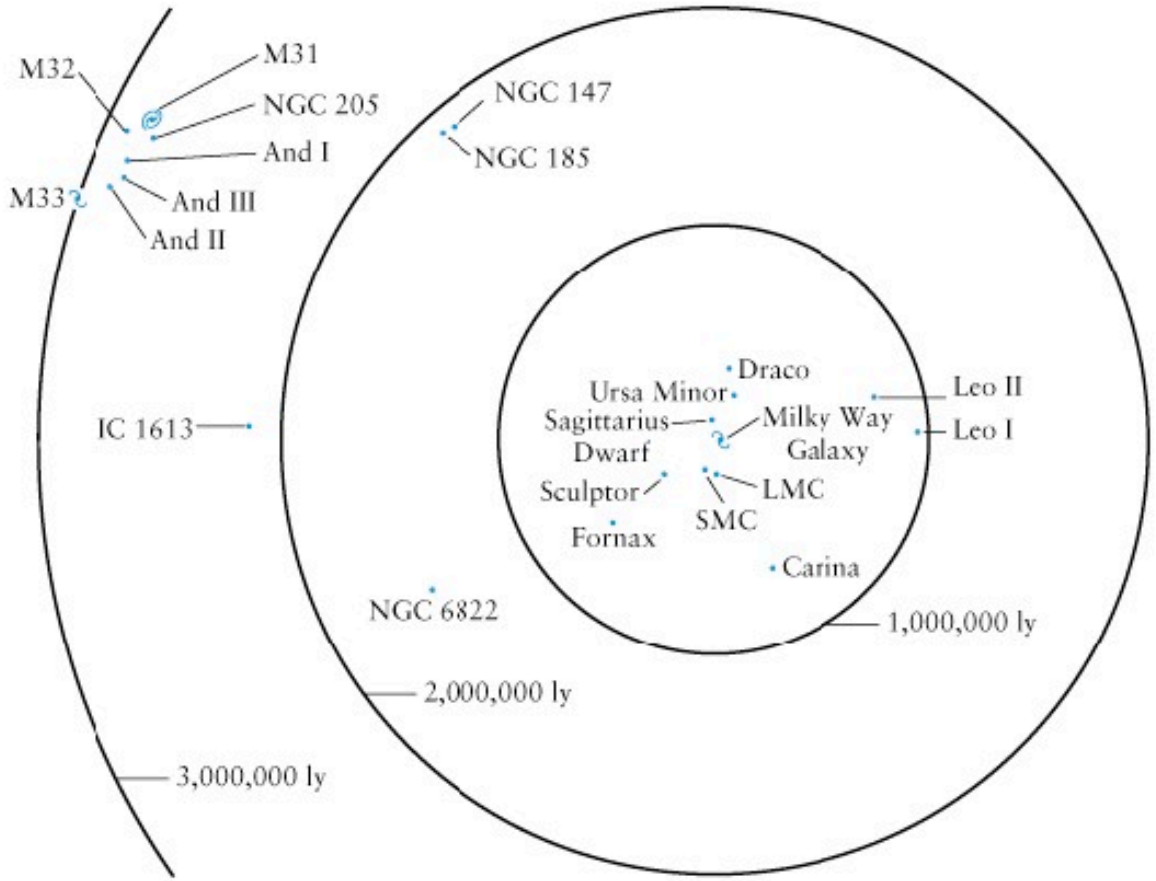
$$1\ \mathrm{M}_{\odot} = 1.99 \times 10^{30}\mathrm{kg}$$

