Image Credit: Nathan J. Carlson

What the biggest things in the universe can tell us about the oldest and the smallest

After the talk, explore our different interactive activities and the telescopes at the McLennan Physical Laboratories, until 10:00pm EST.

Like us on Facebook for event updates:
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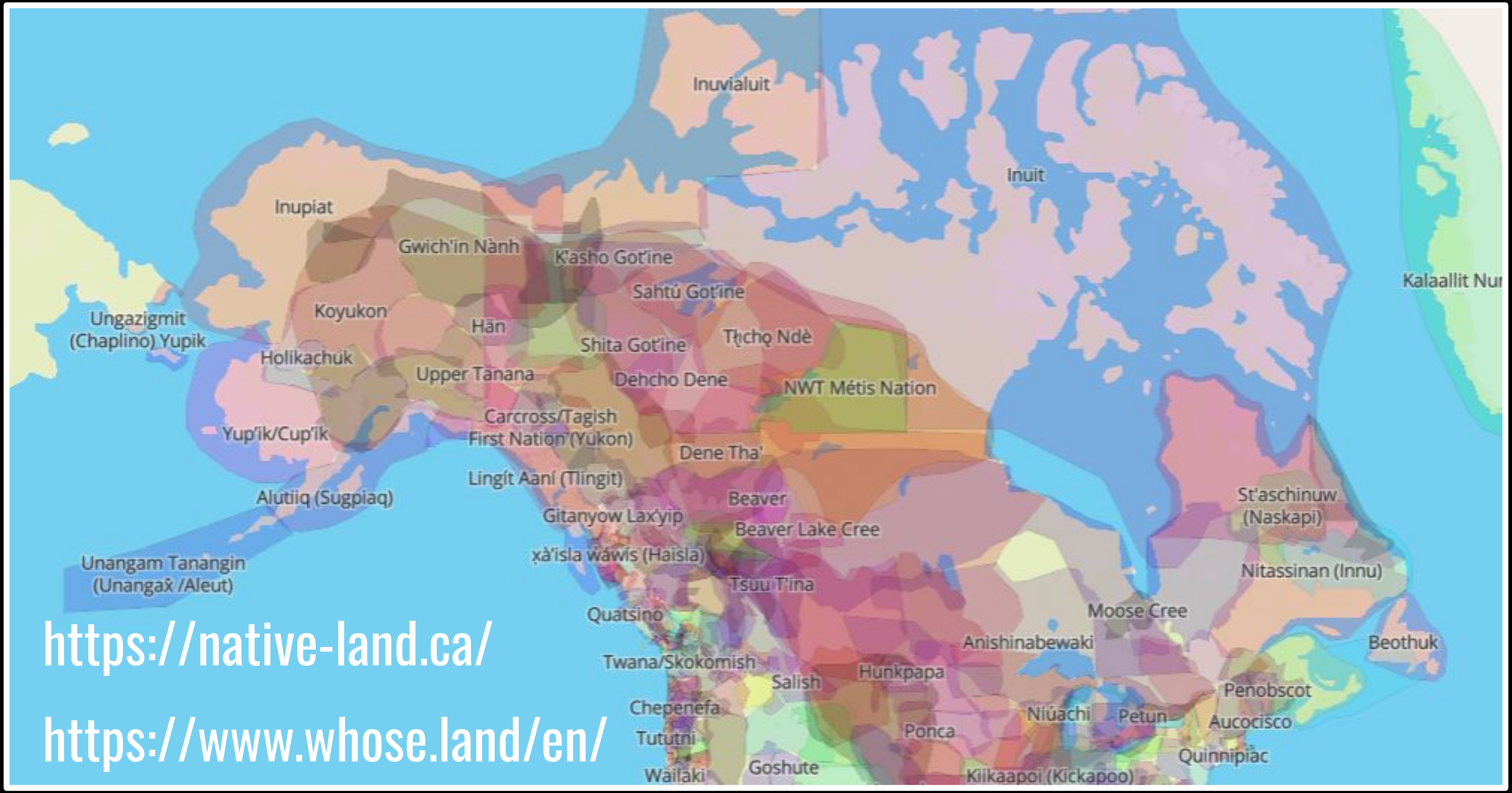
Land Acknowledgment



Tonight's Plan

- ✦ Lecture by Nathan J. Carlson.

- ✦ Go to the McLennan Physical Laboratories and explore our different interactive activities and visit the telescopes, until 10:00pm EST.

- ✦ Please fill out our feedback form here: https://bit.ly/astrotours

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Upcoming Events

January AstroTour:

- ✦ Speaker James Lane
- ✦ Thurs. January 11th, 8:00PM EST
- ✦ Location: TBD

Like us on Facebook for event updates:
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Upcoming Events

✦ Variety of online and in person events being held this month by the Royal Astronomical Society of Canada, visit their website for more information: https://rascto.ca/events

Like us on Facebook for event updates:
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Tonight's Speaker

Nathan J Carlson

Nathan is 5th year PhD candidate in the Department of Physics and at the Canadian Institute for Theoretical Astrophysics at the University of Toronto. His research focuses on simulating the distribution of energy in the early Universe to model the evolution of large scale structure (the clumping together of galaxies over cosmic time) in order to better understand the epoch of inflation (a period of time when the very early Universe expanded very, very rapidly). Nathan was born and raised in Ottawa, completing his BSc in Physics at UOttawa before coming to UofT to start his PhD. In his free time, Nathan is very outdoorsy, and likes to do things outside, like hiking and canoeing. In fact, Nathan has seen at least four different species of wild deer.

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ASTROTOURS

What the biggest things in the universe can tell us about the oldest and smallest

Physics
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CITA
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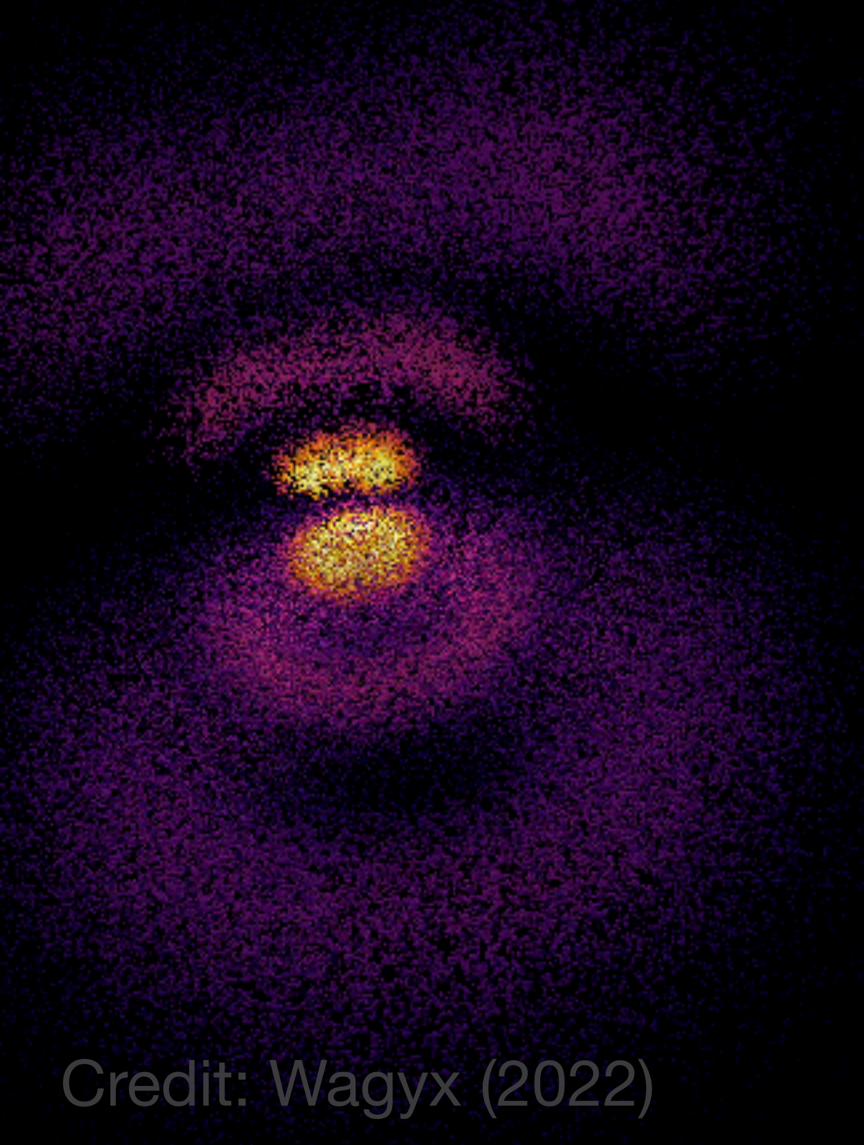
Nathan J. Carlson - CITA/UofT - AstroTours December 6, 2023

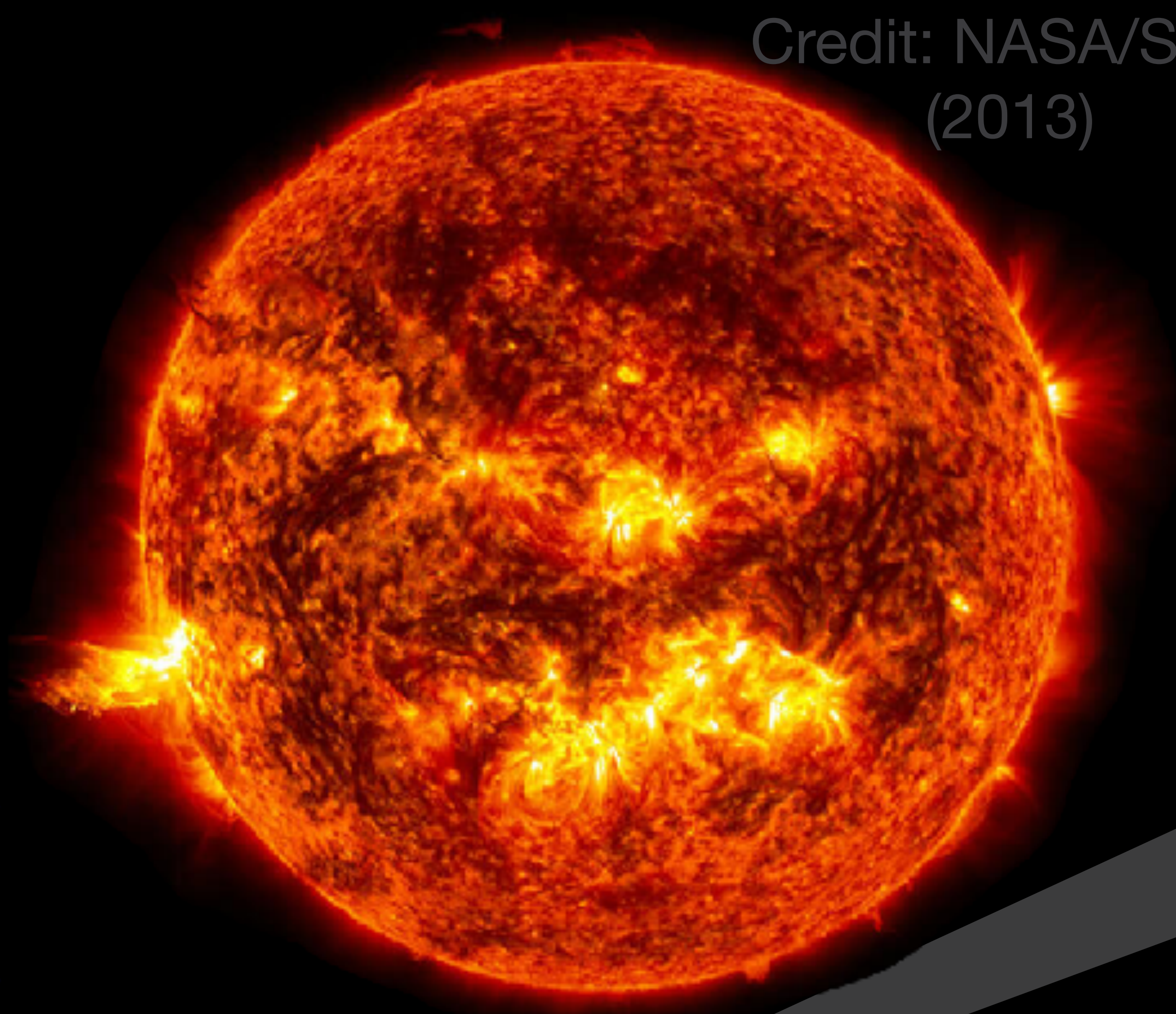
What *is* cosmology?

We care about things that are a huge range of sizes!

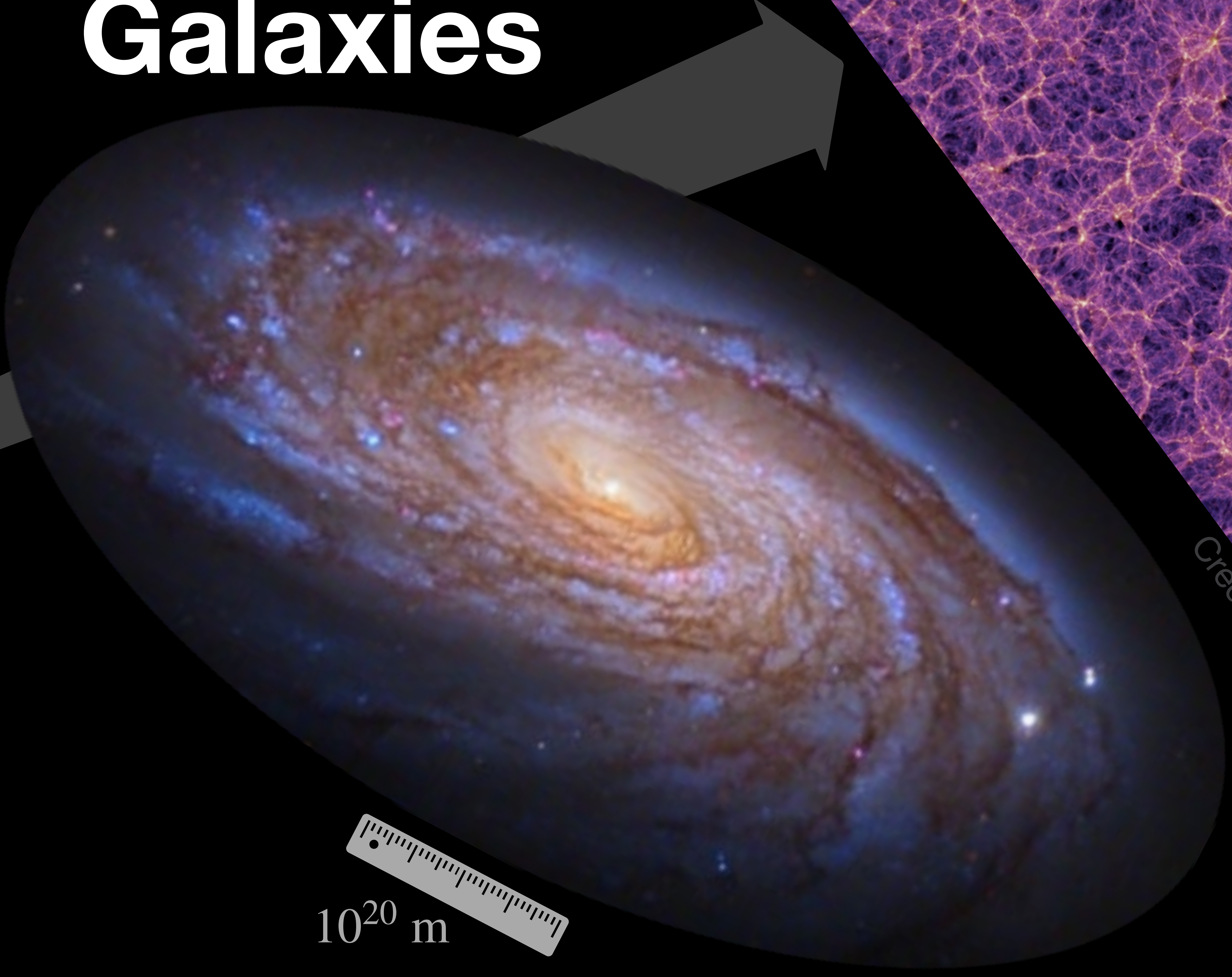
Quantum fluctuations



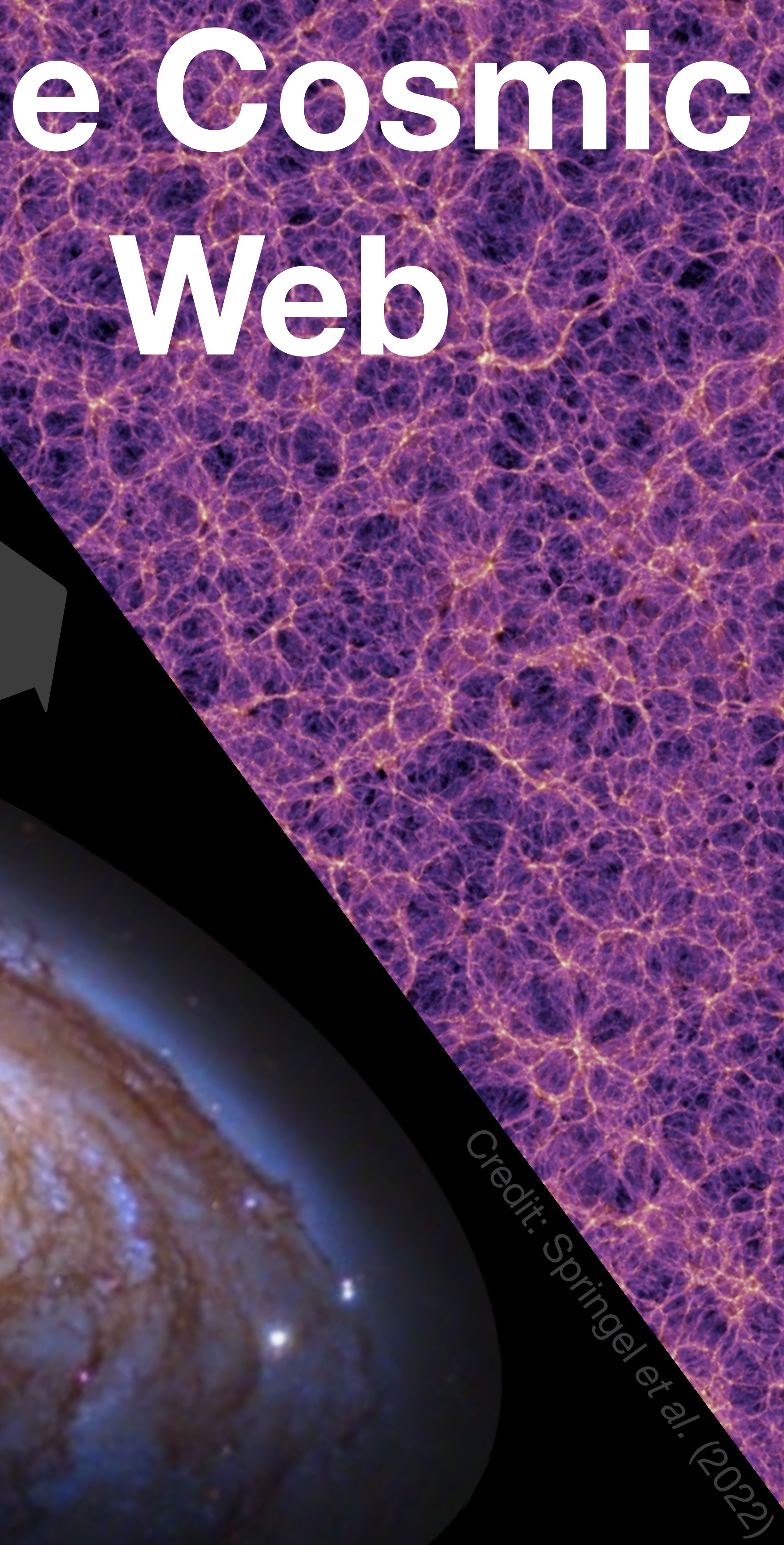
Stars



Galaxies



The Cosmic Web



What *is* cosmology?

