

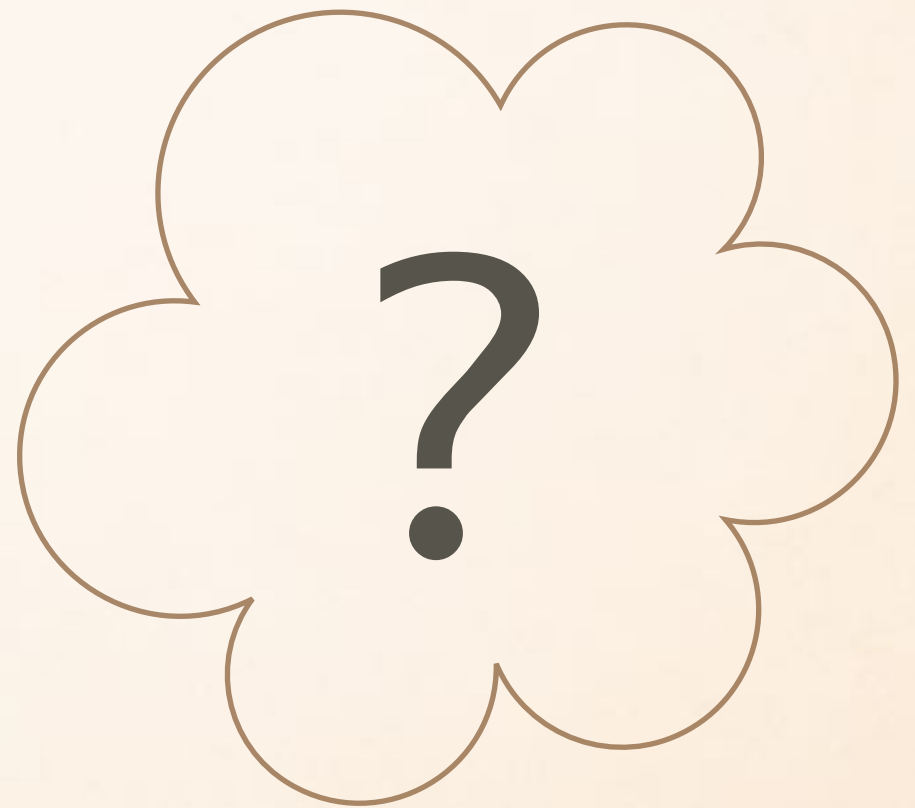
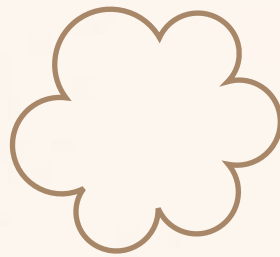
A BEGINNER'S GUIDE TO THE BIG BANG