# galaxies

Collections of ~$10^{11}$~ $10^{12}$ Stars

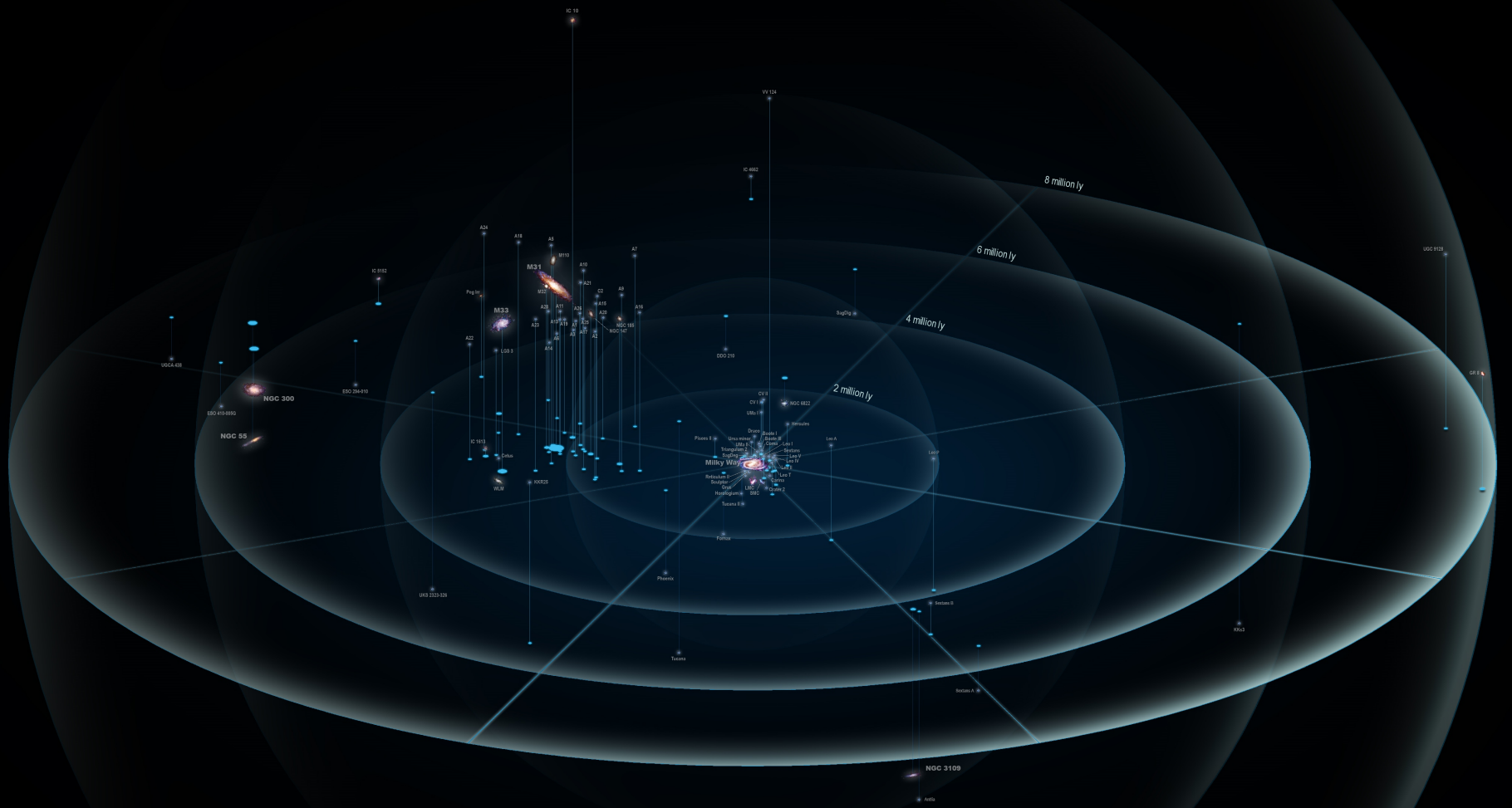