We also care about things that happened over a huge span of time (13.8 billion years to be precise!)

Credit: NAOJ/ESO

What interests me as a cosmologist? Why does the universe look like this and not like something else?

Credit: NASA/JWST

Light has a speed, so it takes time to get to us, and so we see far, far away things as they were a long time ago

Credit: presumably Disney, they own everything now

Let's do some cosmic detective work. Can we figure out what the universe looked like in the distant past?

Credit: A. Block/U. Arizona (2022)

The Doppler effect tells us that things that look red are actually moving away from us!

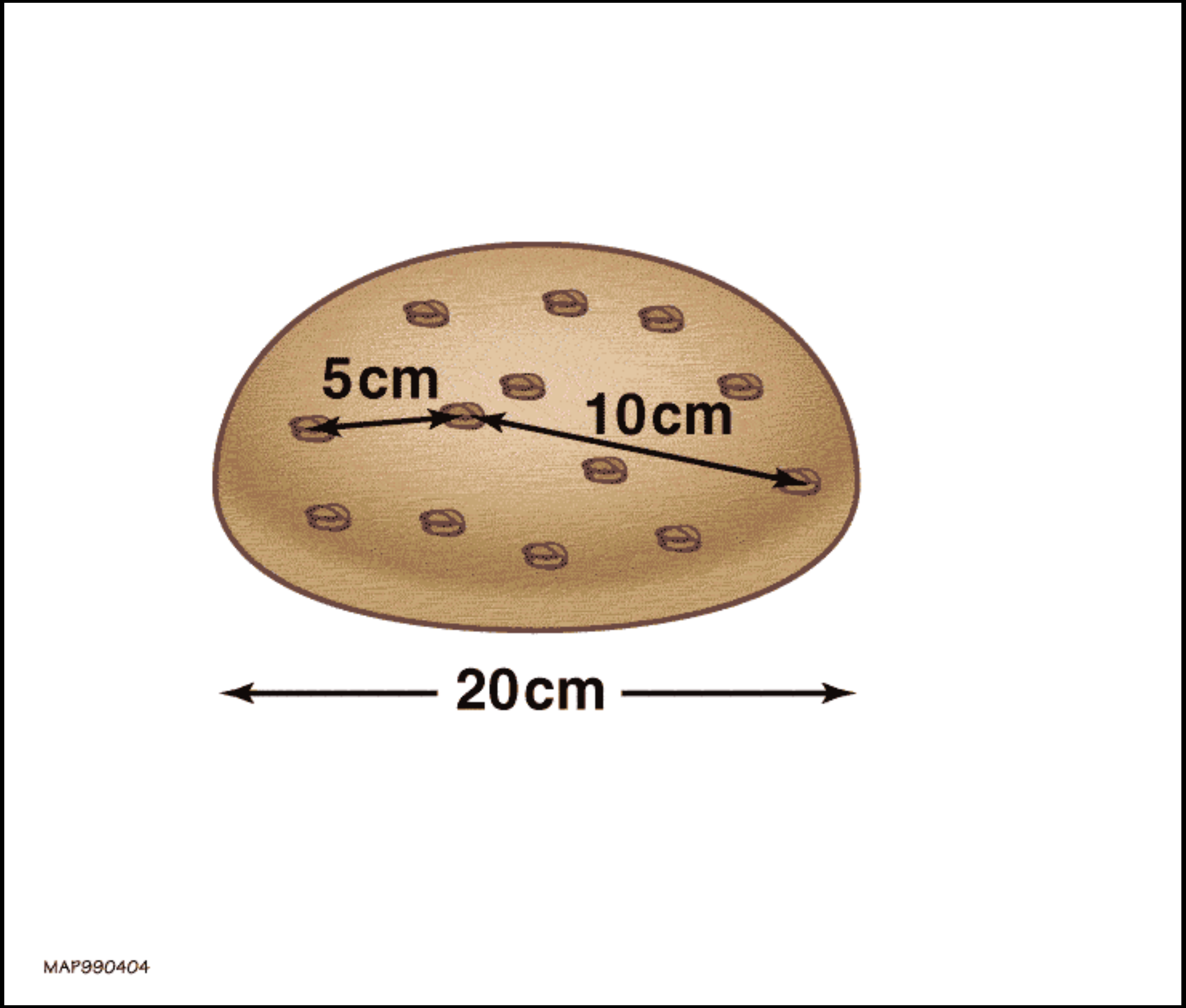
Credit: own work

Let's do some cosmic detective work. Can we figure out what the universe looked like in the distant past?

Credit: A. Block/U. Arizona (2022)

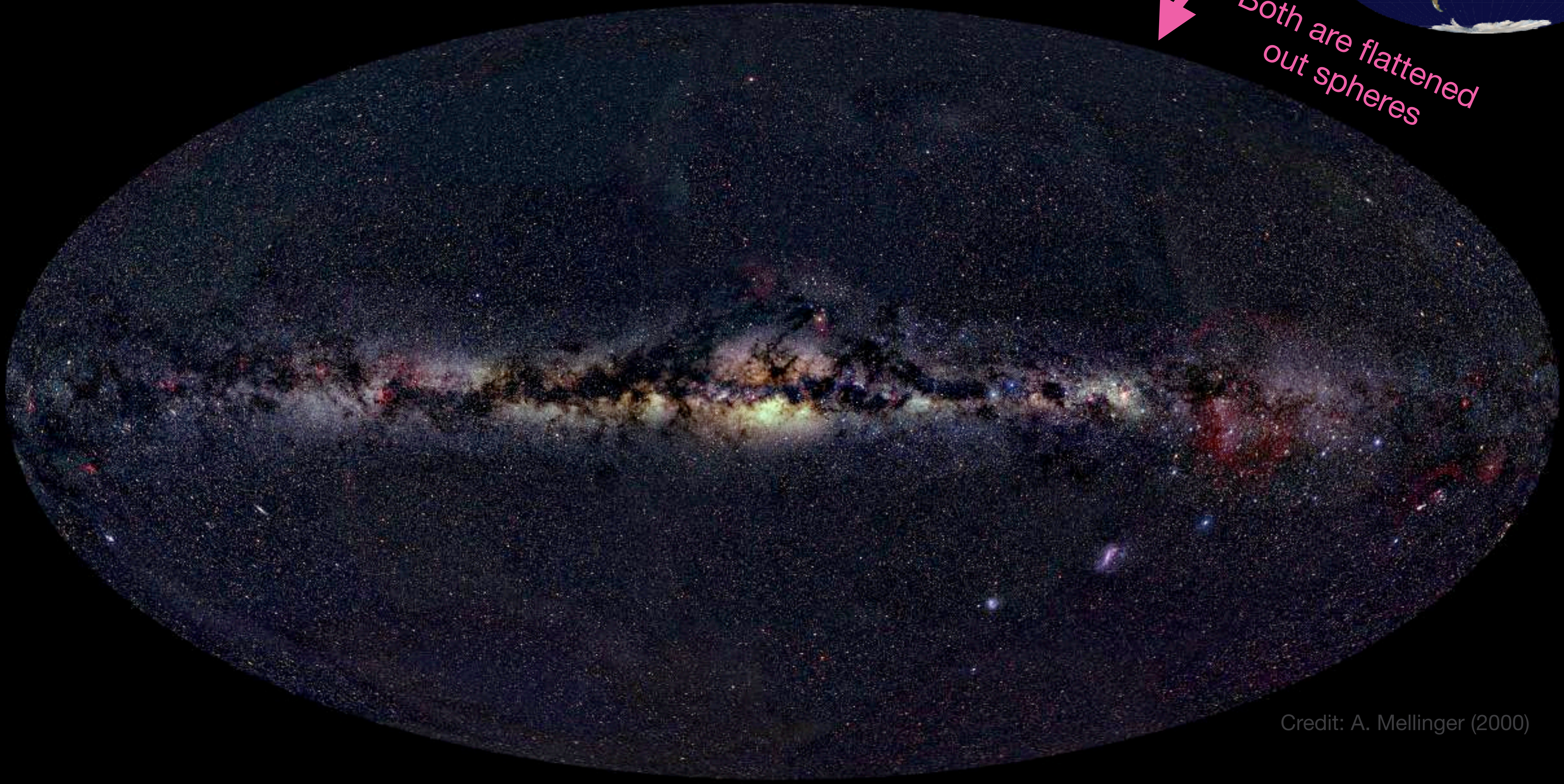
The universe is expanding like a loaf of raisin bread baking in the oven.

(and whether we like it or not, we're probably not in the middle of it)



Credit: NASA/ WMAP (2013)

The farthest back we can see …



The farthest back we can see is the **CMB**!

(Cosmic Microwave Background)

Both are flattened out spheres

Credit: ESA/*Planck Collaboration* (2013)

How could you get a CMB?

All matter emits light with a colour that depends only on its temperature.

Credit: S. Wasilewski (2017)

Iron or steel glow **orange** when heated up by a blacksmith to around $1000^{\circ}\mathrm{C}$.

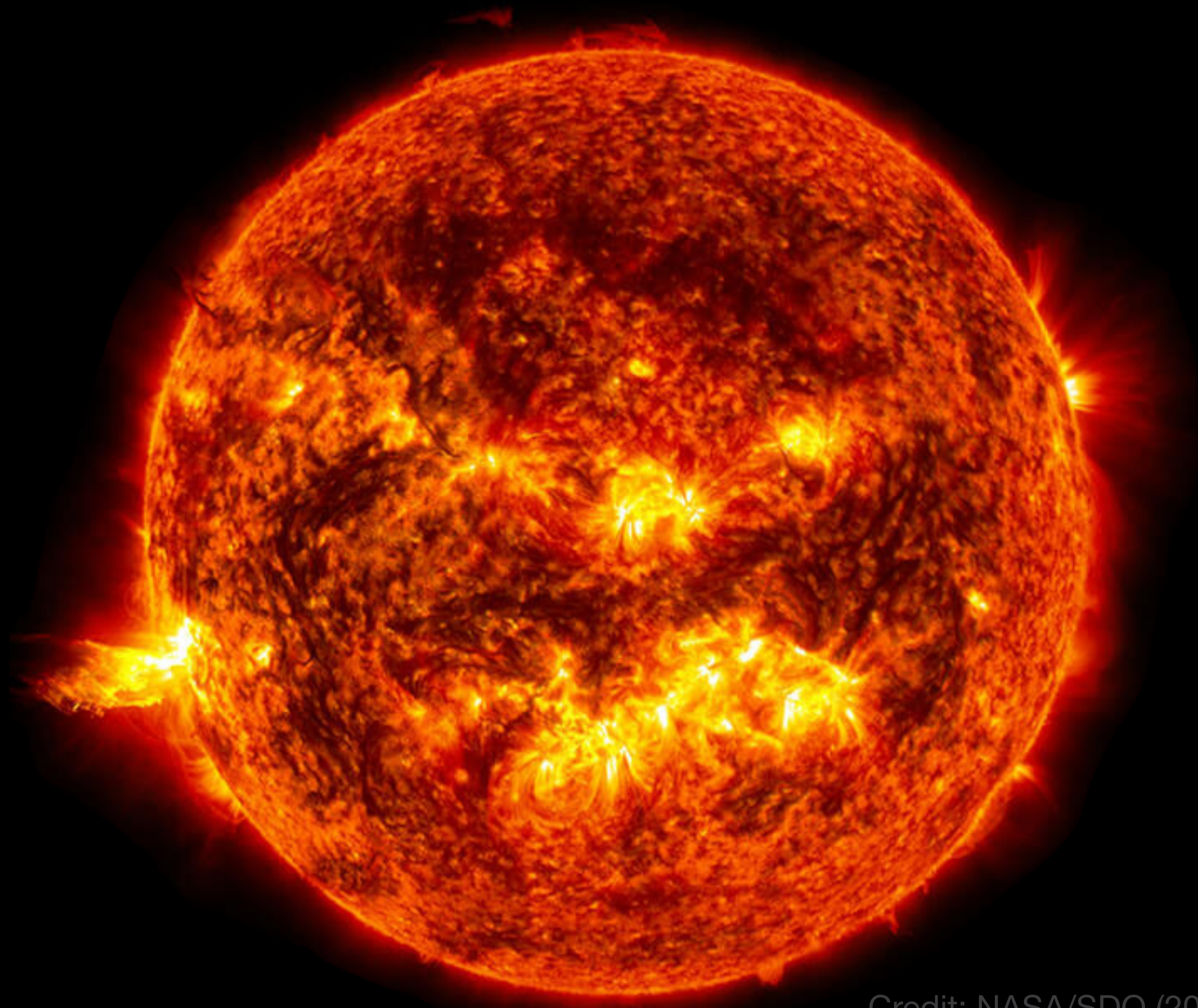
Credit: *Prehistoric Planet II*/BBC (2023)

Animals at around $37^{\circ}\mathrm{C}$ (like you or these dinosaurs) emit ***infrared*** light! We can't see it, but it's made up of the same stuff as the light we can see!

Our atmosphere is made of neutral gas, so we can see through it.