MATT BOTHWELL
INSTITUTE OF ASTRONOMY
CAMBRIDGE UNIVERSITY

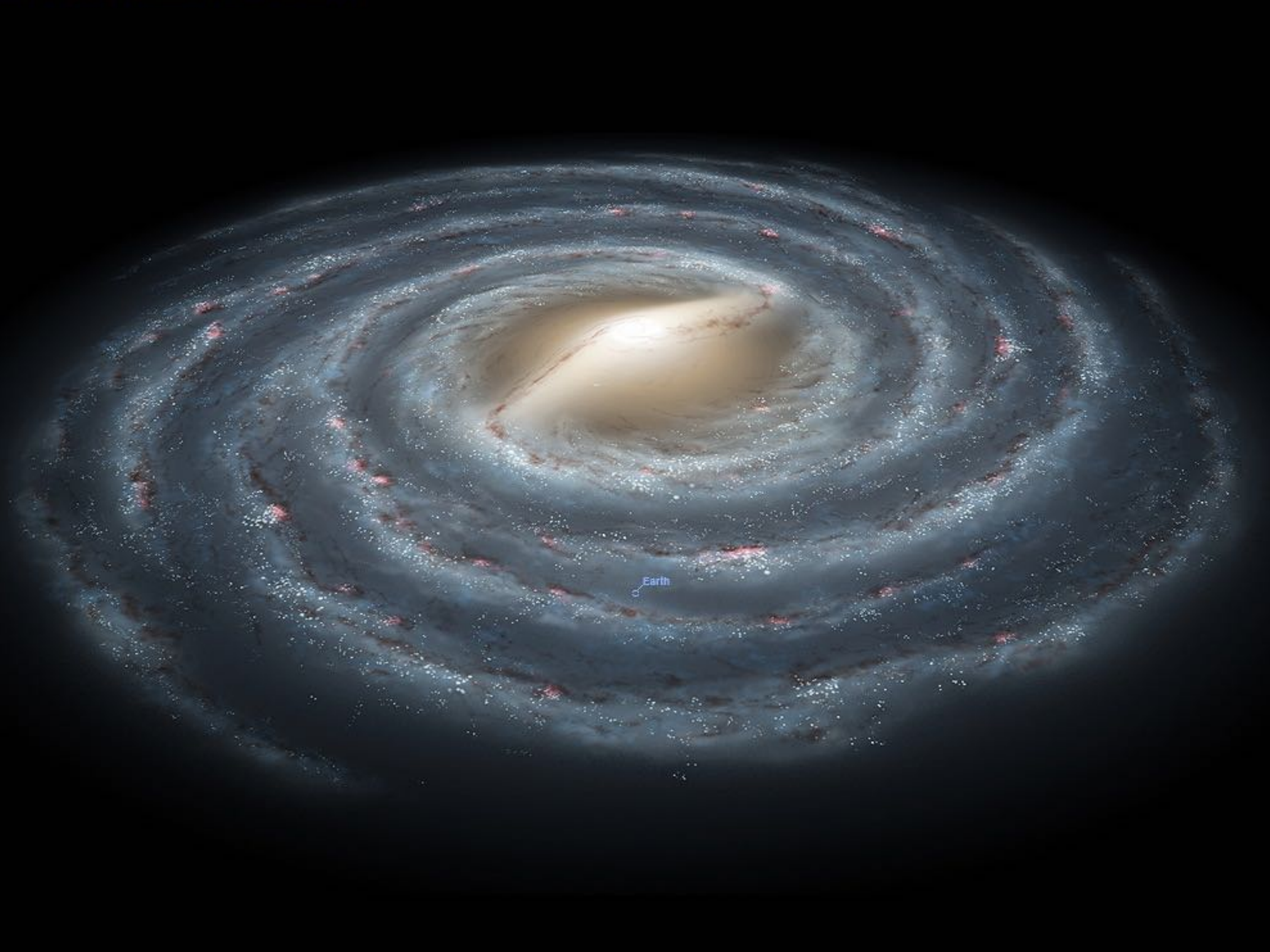


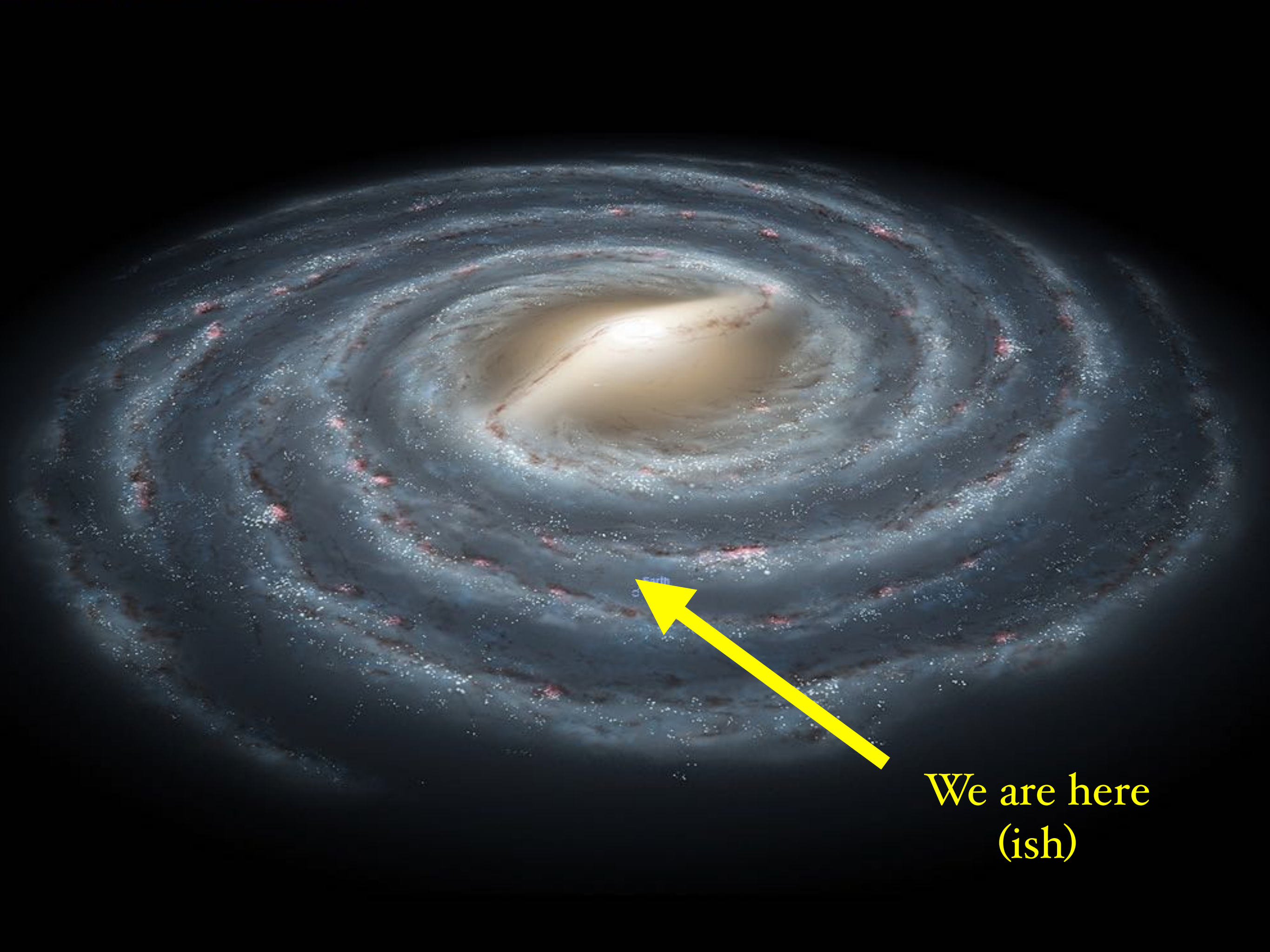
PEOPLE HAVE BEEN ASKING
COSMOLOGICAL QUESTIONS
FOR THOUSANDS OF YEARS...



WE ARE FINDING
ANSWERS NOW!



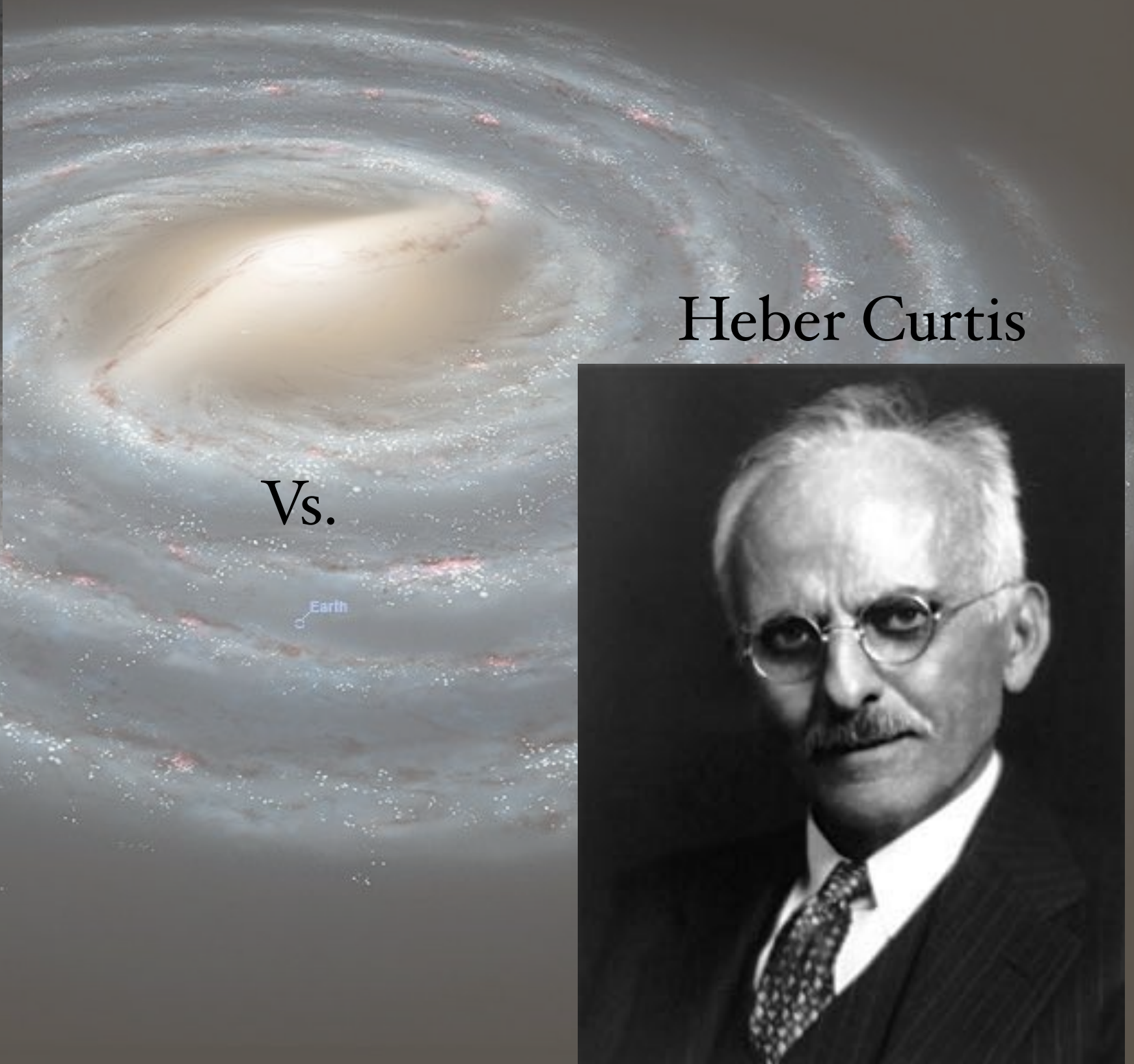




We are here
(ish)



Harlow Shapley



Vs.