# The local group

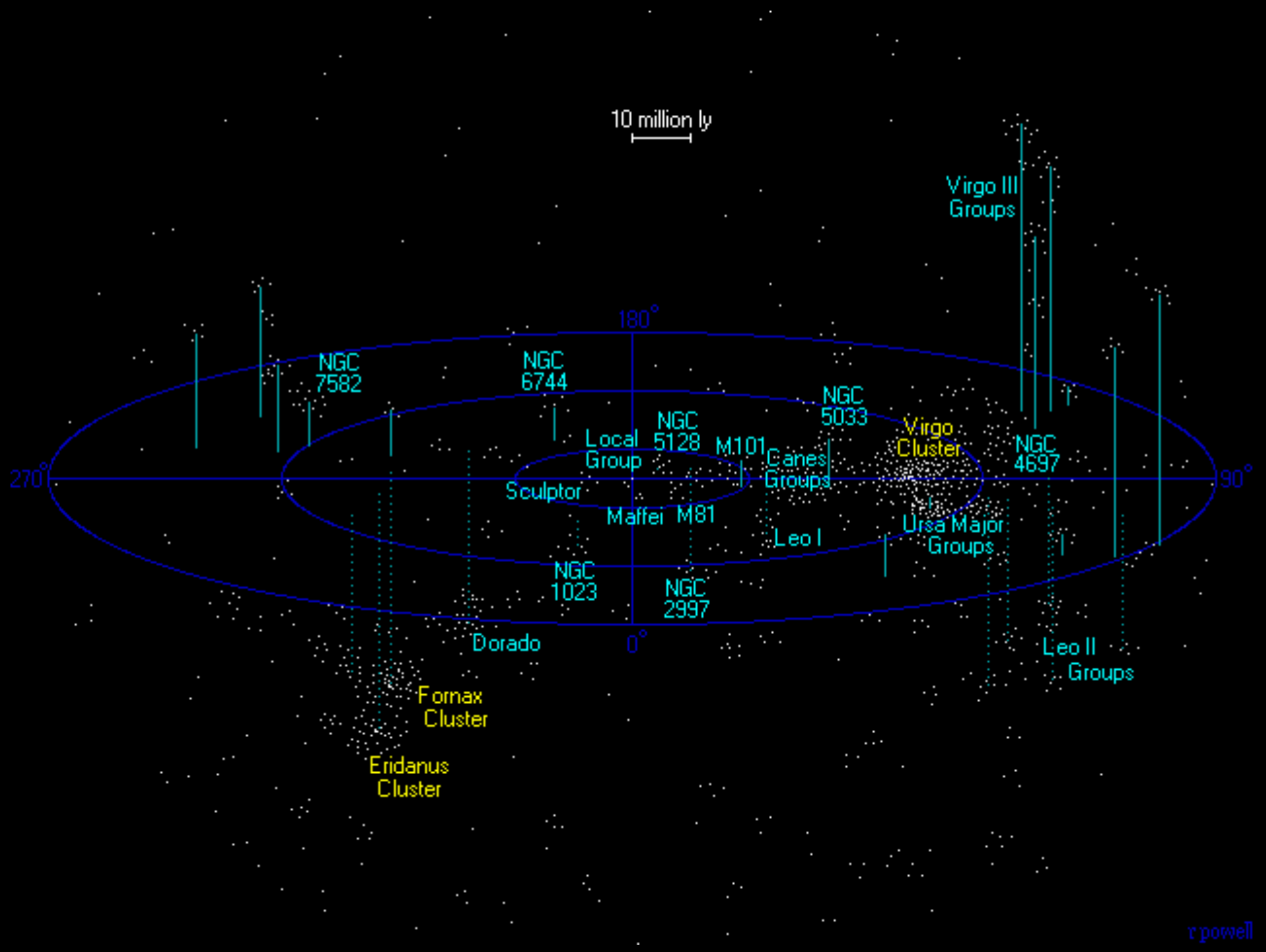



Entering the regime of cosmology….