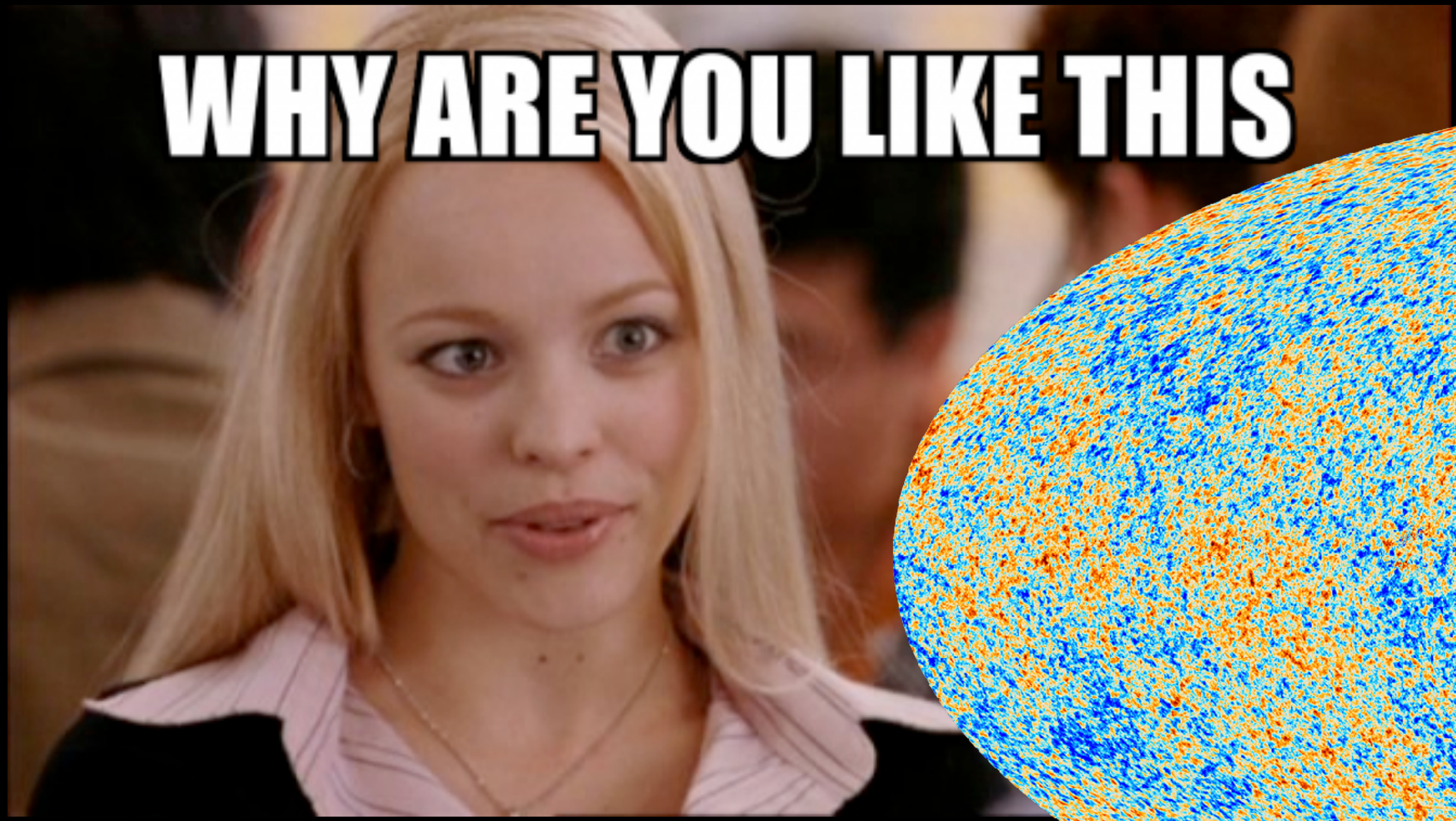
Credit: own work

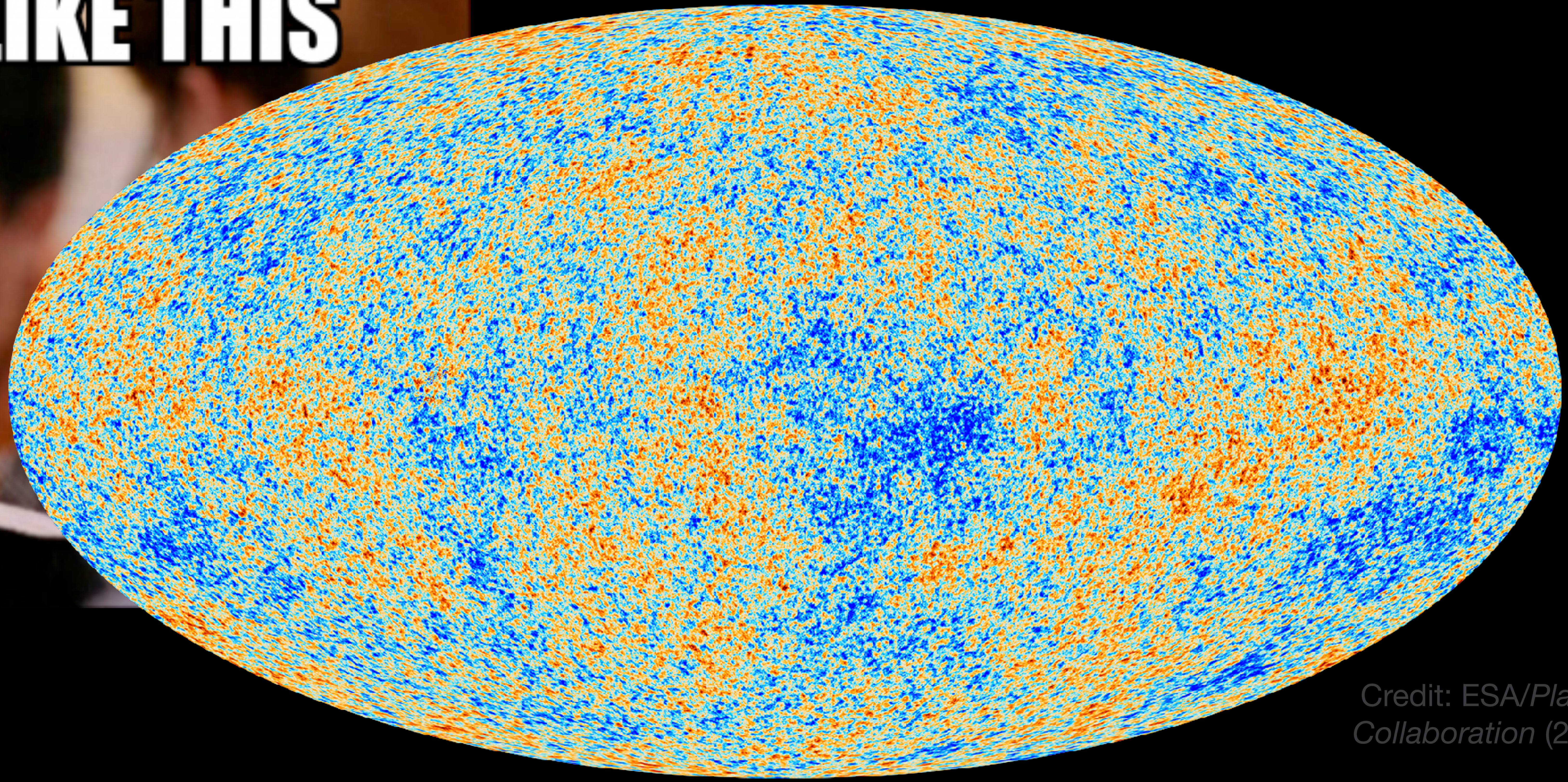
Stars are made of more ionized gas, so we can't see through them.



Credit: NASA/SDO (2013)

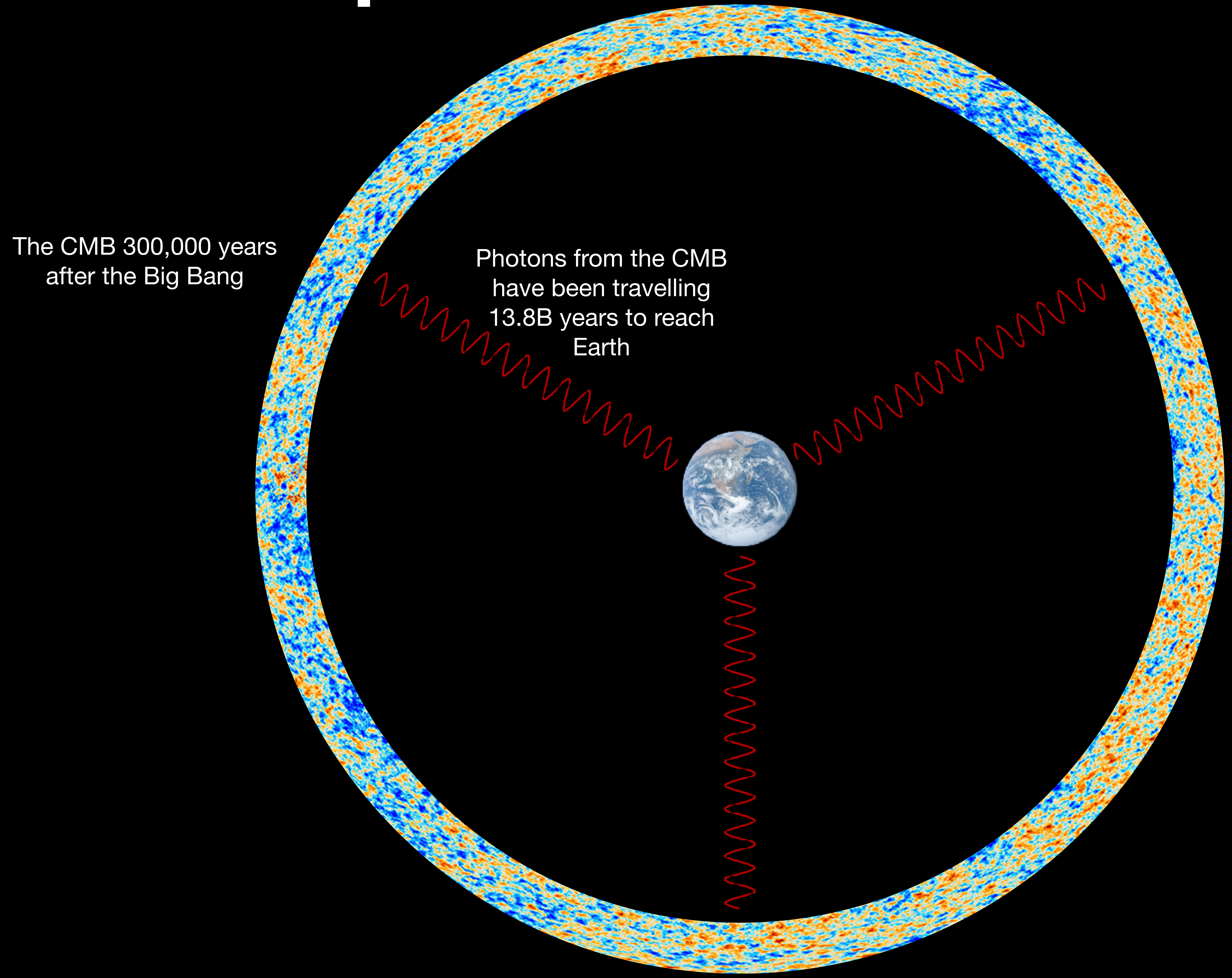
All this evidence points to the *Big Bang*. But there are still some physics problems that the Big Bang alone can't explain.





Credit: ESA/*Planck Collaboration* (2013)

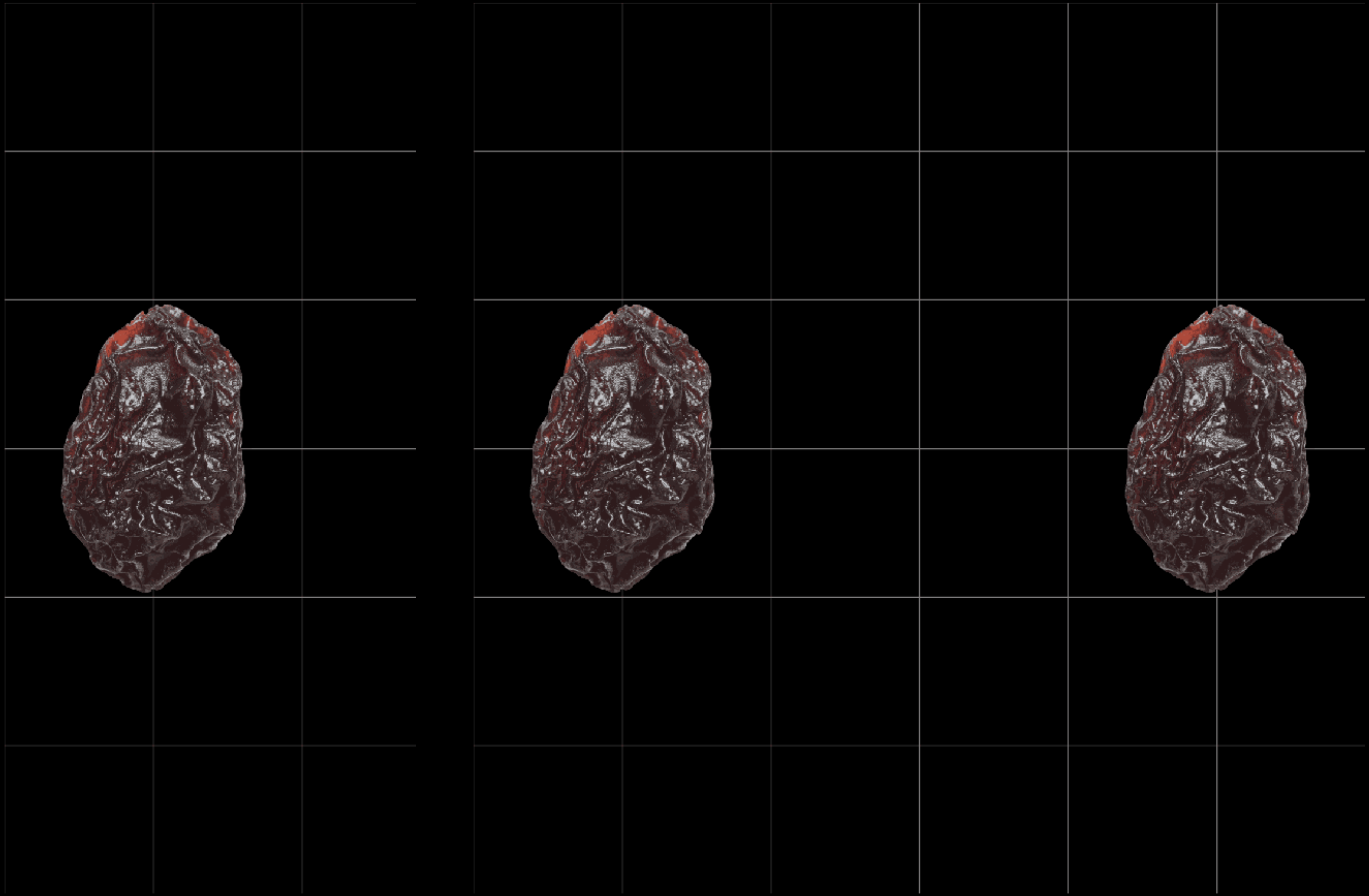
The horizon problem



Credits: ESA/*Planck Collaboration* (2013), NASA/Apollo 17 (1972), own work

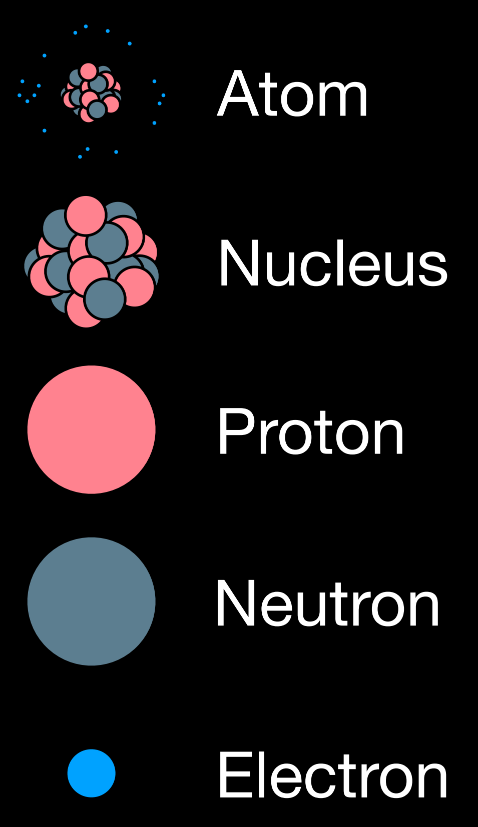
Before Inflation

During Inflation

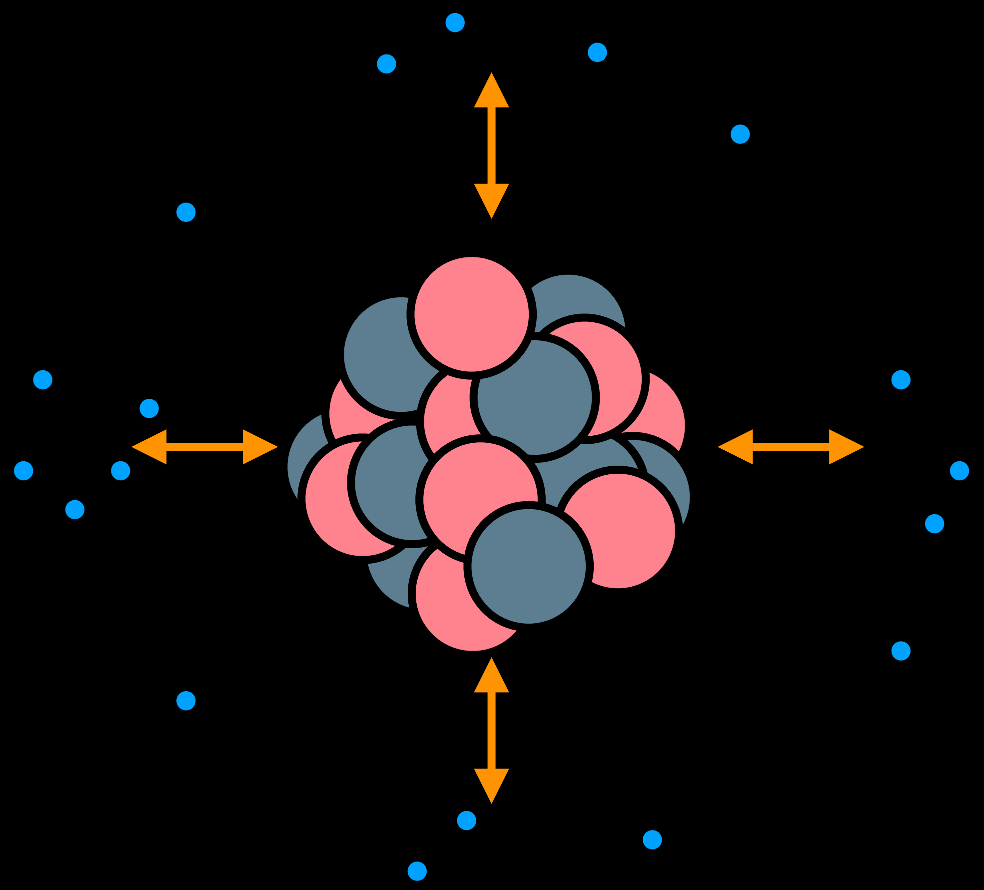


Credits: own work

How could inflation happen? Theoretical physics might be able to tell us. There are four fundamental forces in nature.