Heber Curtis

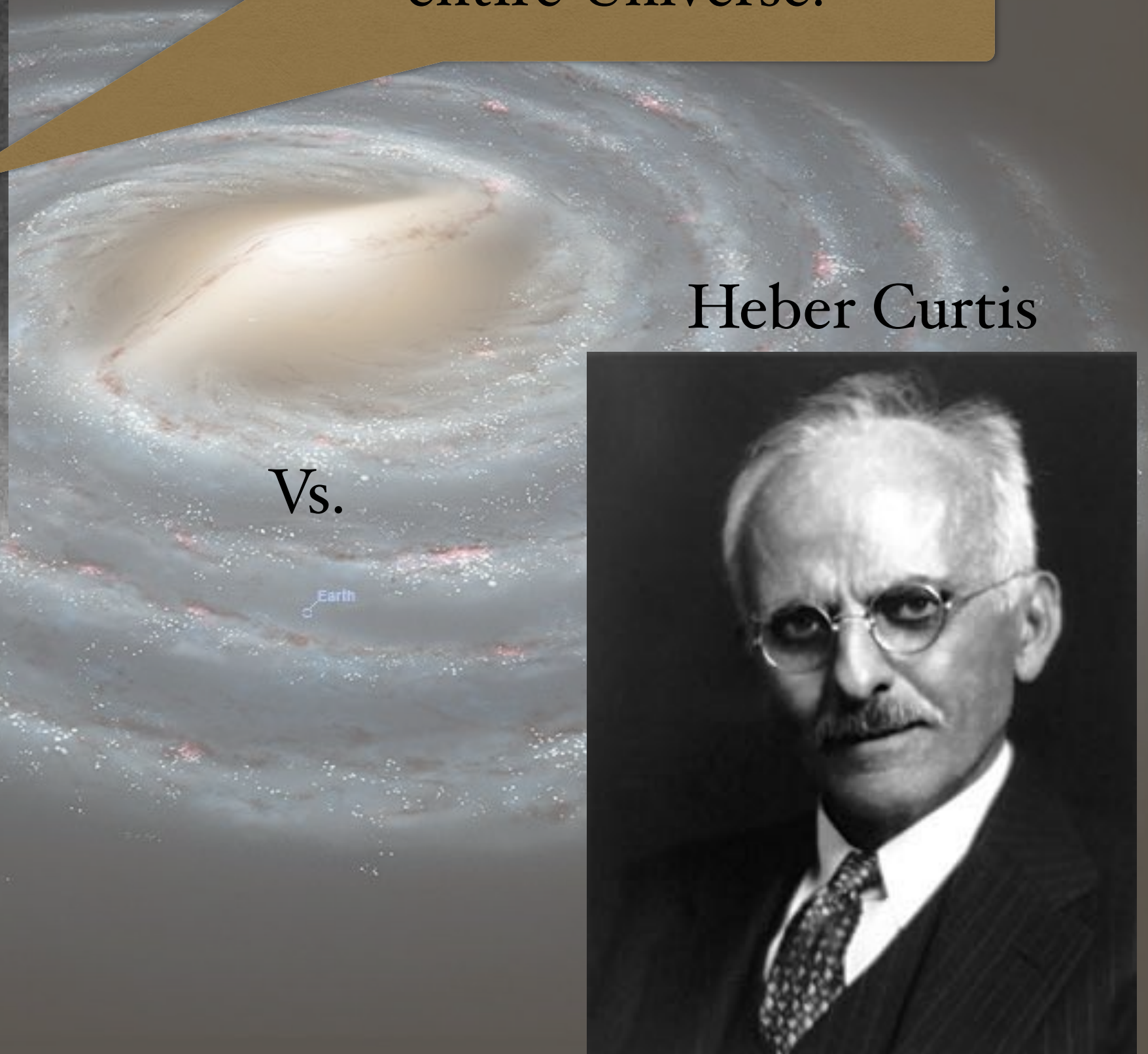




Harlow Shapley

The Milky Way is the
entire Universe!

Vs.