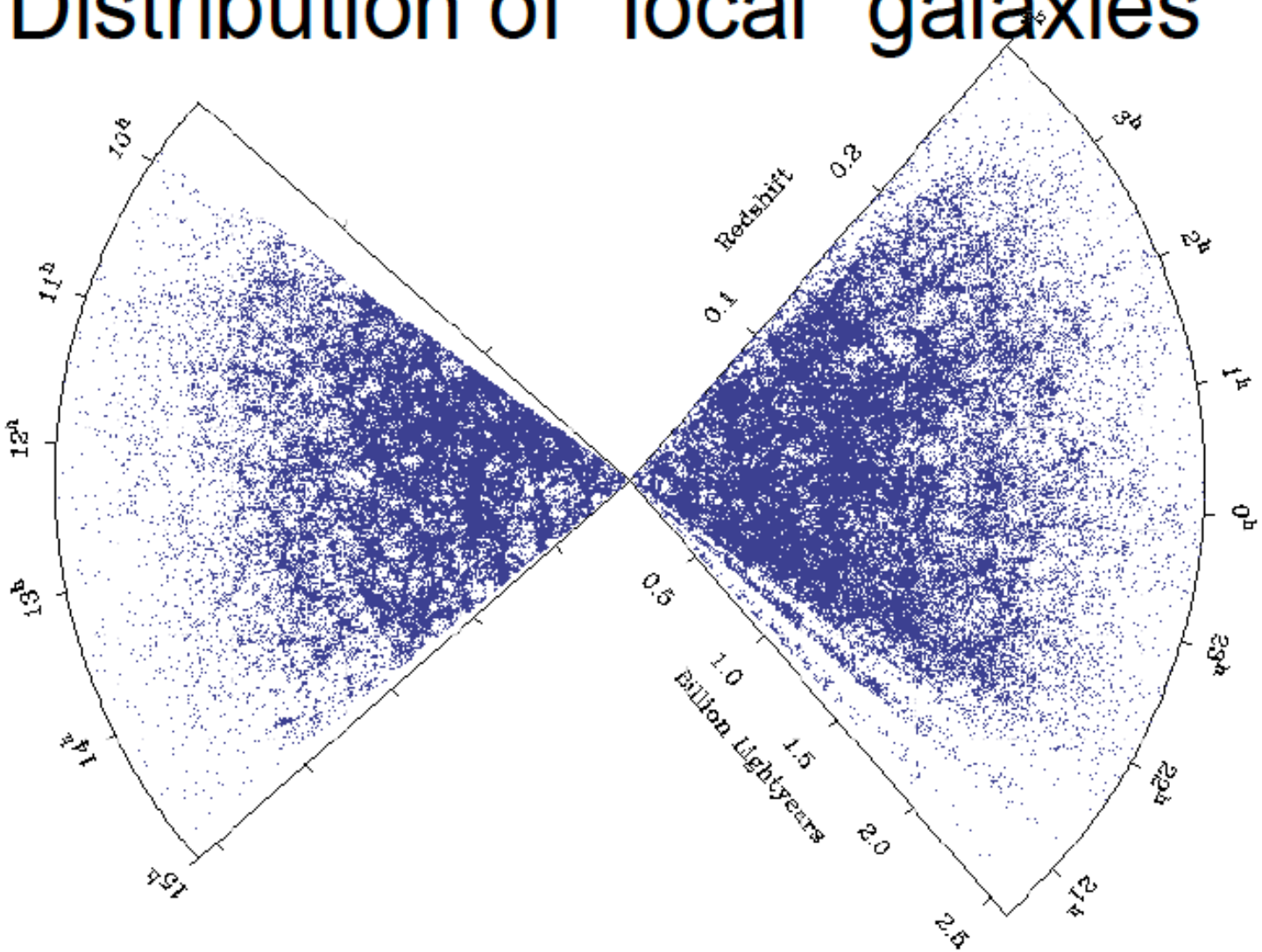
# Local Group and nearest galaxies




By Antonio Ciccolella - Own work, CC BY-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=50409931


10 million ly
Virgo III
Groups
180°
NGC
7582
NGC
6744
NGC
5033
NGC
5128
Local
Group
M101
Virgo
Cluster
NGC
4697
270°
90°
Canes
Groups
Sculptor
Maffei
M81
Leo I
Ursa Major
Groups
NGC
1023
NGC
2997
0°
Dorado
Leo II
Groups
Fornax
Cluster
Eridanus
Cluster
r powell

# Distribution of “local” galaxies




Homogeneous and isotropic at large scales

# Looking far away is looking back in time!

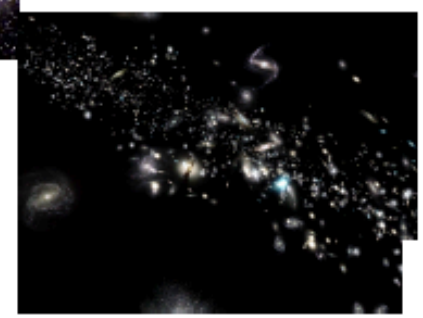
**8 minutes ago**


**28000 years ago**

Cosmic archeology

Andromeda, M31

**2.2 million years ago**



**3 billion years ago**

Looking far away in space= looking back in time