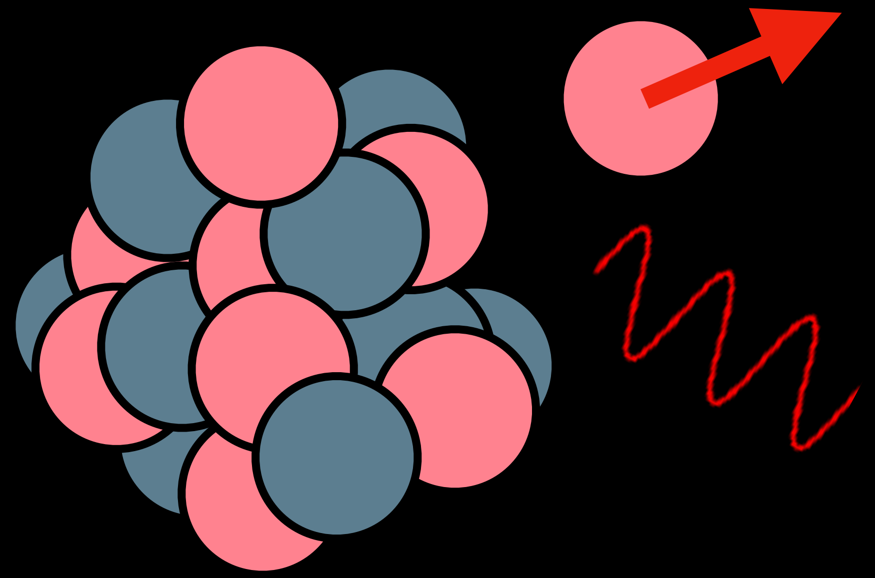


Electromagnetism



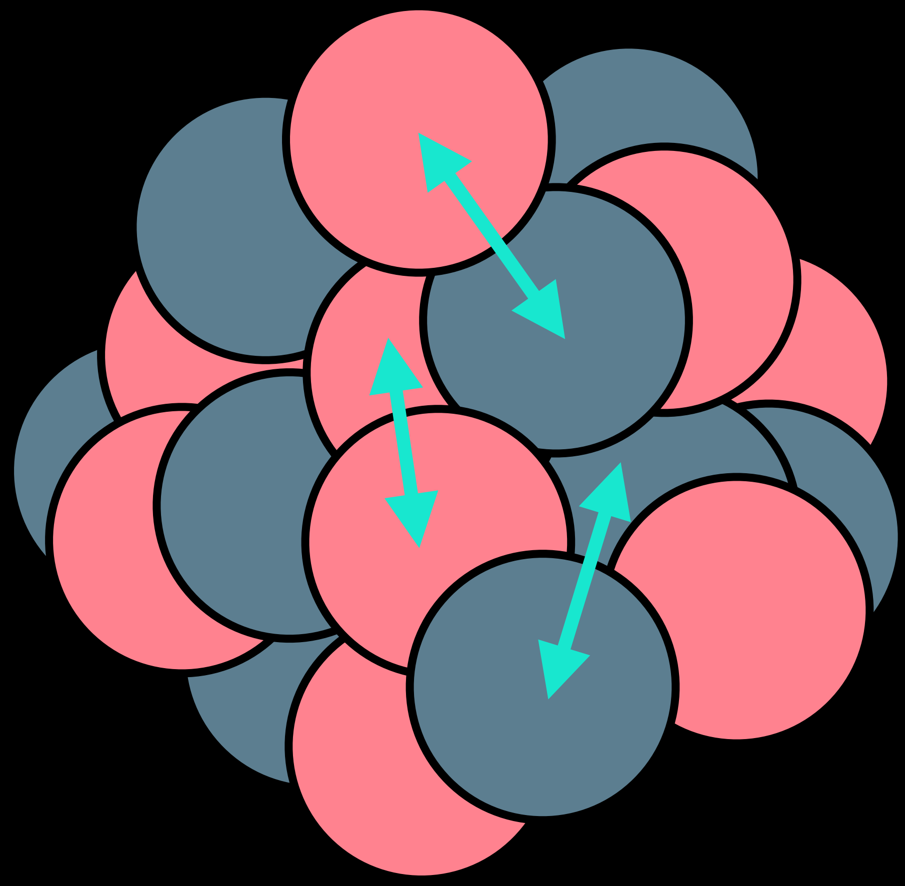
Holds atoms together.

Weak Nuclear Force



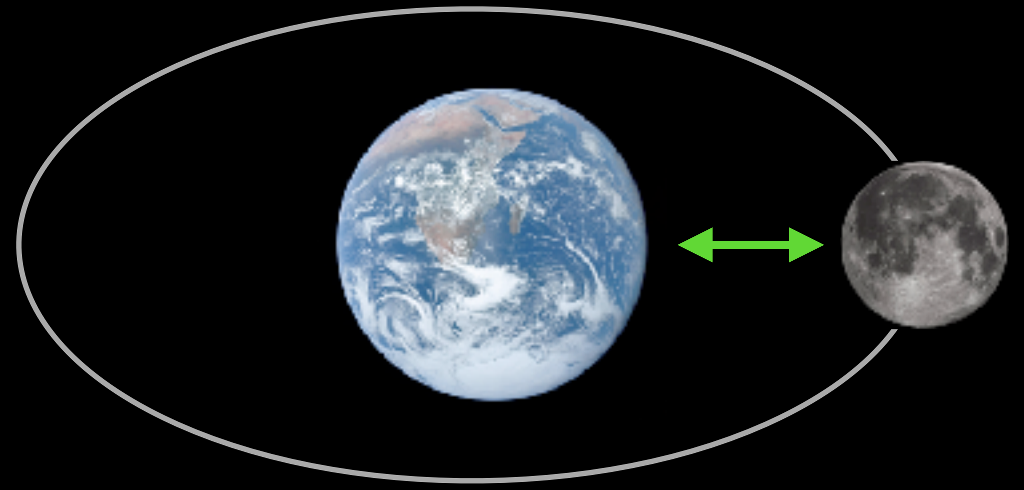
Involved in nuclear decay.

Strong Nuclear Force



Holds atomic nuclei together.

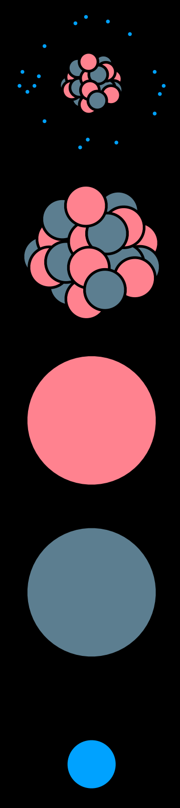
Gravity



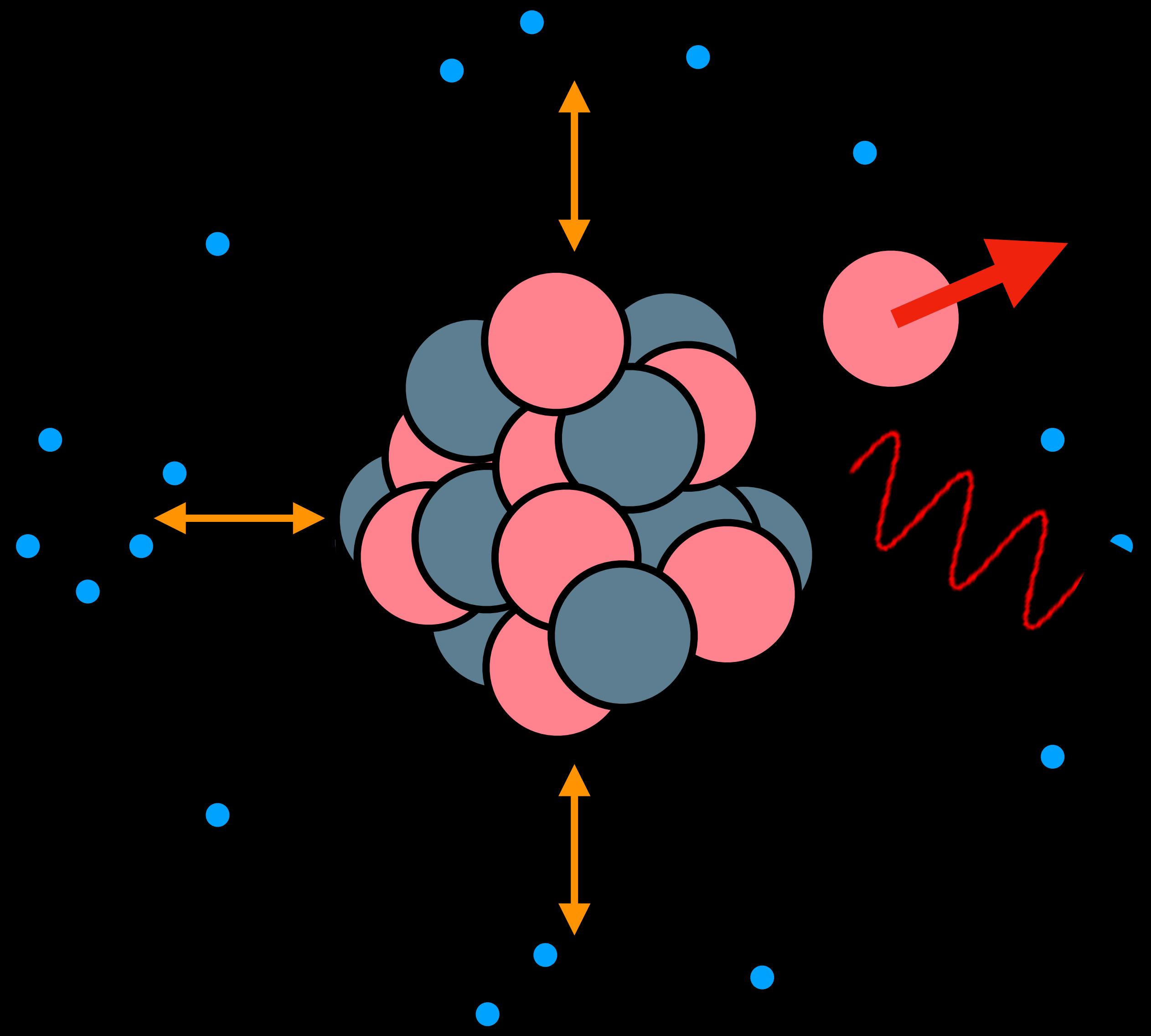
Makes apples fall on Newton’s head.

Credits: NASA/Apollo 17 (1972), own work

If things get hot enough, the forces can merge. If a hot thing cools, the unmerging releases lots of energy.

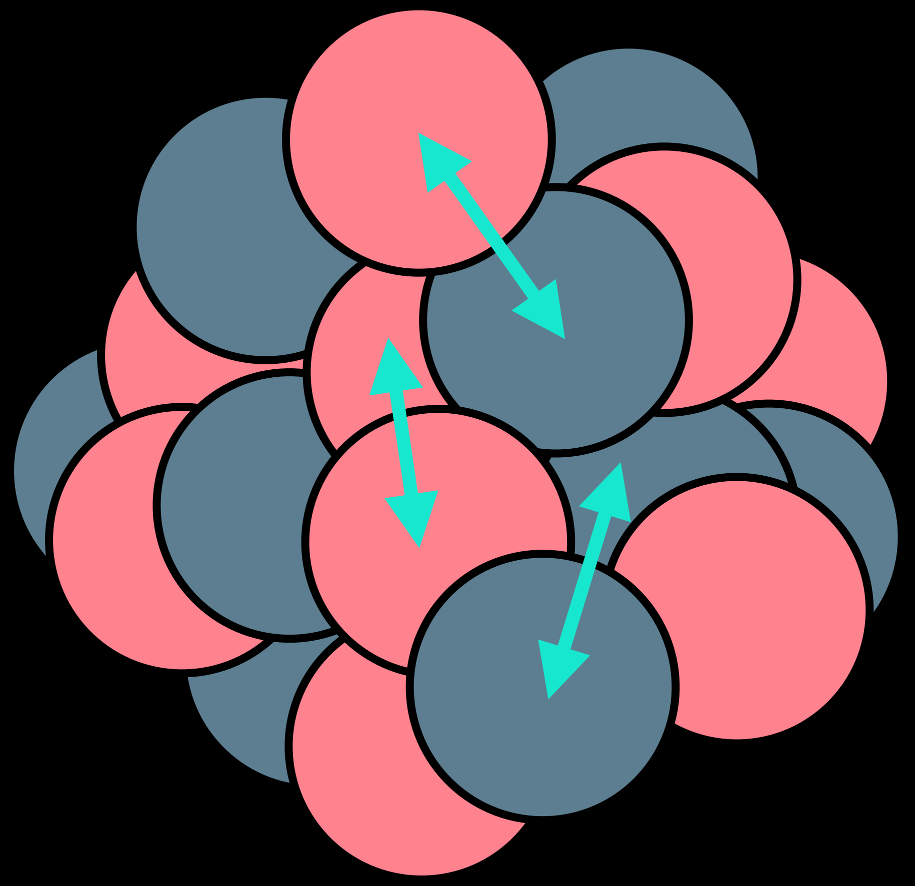


Electroweak Force



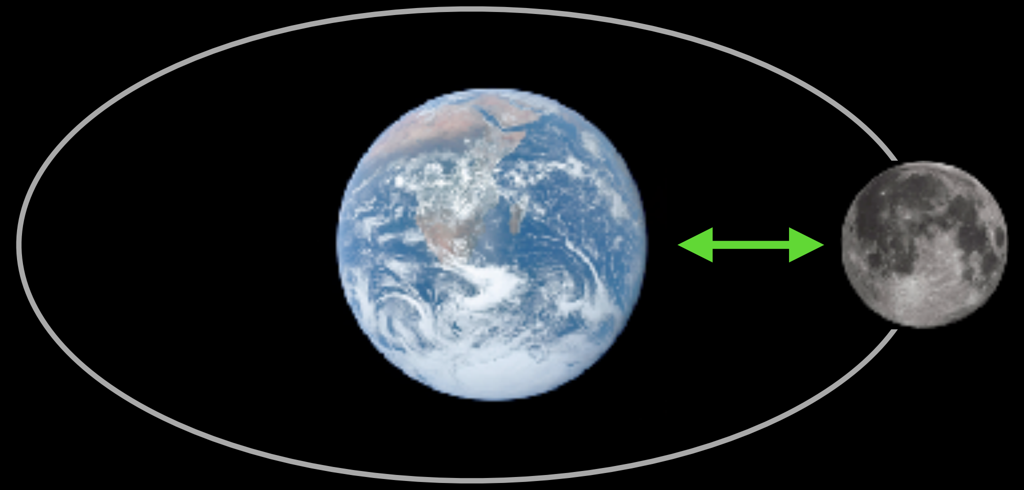
These forces become one at around 1 quadrillion °C

Strong Nuclear Force



Holds atomic nuclei together.

Gravity

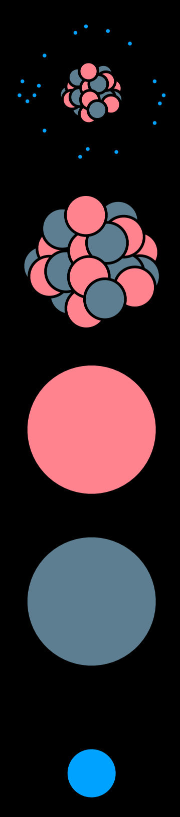


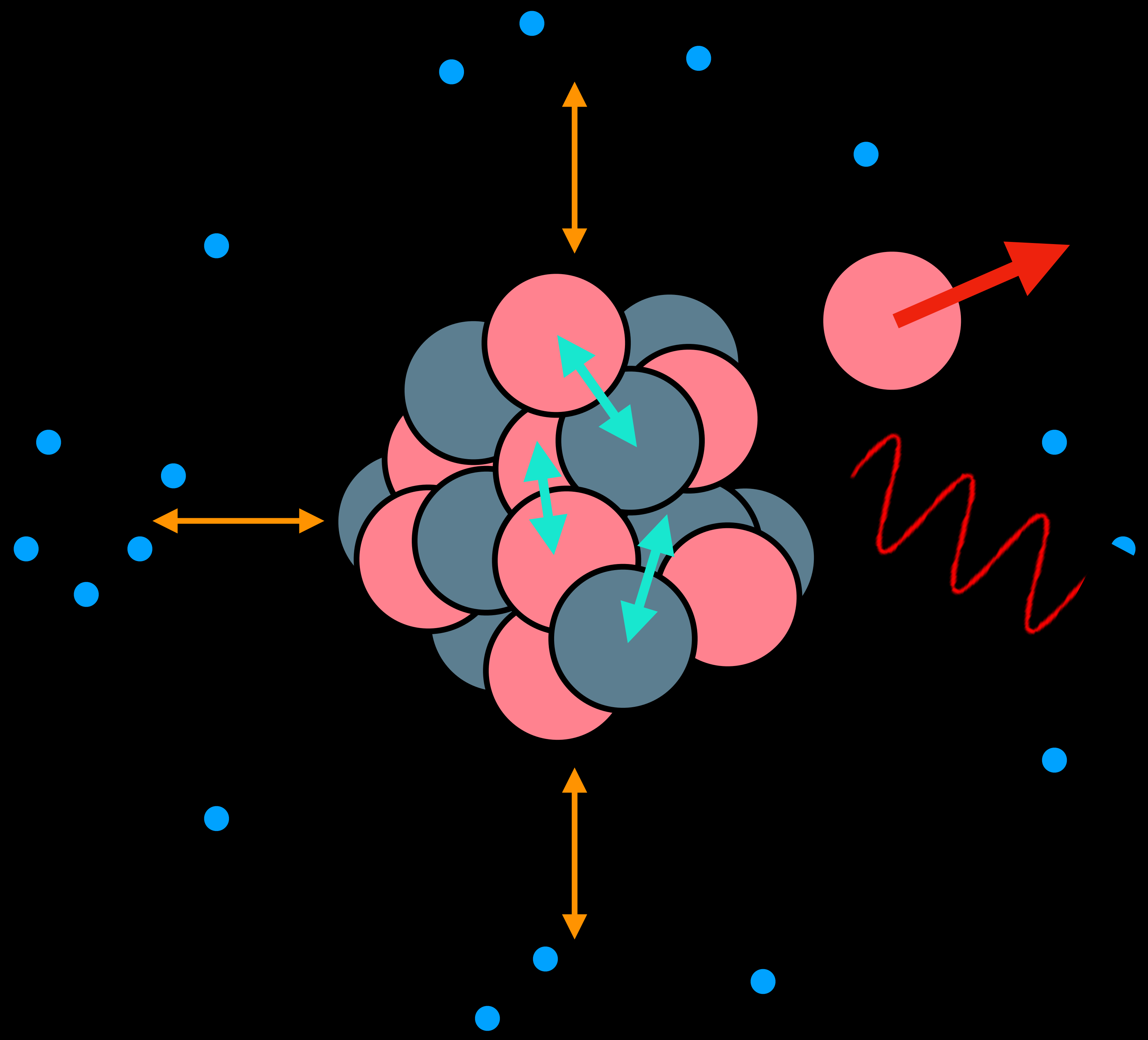
Makes apples fall on Newton's head.