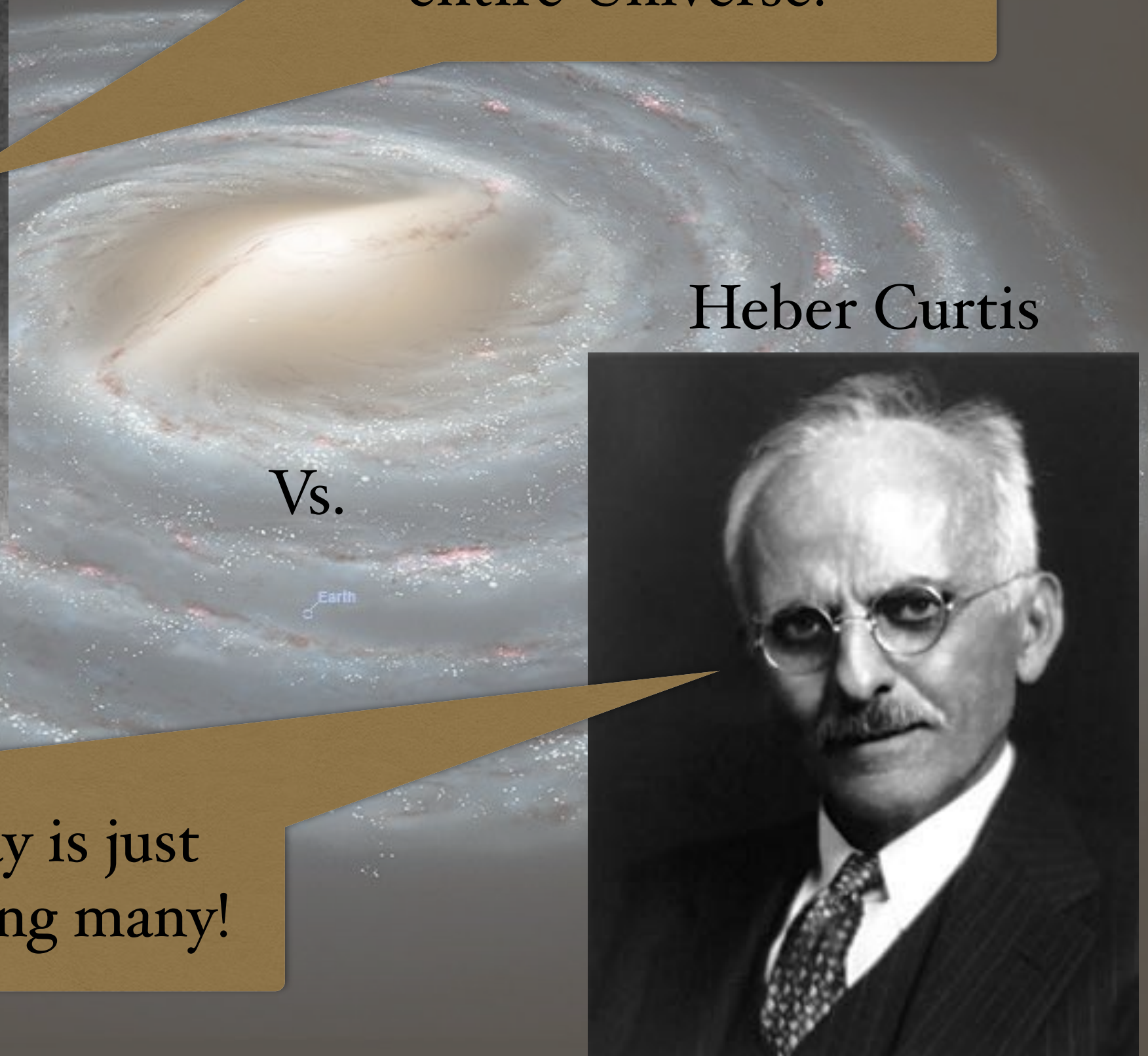
Heber Curtis





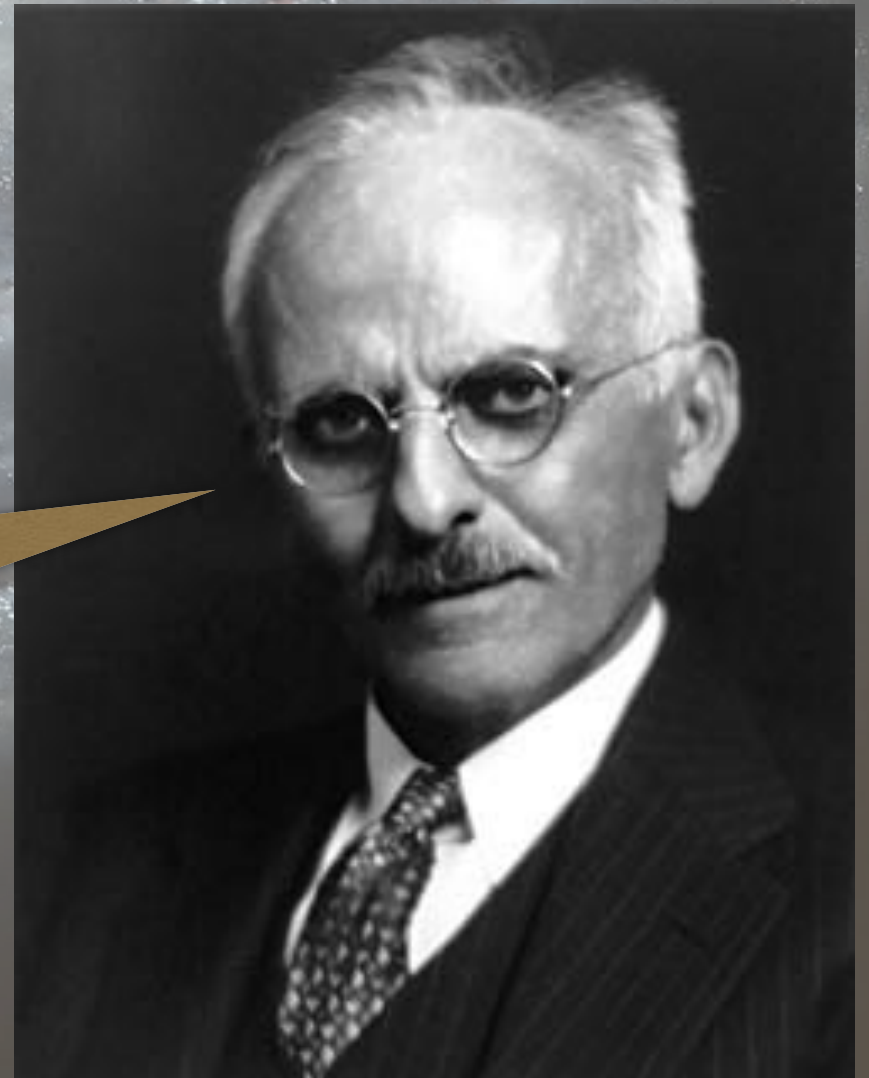
Harlow Shapley

The Milky Way is the
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Vs.

Heber Curtis



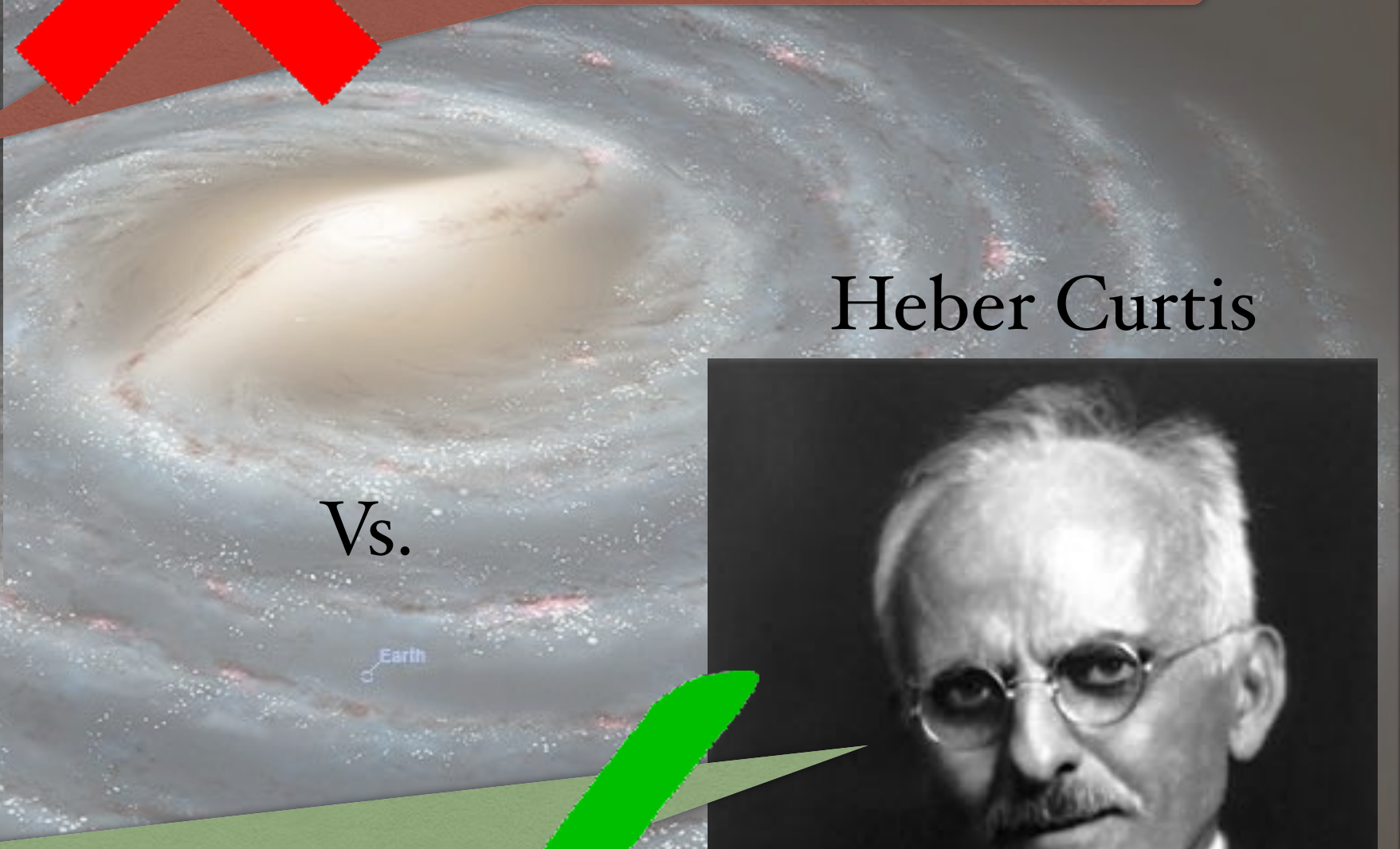
The Milky Way is just
one galaxy among many!



Harlow Shapley

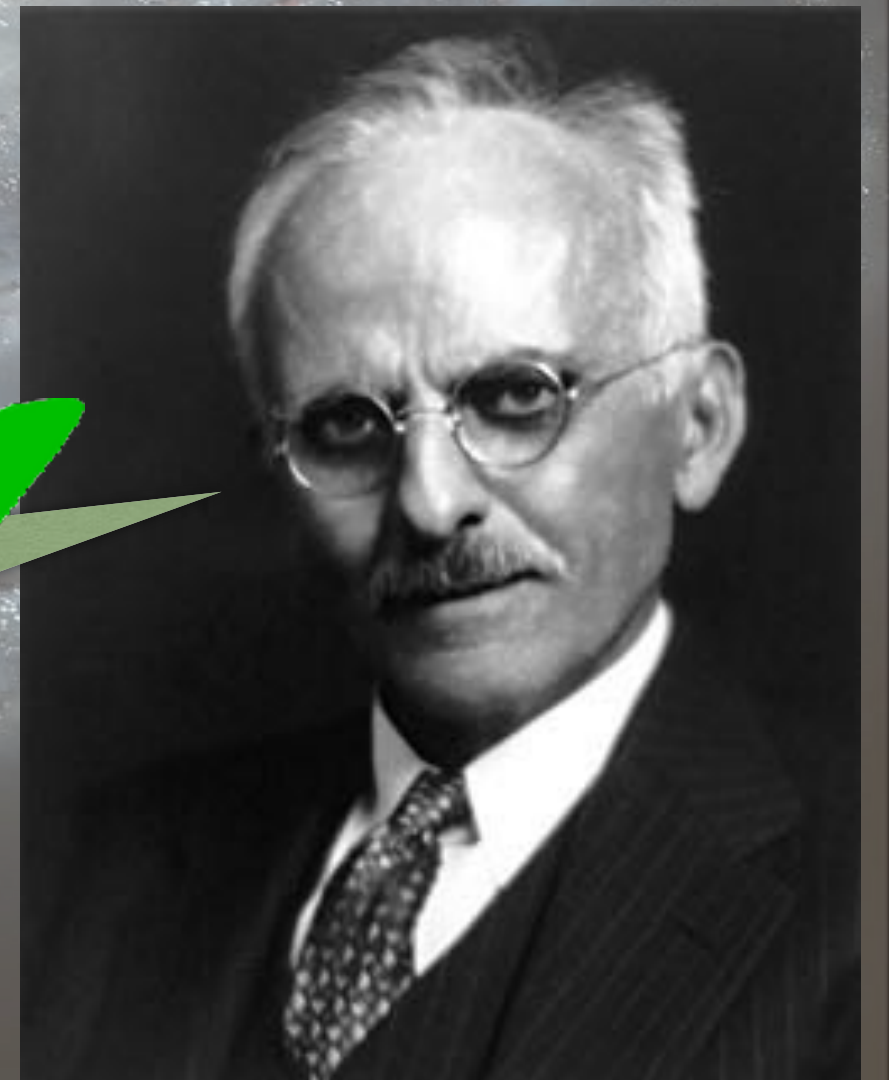


The Milky Way is the
entire Universe!



Vs.

Heber Curtis



The Milky Way is just
one galaxy among many!



HOW WAS THIS SETTLED?

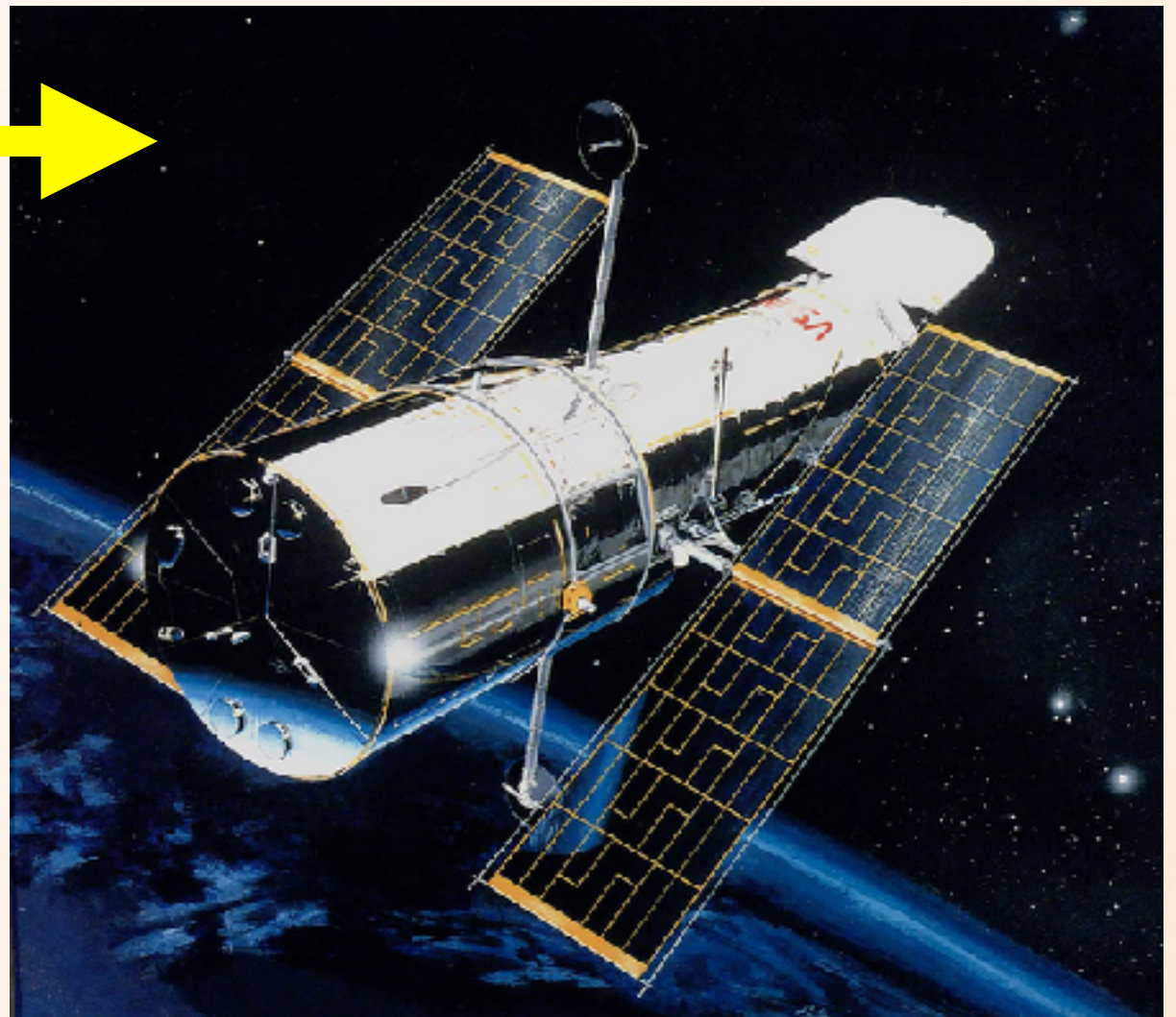


Edwin Hubble

HOW WAS THIS SETTLED?



Edwin Hubble



Hubble Space Telescope

HOW WAS THIS SETTLED?



Edwin Hubble

Hubble breakthrough was to measure **accurate** distances to nearby galaxies, proving they were outside the Milky Way

HOW WAS THIS SETTLED?



Edwin Hubble

Washington, Nov. 22. Confirmation of the view that spiral nebulae, which appear in the heavens as whirling clouds, are in reality distant stellar systems, or 'island universes', has been obtained by Dr. Edwin Hubble of the Carnegie Institution's Mount Wilson Observatory, through investigations carried out with the observatory's powerful telescopes. The number of spiral nebulae, the observatory officials have reported to the institution, is very great, amounting to hundreds of thousands, and their apparent sizes range from small objects, almost star-like in character, to the great nebula in Andromeda, which stretches across an angle of some 3 degrees in the heavens, about six times the diameter of the full moon.