Credits: NASA/Apollo 17 (1972), own work

If things get hot enough, the forces can merge. If a hot thing cools, the unmerging releases lots of energy.

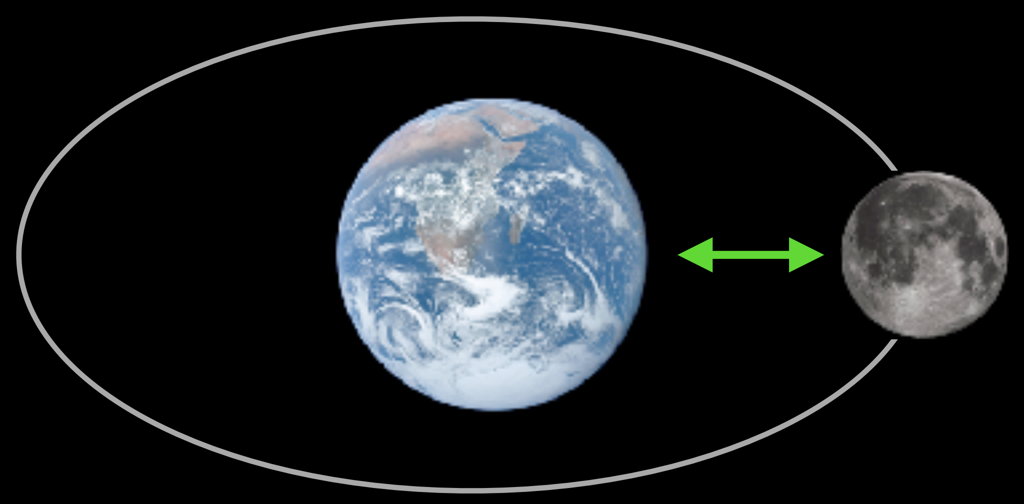
Grand Unified Theory





These forces become one at around 10 trillion times hotter than that!

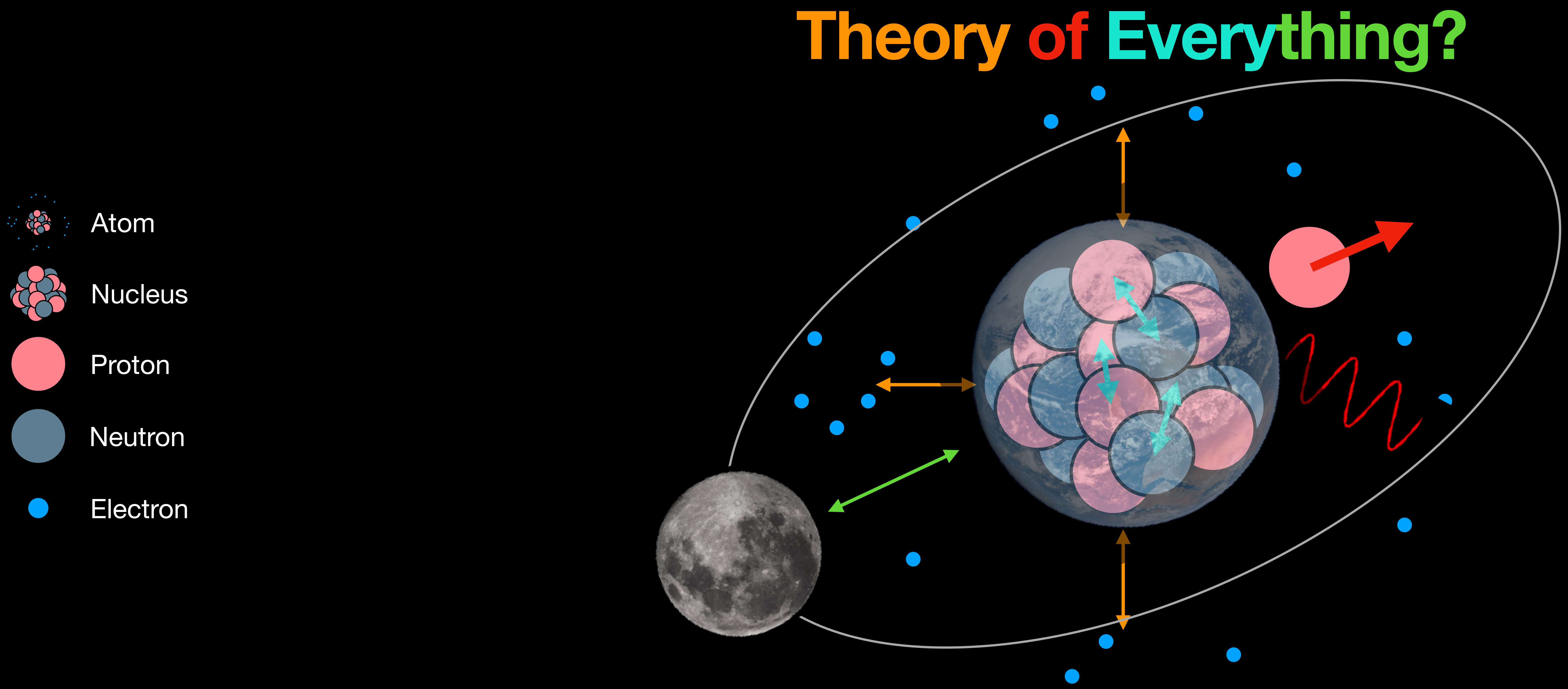
Gravity



Makes apples fall on Newton's head.

Credits: NASA/Apollo 17 (1972), own work

If things get hot enough, the forces can merge. If a hot thing cools, the unmerging releases lots of energy.



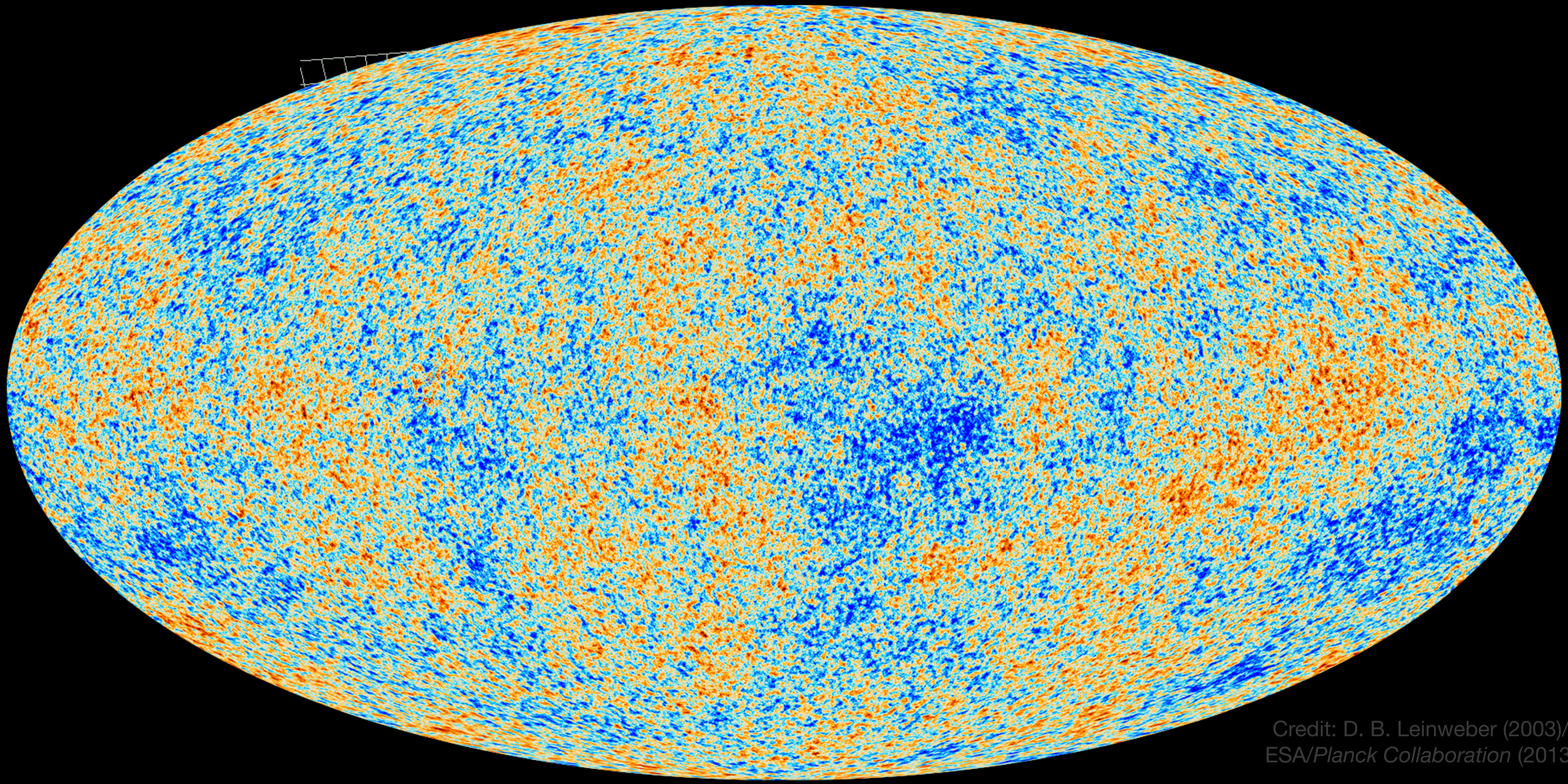
We have no idea if this is possible…

Credits: NASA/Apollo 17 (1972), own work

What proof do we have that inflation actually happened?

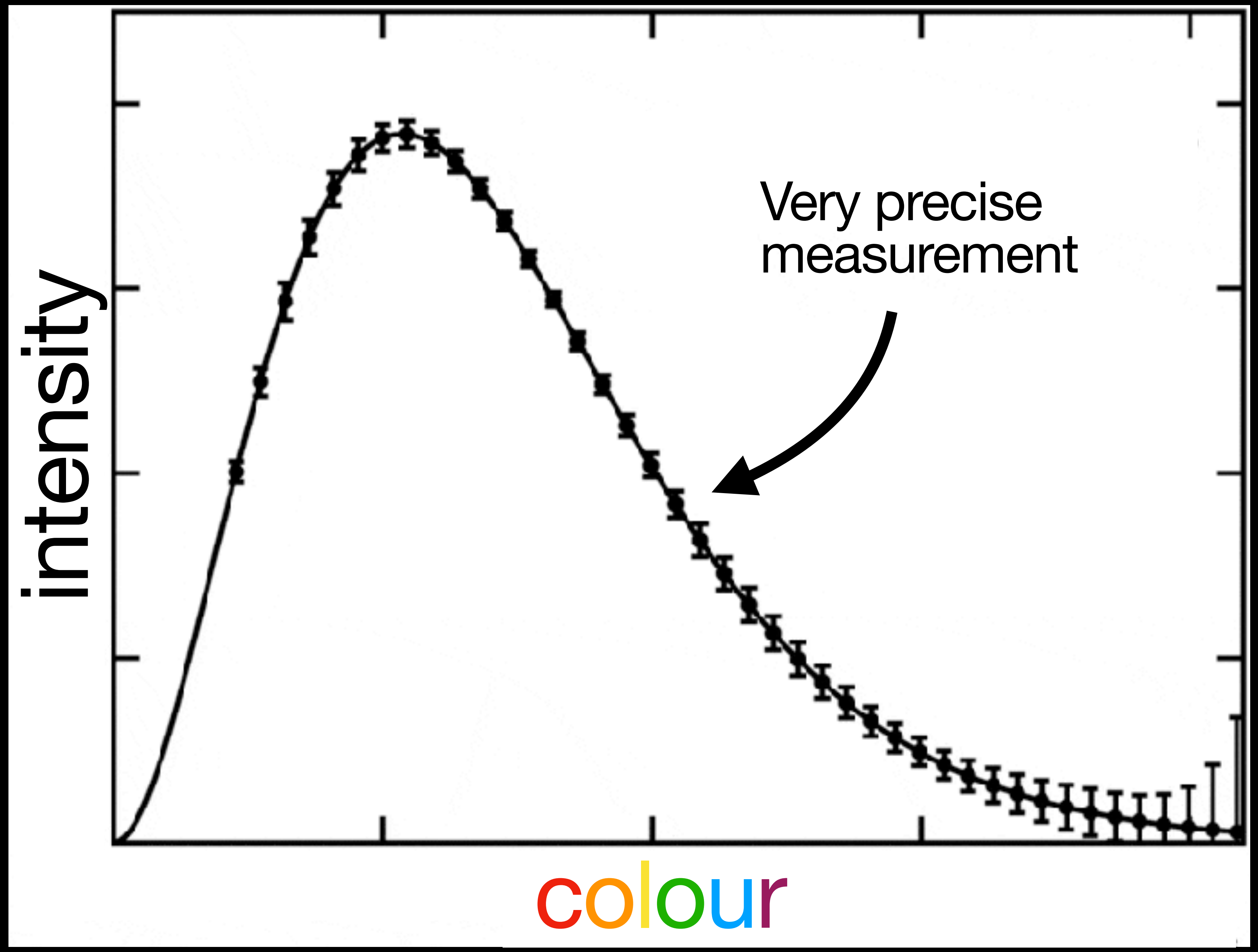
The often bizarre seeming theory of ***Quantum Mechanics*** offers one piece of evidence.

What proof do we have that inflation actually happened?



Credit: D. B. Leinweber (2003)/
ESA/*Planck Collaboration* (2013)

Inflation predicts a CMB and the CMB has *a lot* that it can tell us



Inflation predicts that we should see the CMB and that it should have the exact same colour that we see with our microwave telescopes.

Credit: N. Wright (1996)

We see different things when we look at the Earth and focus on objects of different sizes.