New York Times,
22 November 1924

HOW WAS THIS SETTLED?

Washington, Nov. 22. Confirmation of the view that spiral nebulae, which appear in the heavens as whirling clouds, are in reality distant stellar systems, or 'island universes', has been obtained by Dr. Edwin Hubble of the Carnegie Institution's Mount Wilson Observatory, through investigations carried out with the observatory's powerful telescopes. The number of spiral nebulae, the observatory officials have reported to the institution, is very great, amounting to hundreds of thousands, and their apparent sizes range from small objects, almost star-like in character, to the great nebula in Andromeda, which stretches across an angle of some 3 degrees in the heavens, about six times the diameter of the full moon.

New York Times,
22 November 1924

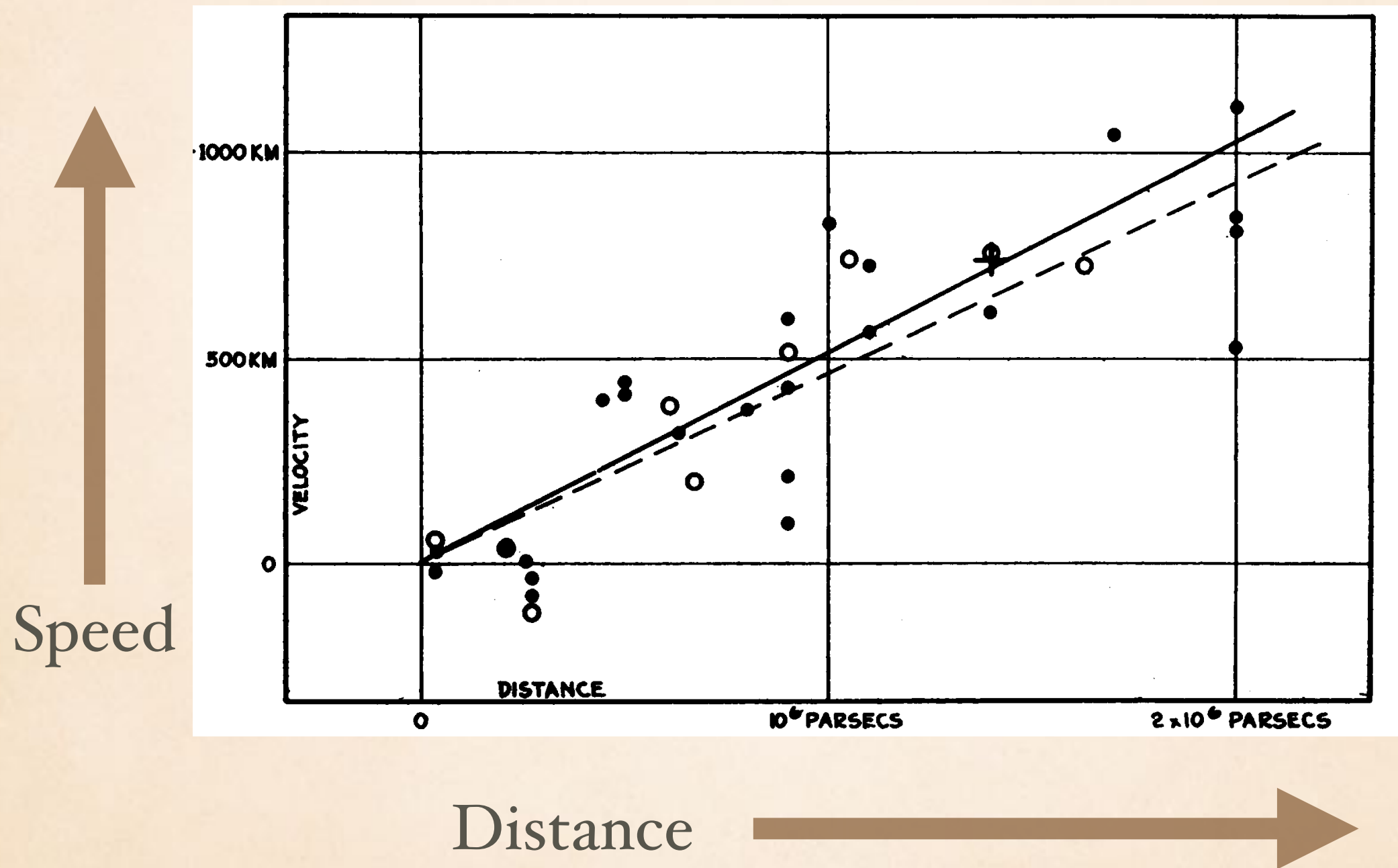


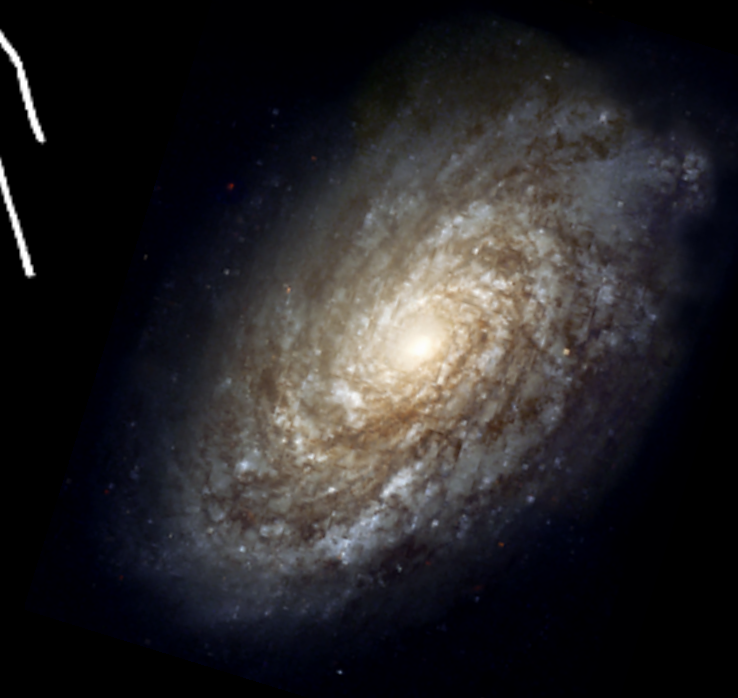


THINGS GET MORE INTERESTING...

- ❖ Hubble had found a way to accurately measure *distances* to galaxies
- ❖ Astronomers already knew how to measure the *velocity* of galaxies

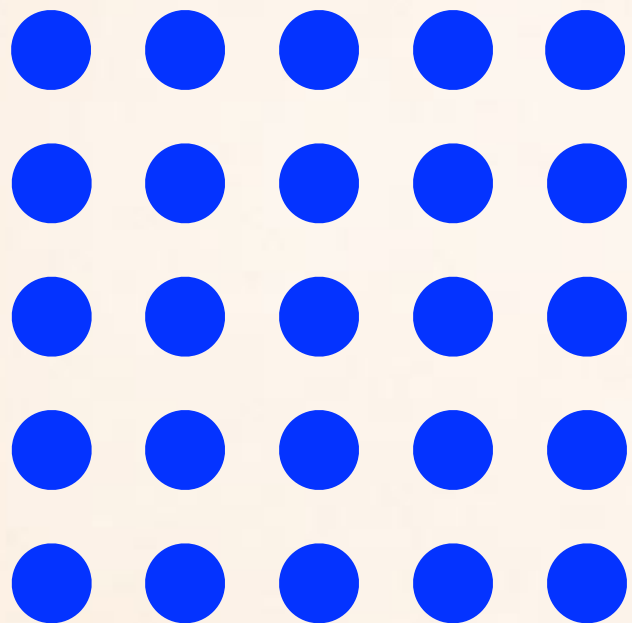
THE UNIVERSE IS EXPANDING!



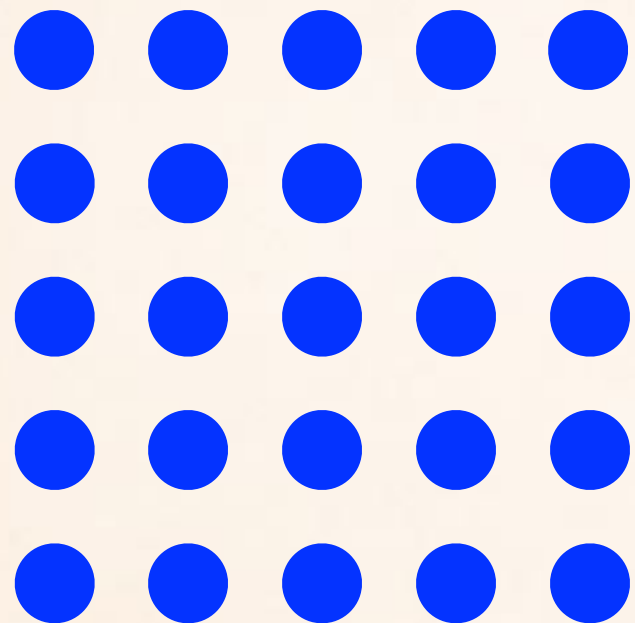




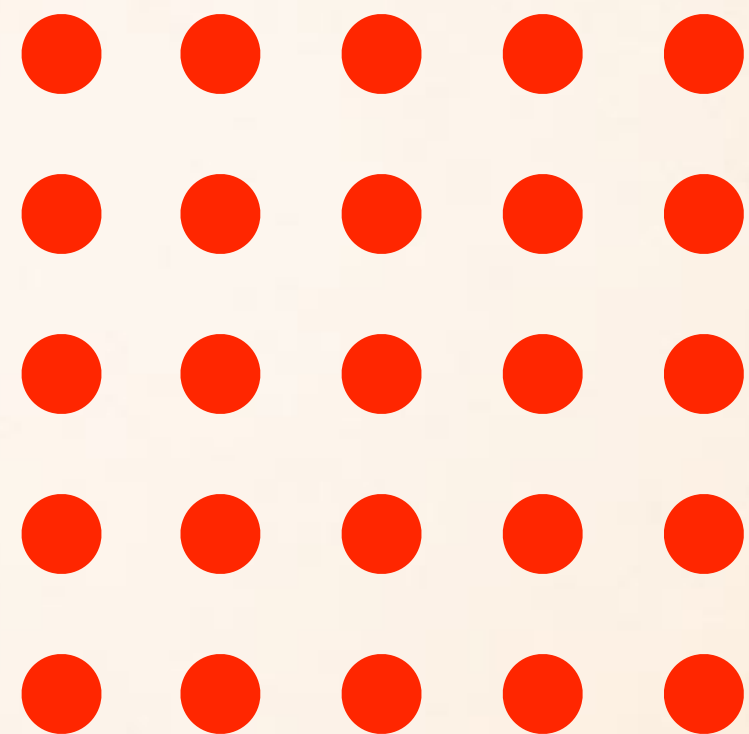
Now



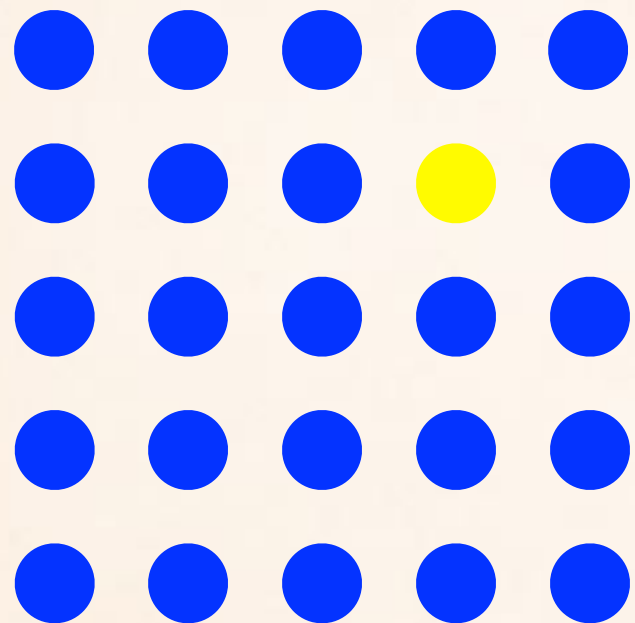
Now



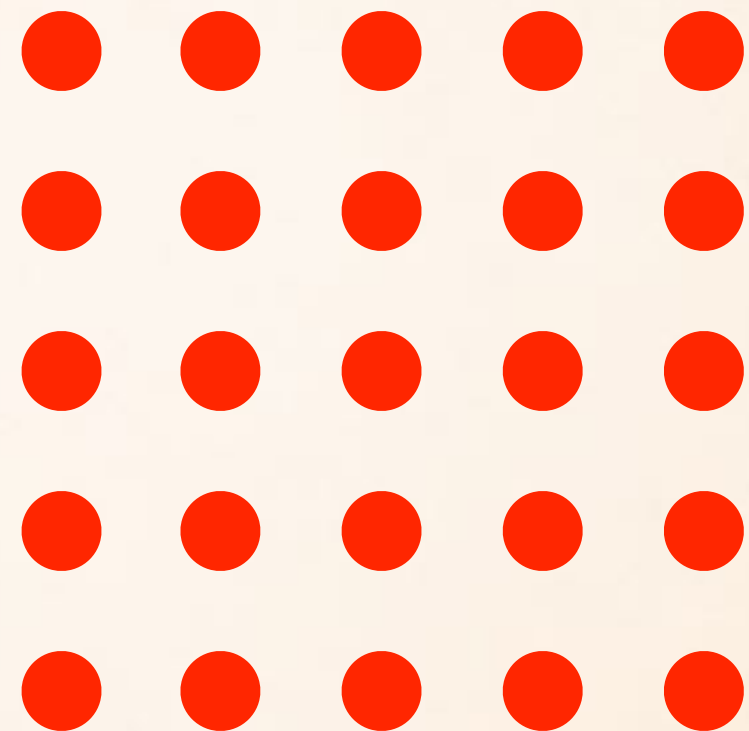
Later



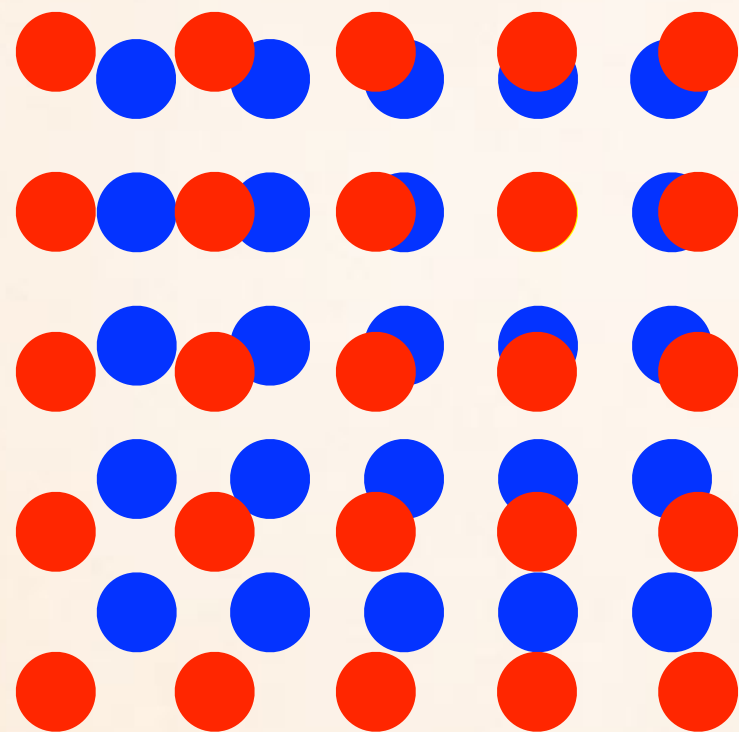