Credit: Google


Credit: Google


Credit: Google

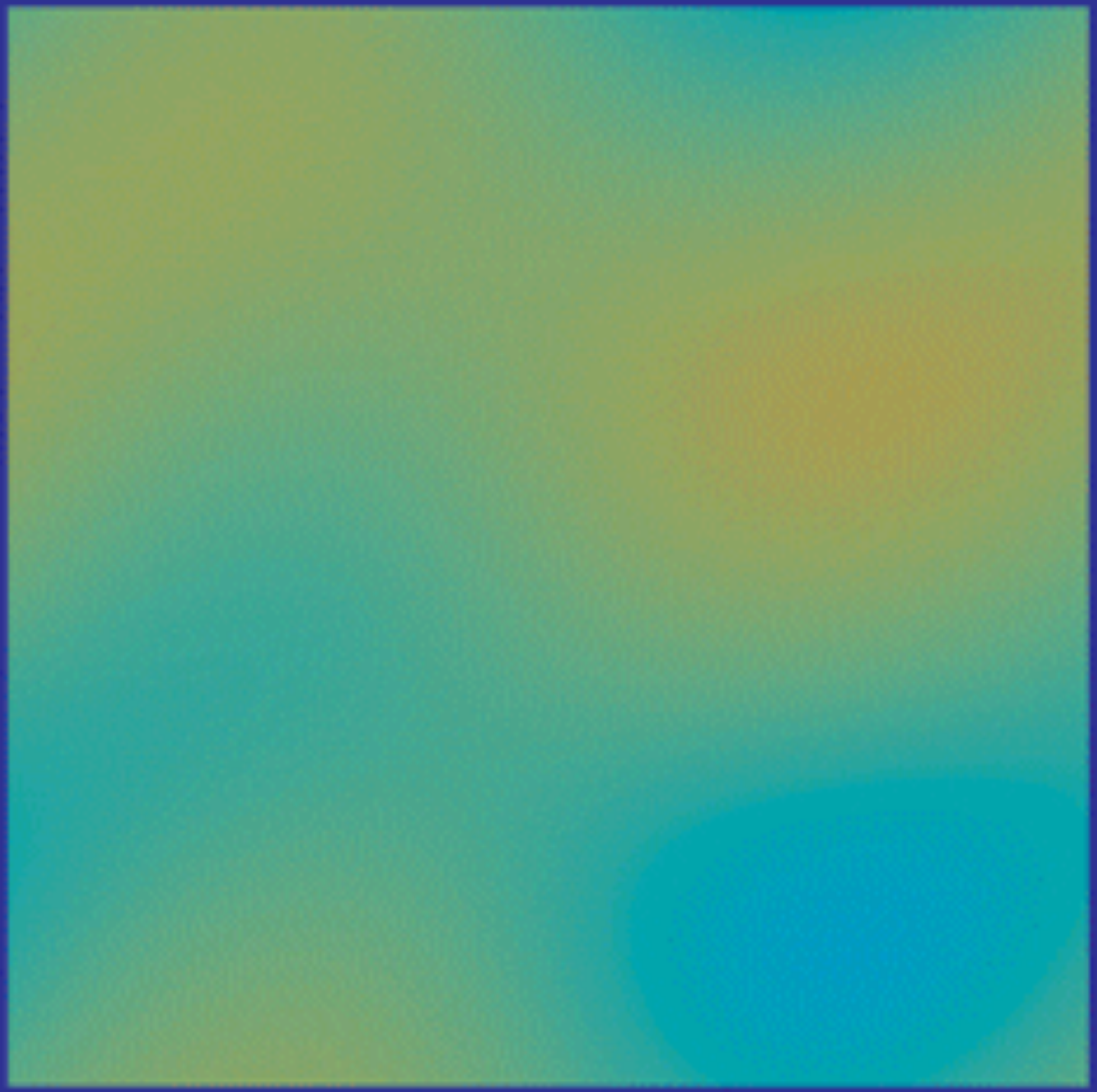
Credit: Google

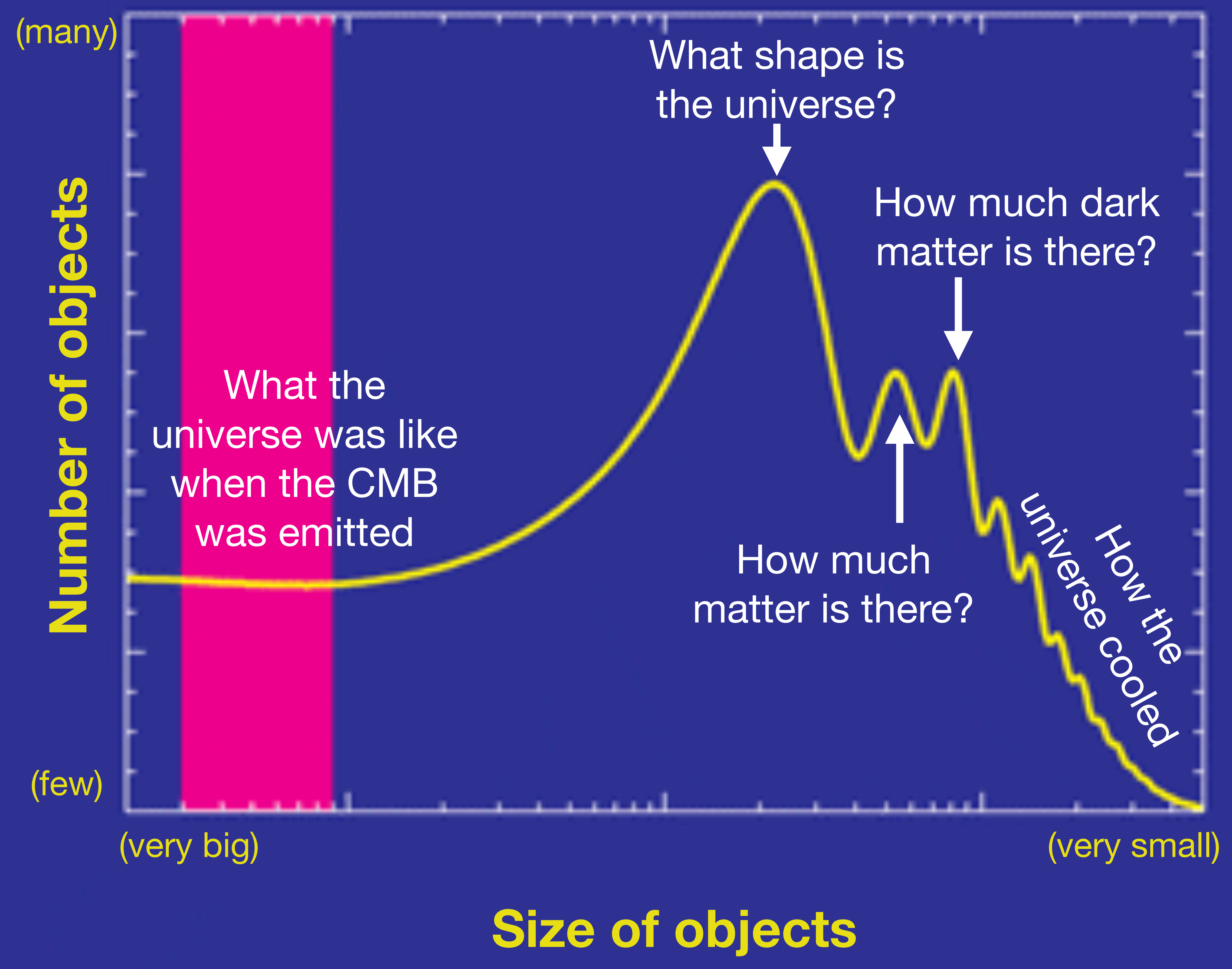

Credit: Google


Credit: Google


Credit: Google

Now, instead of zooming in, let's look at a region of the CMB and gradually increase the resolution of the image, resolving finer and finer detail.



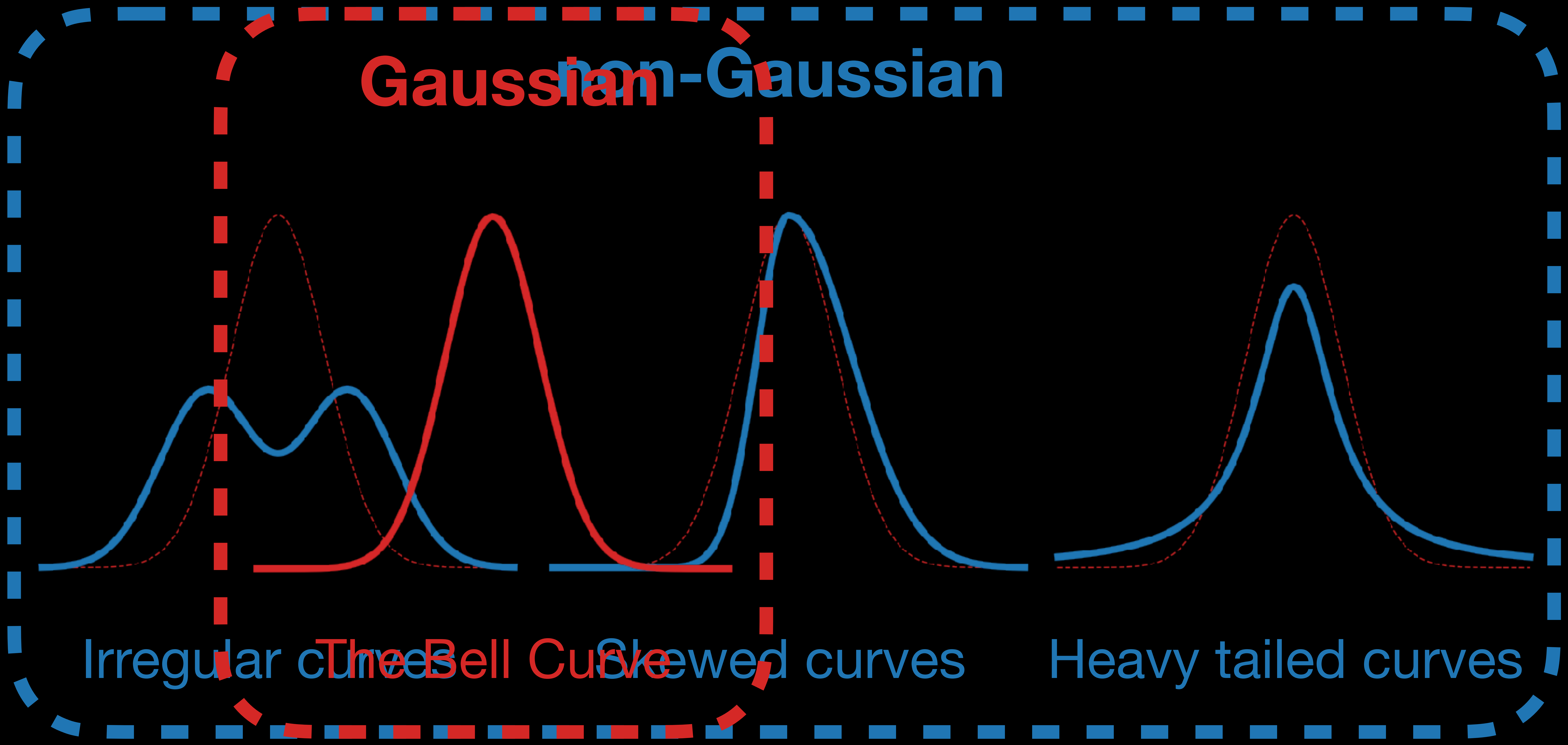


Credit: W. Hu & M. White (2004)

We can't see inflation, the CMB is blocking our view, so we don't know exactly what happened during inflation.

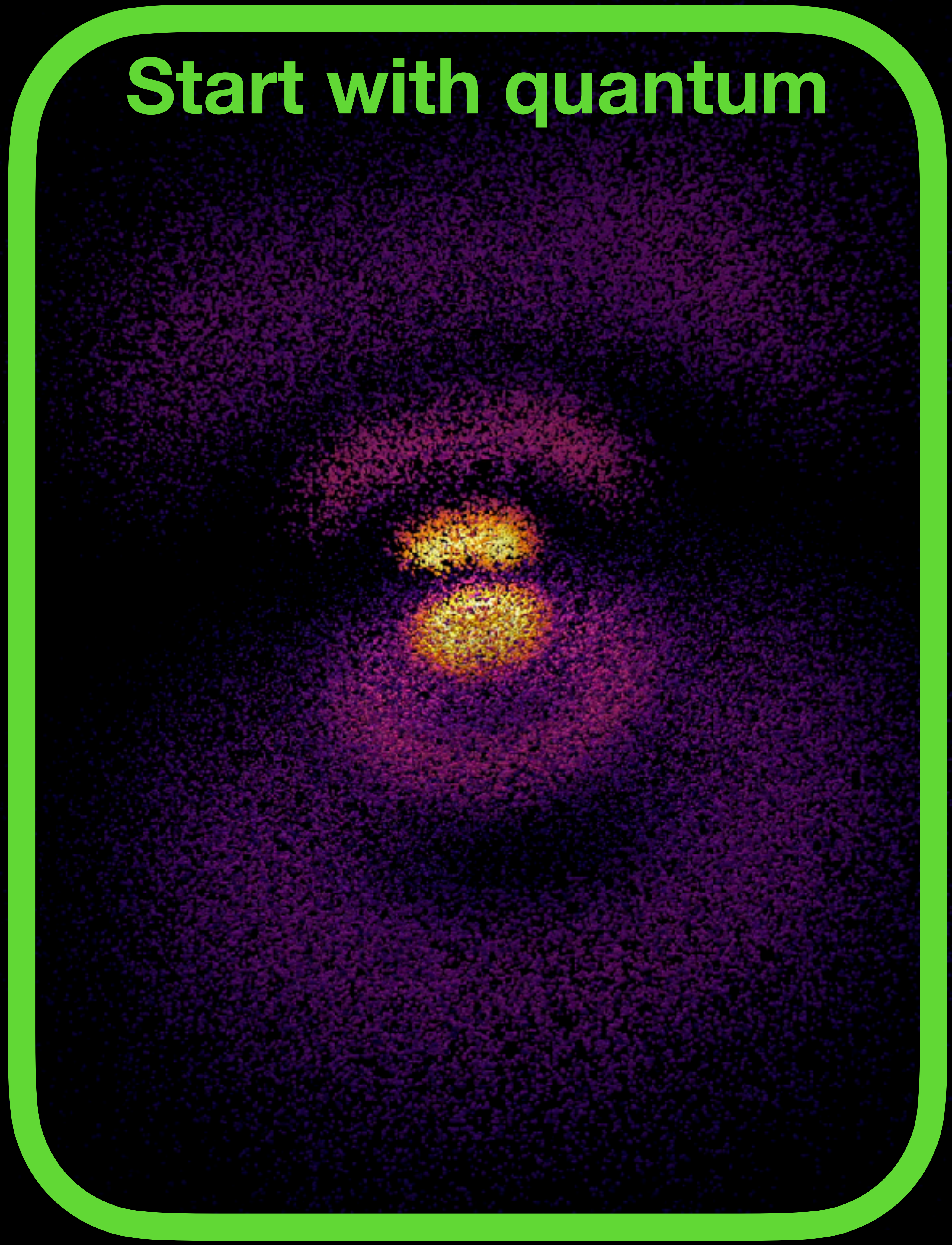
The CMB like many things in nature, very closely follows the same "Bell Curve" that you might be familiar from grading in schools.

The "Bell Curve" is also called a Gaussian. A non-Gaussian is any distribution that differs from the Bell Curve.

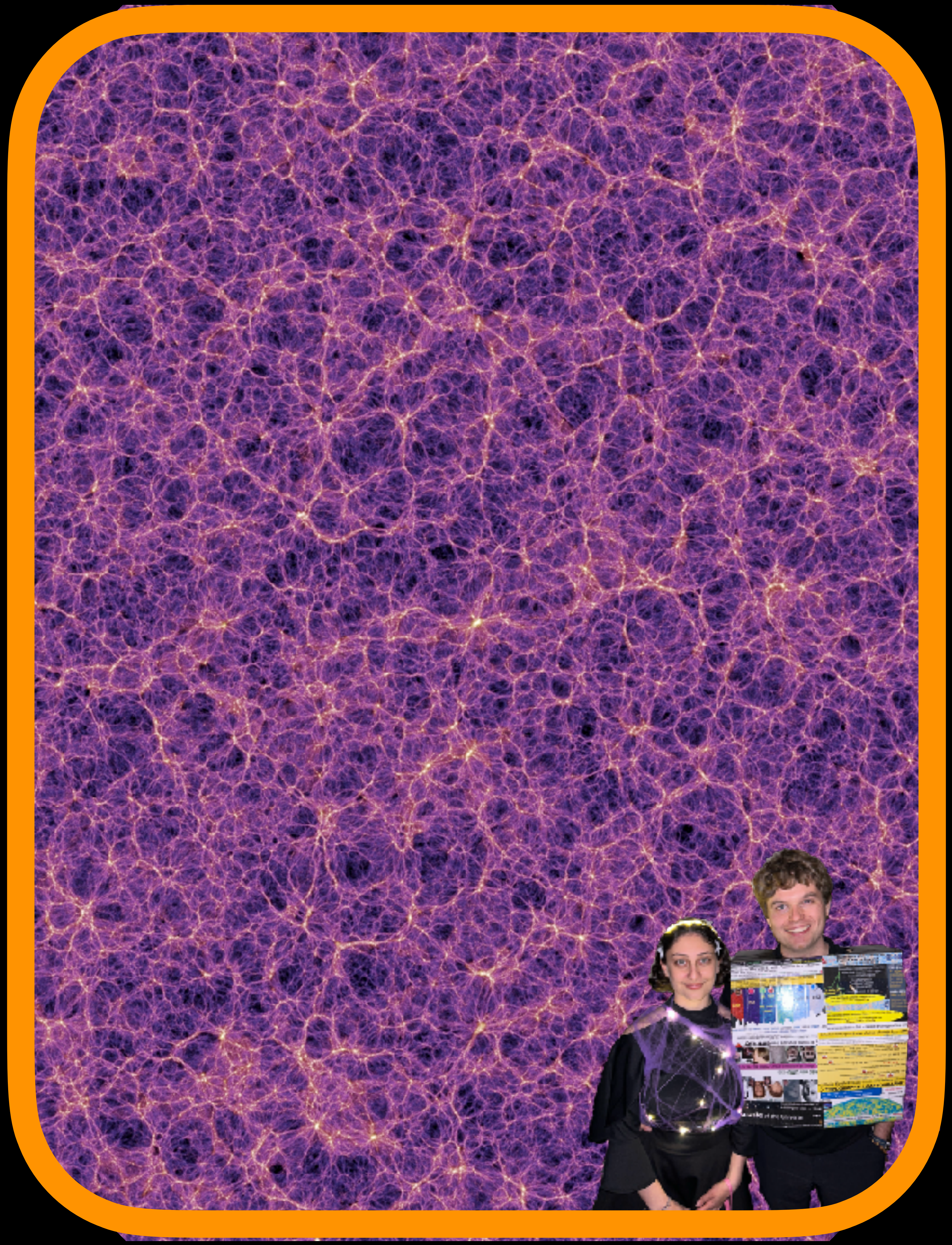


Credits: own work

I make simulations of the the the Cosmic Web starting from different types of inflation.



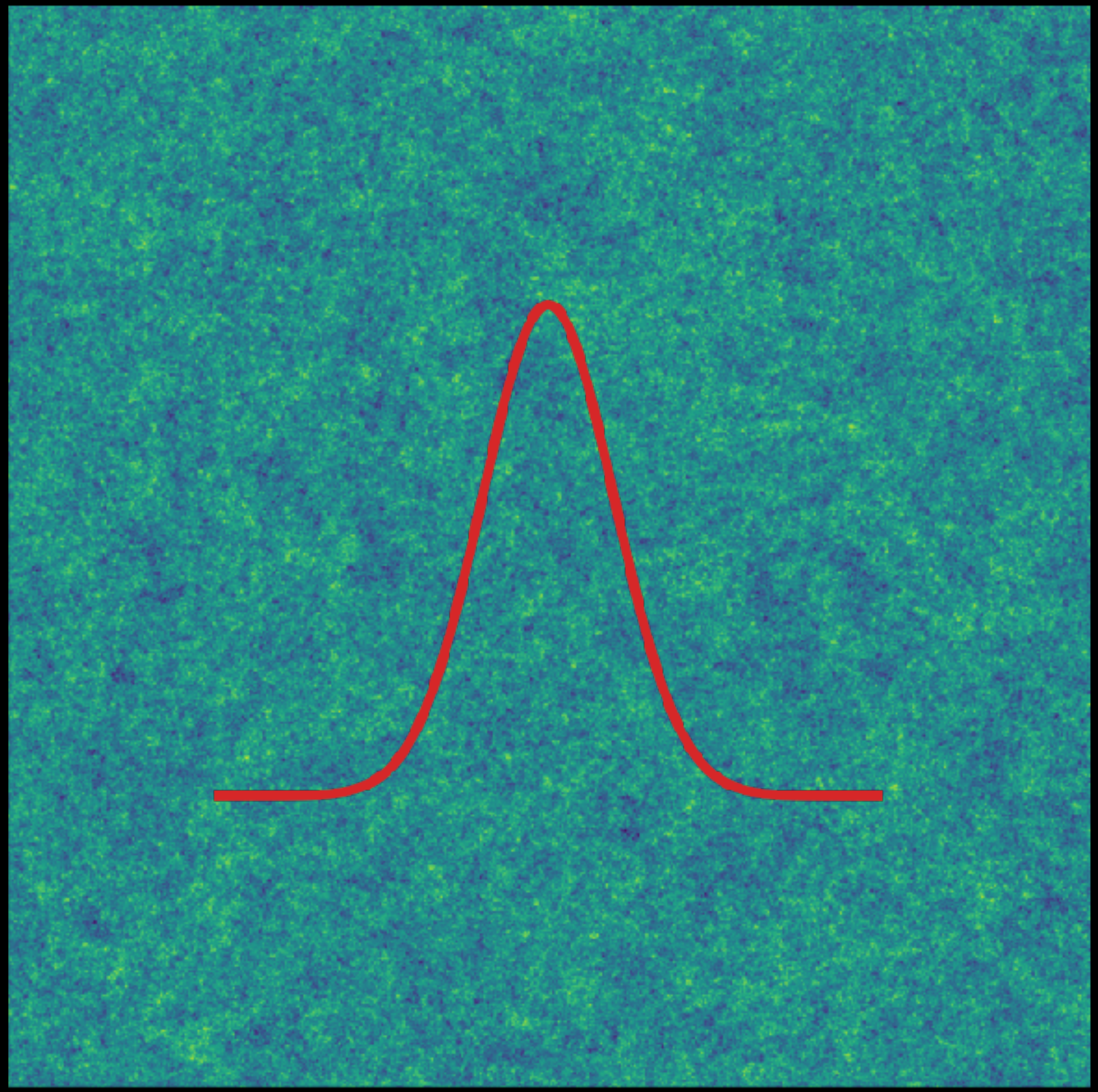
Make the Cosmic Web



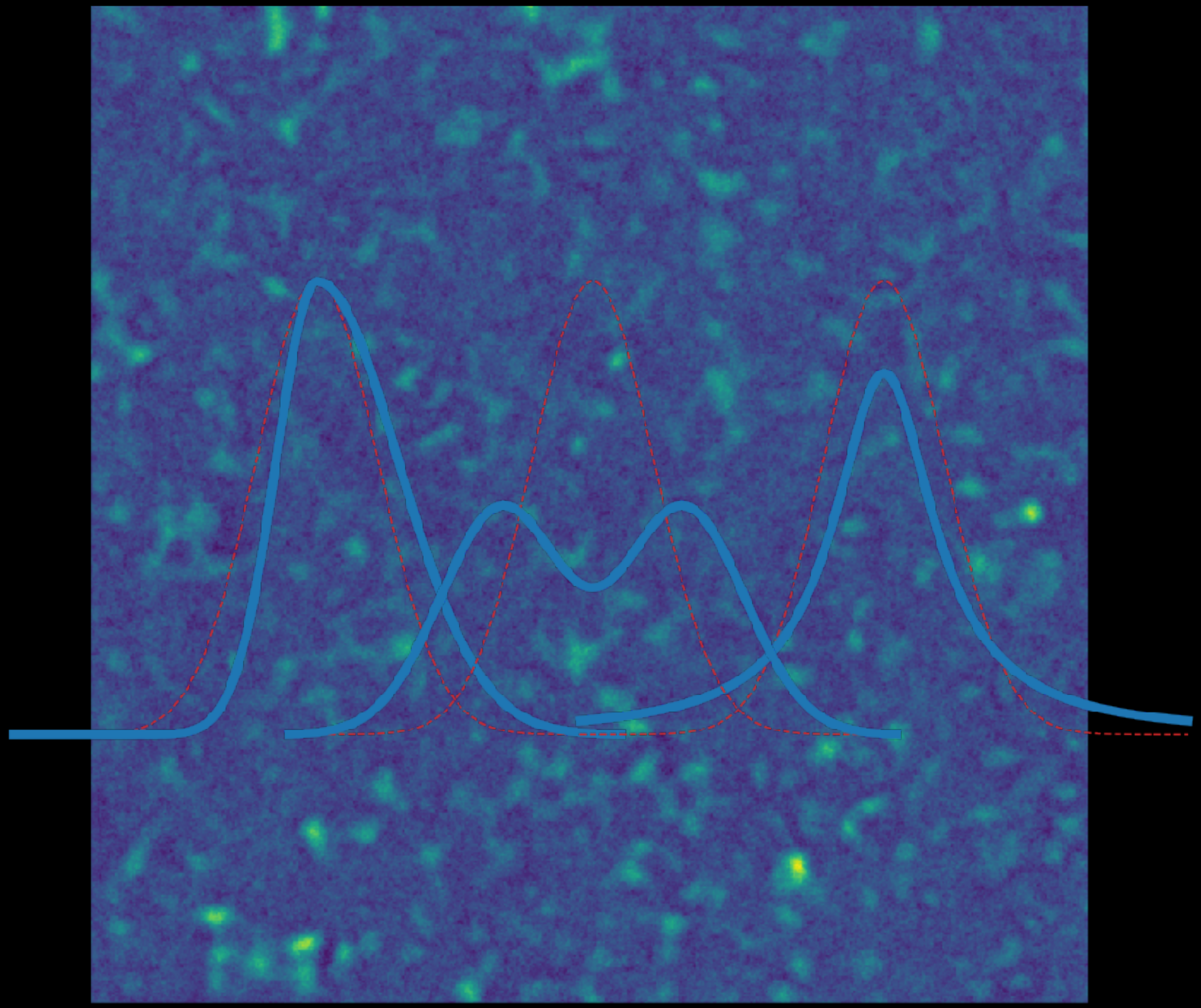
Credit: Wagyx (2022) / Springel et al. (2022)

I make simulations of the the the Cosmic Web starting from different types of inflation.

The distribution of energy in the universe just after inflation (light means lots of energy, dark means little energy):



Gaussian
(following a bell curve)



Non-Gaussian
(not following a bell curve)

Credit: own work.

My simulations let us map out the matter in a universe that would form after a given type of inflation.

Gaussian simulation

Galaxies form earlier than we expect in non-Gaussian case

Credit: own work.

Spiderweb-like structure

My simulations let us map out the matter in a universe that would form after a given type of inflation.

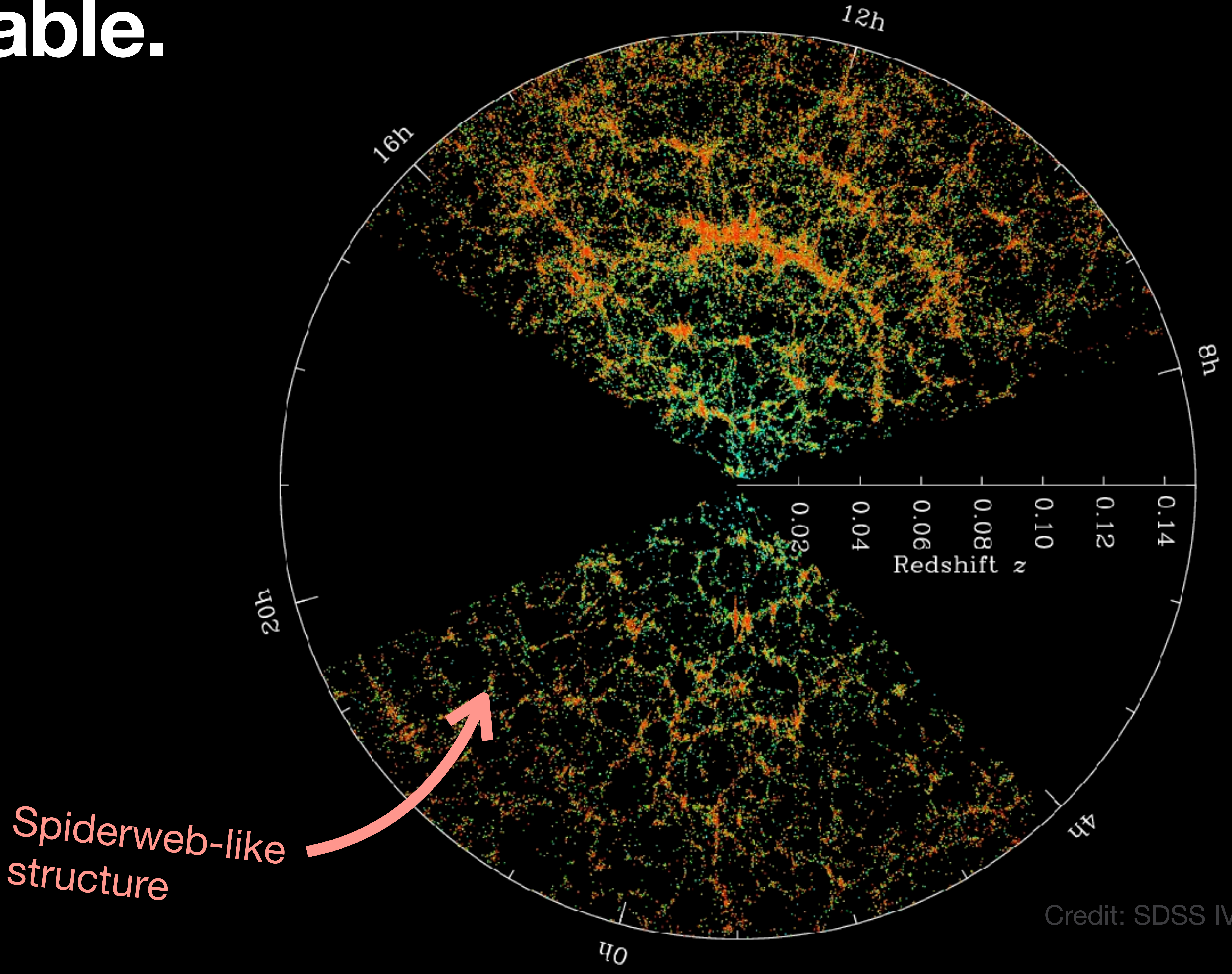
Non-Gaussian simulation

Galaxies form earlier than we expect in non-Gaussian case

Credit: own work.

Spiderweb-like structure

We can compare this to actual observations of the universe to check whether our inflation model is reasonable.



Credit: SDSS IV (2022)

You might have seen news about NASA discovering very distant galaxies, further away and older than we expected. Non-Gaussianity could explain these!

Submit a guest post   Undergrads: submit your research!   Suggest a Paper Topic!

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JWST smashes the record for the earliest galaxy

by Zili Shen | Dec 16, 2022 | Daily Paper Summaries | 5 comments

Title: Discovery and properties of the earliest galaxies with confirmed distances

Authors: *B. E. Robertson, *S. Tacchella, B. D. Johnson, K. Hainline, L. Whitler, D. J. Eisenstein, R. Endsley, M. Rieke, D. P. Stark, S. Alberts, A. Dressler, E. Egami, R. Hausen, G. Rieke, I. Shivaei, C. C. Williams, C. N. A. Willmer, S. Arribas, N. Bonaventura, A. Bunker, A. J. Cameron, S. Carniani, S. Charlot, J. Chevallard, M. Curti, E. Curtis-Lake, F. D'Eugenio, P. Jakobsen, T. J. Looser, N. Lützgendorf, R. Maiolino, M. V. Maseda, T. Rawle, H.-W. Rix, R. Smit, H. Übler, C. Willott, J. Witstok, S. Baum, R. Bhatawdekar, K. Boyett, Z. Chen, A. de Graaff, M. Florian, J. M. Helton, R. E. Hviding, Z. Ji, N. Kumari, J. Lyu, E. Nelson, L. Sandles, A. Saxena, K. A. Suess, F. Sun, M. Topping, I. E. B. Wallace (* equal contribution)

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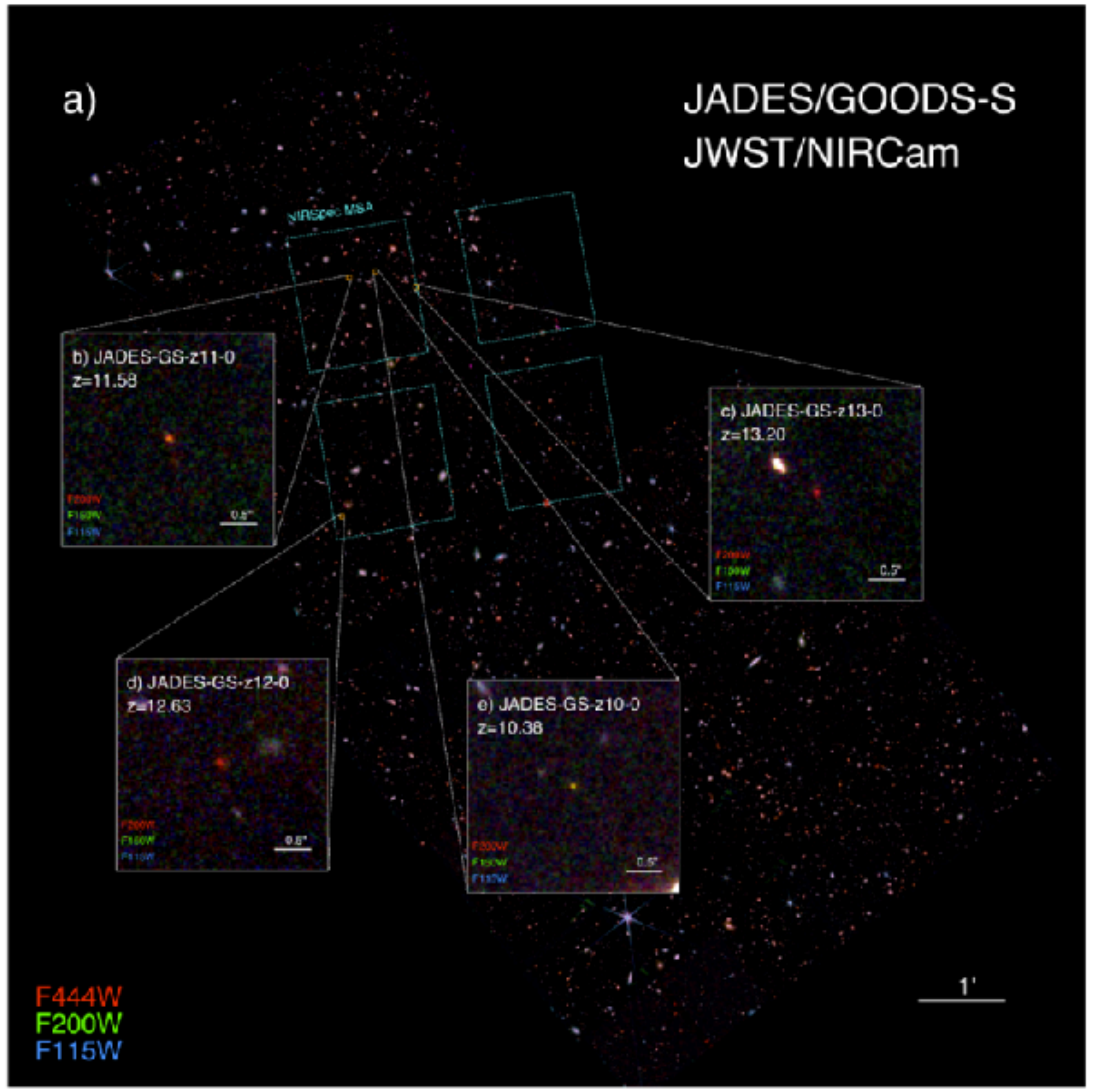

Figure 1: JWST NIRCam image of the GOODS-South field. b-e) are spectroscopically confirmed high-redshift galaxies. *Reproduced from Fig 1 of the paper.*

galaxy evolution   AAS   spectroscopy   supernovae

Posts by Category

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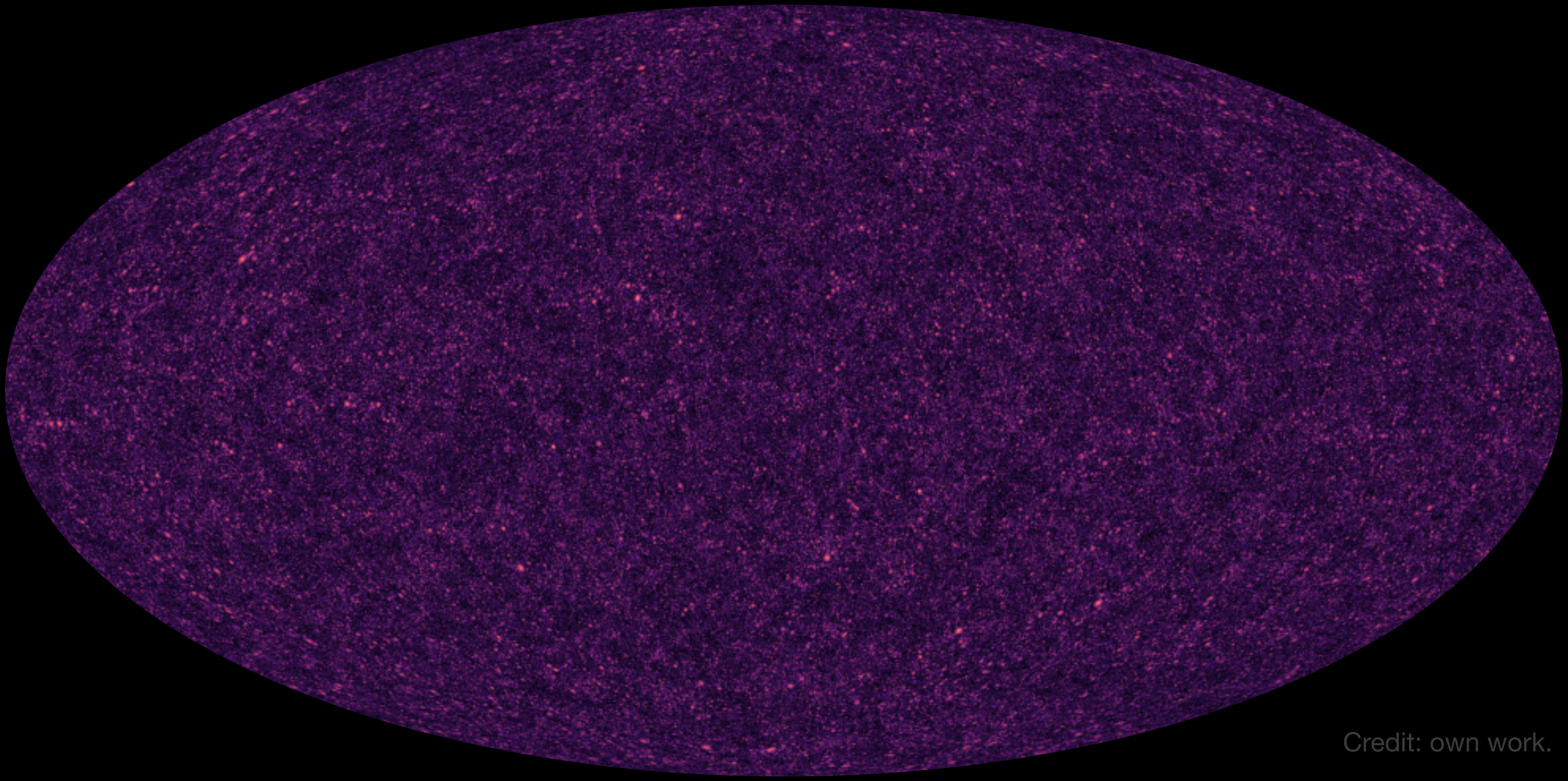
(Organized under ScienceBites)

Astrobitos (Astrobites in Spanish)

Astropontos (Astrobites in Portugese)

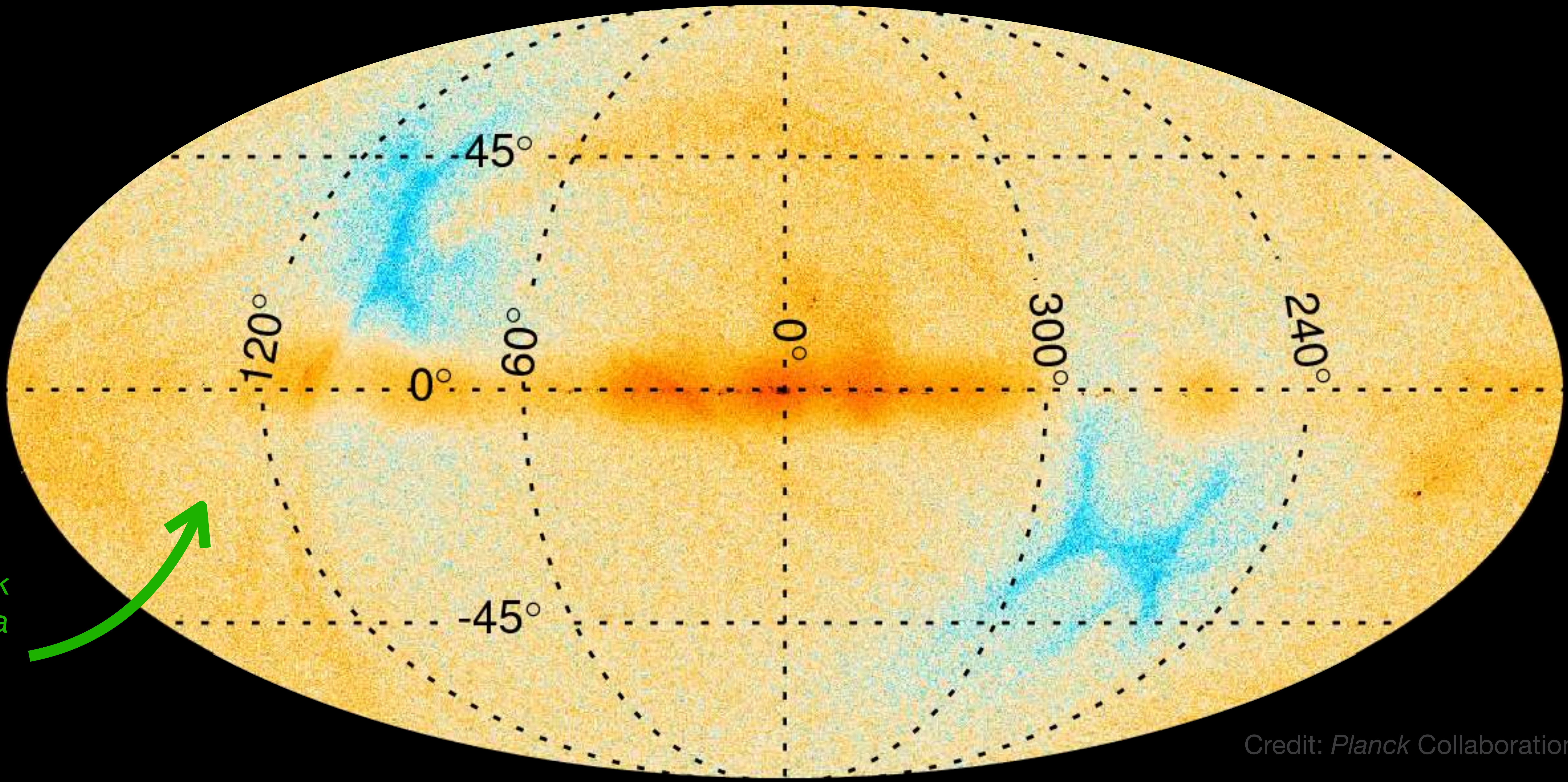
My simulations also let us make maps of the sky as they would be seen by certain telescopes.



Credit: own work.

Here, I'm showing a series of inflation models with increasing amounts of non-Gaussianity.

We cam compare simulations to observations from the Planck satellite

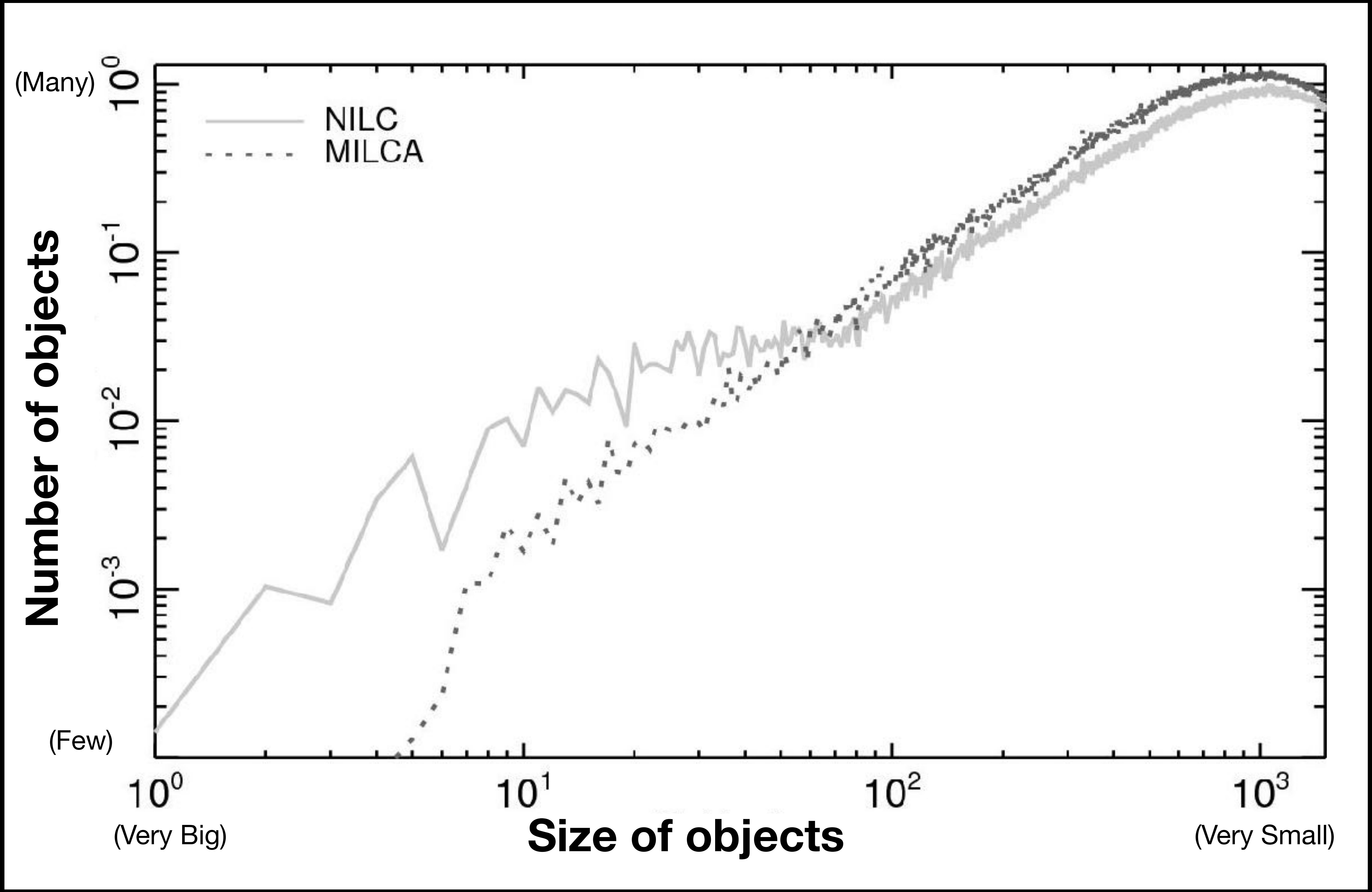


These colours look different because a different "colour map" is used here.

Credit: *Planck* Collaboration (2015)

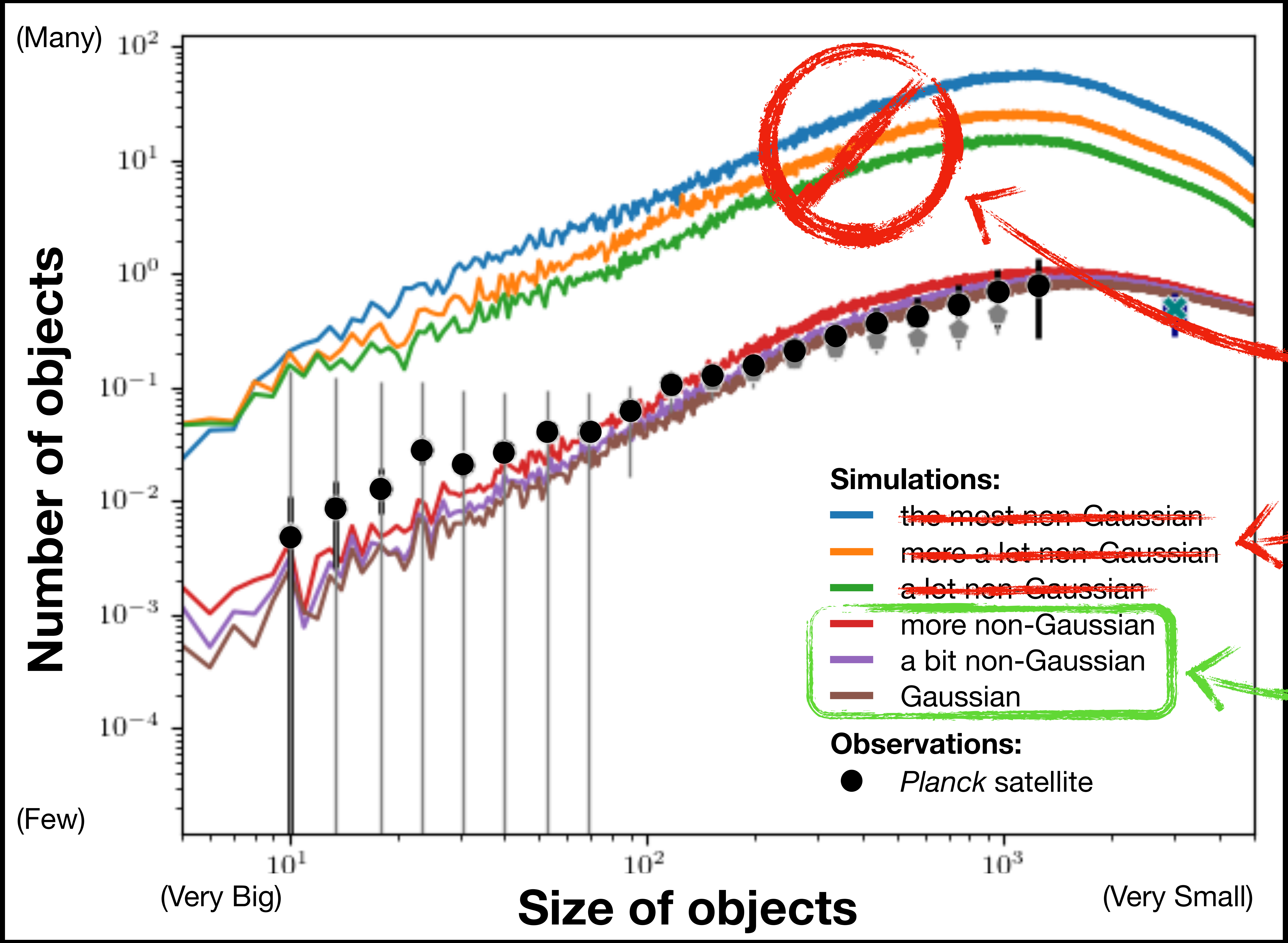
Observations don't look exactly like simulations because actual observations pick up some accidental signals from things between us and the CMB. We can compare statistically though…

Everything the maps of the sky have to tell us is in their statistics. They tell us how much stuff there is of each size. The observational data is:



Credit: *Planck* Collaboration (2015)

Everything the maps of the sky have to tell us is in their statistics. They tell us how much stuff there is of each size. We can compare with my simulations compare:



These types of inflation are definitely impossible!

These types of inflation are allowed!

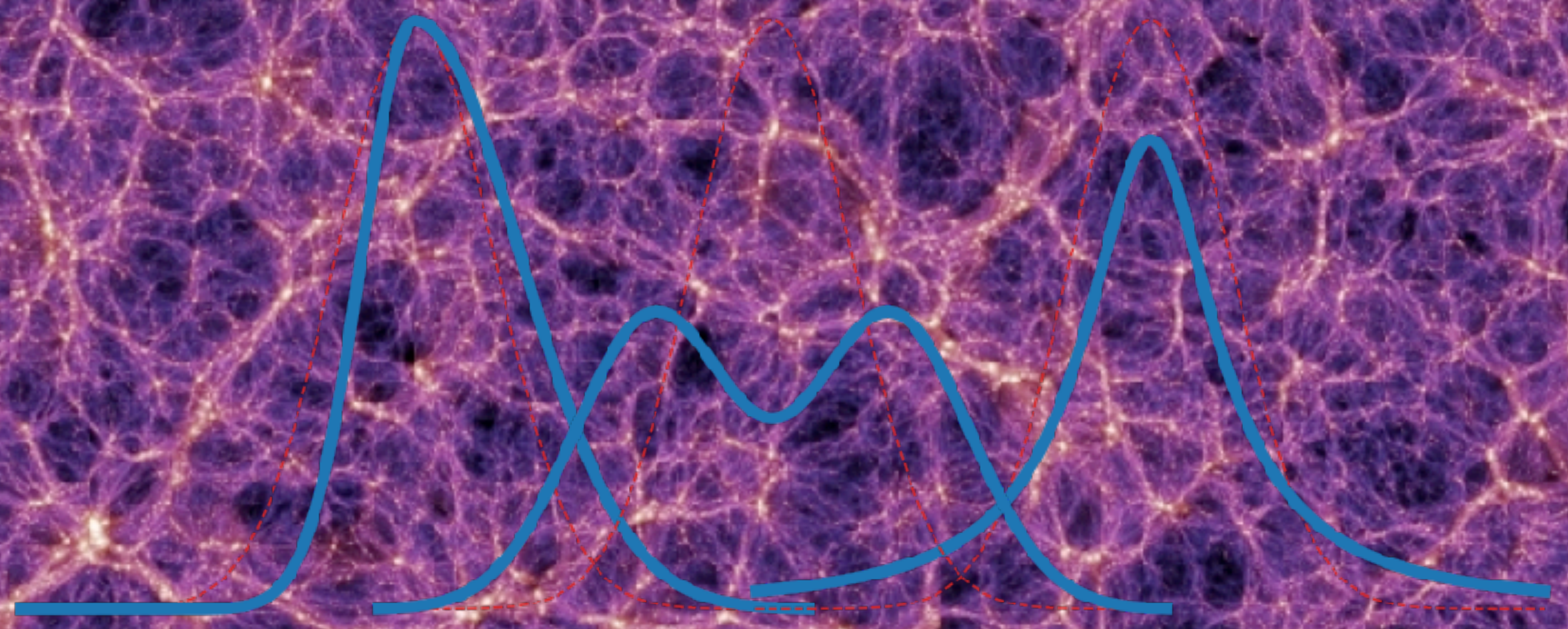
Credit: own work.

What we've learned today

1. The Cosmic Web is the biggest structure in the universe, it's made up of trillions of galaxies

2. Inflation is a period of rapid expansion very early in the universe. It stretches tiny quantum fluctuations into the seeds of galaxies.

3. Different models of inflation leave measurable differences in the statistics of the universe.



4. By using these statistics in simulations of the Cosmic Web, we can test inflation models and see back into the depths of cosmic time.

Image Credit: Nathan J. Carlson

Questions?

Ask me anything about cosmology!

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Visit our astronomy activities and the telescopes!

Go to the McLennan Physical Laboratories lobby and roof to explore our different interactive activities, they will take place until 10:00pm EST.

Activities will include:

- Telescopes
- Tactile Astronomy
- World Wide Telescope
- 3D printed telescopes

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