Now



Later

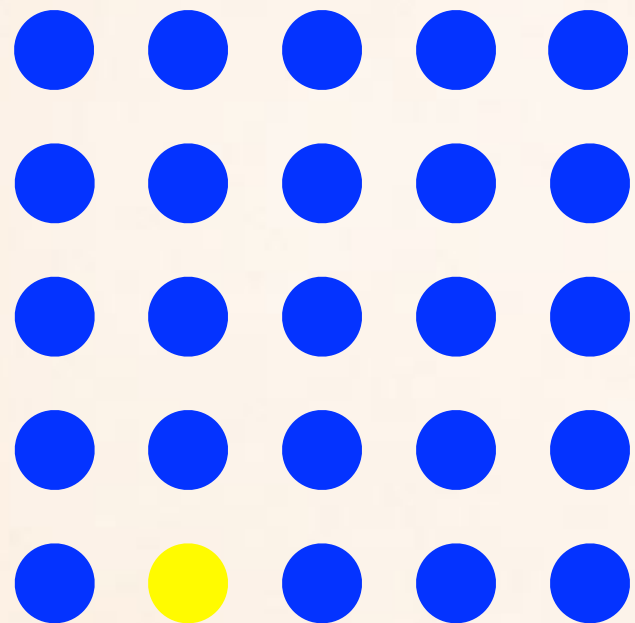


Now

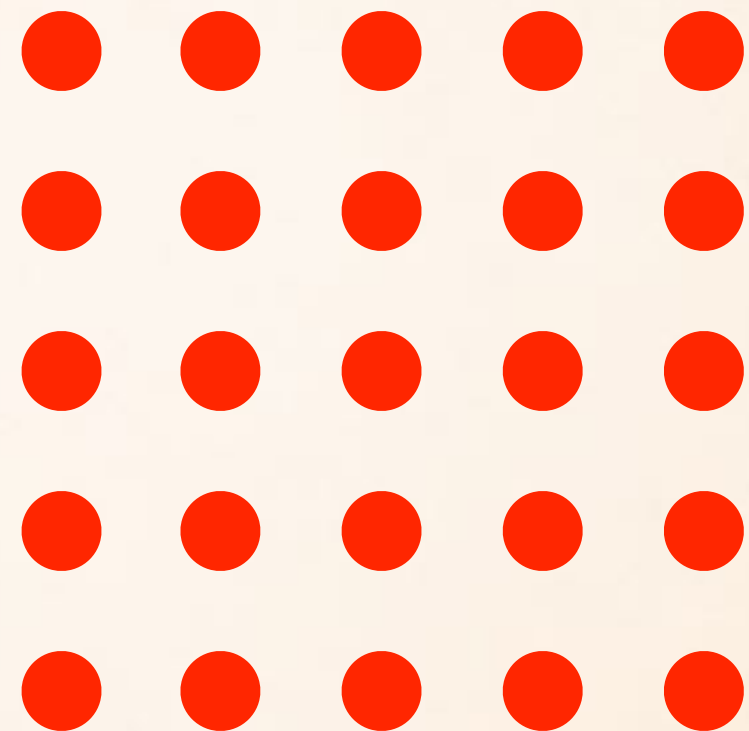


Later

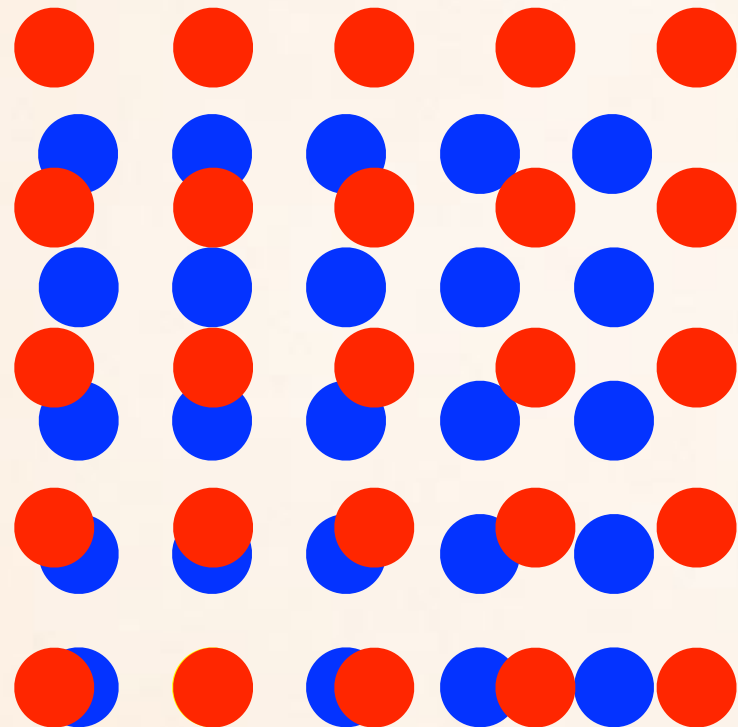
Now



Later

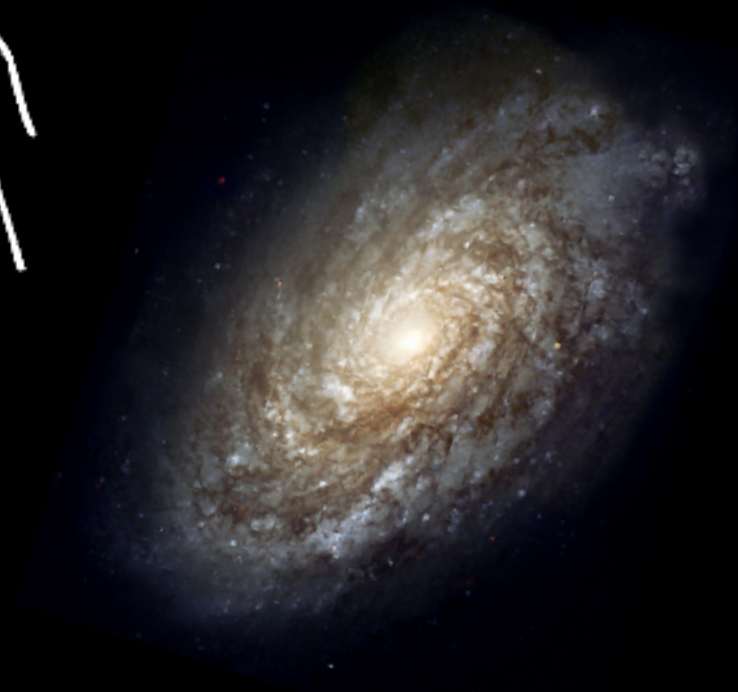


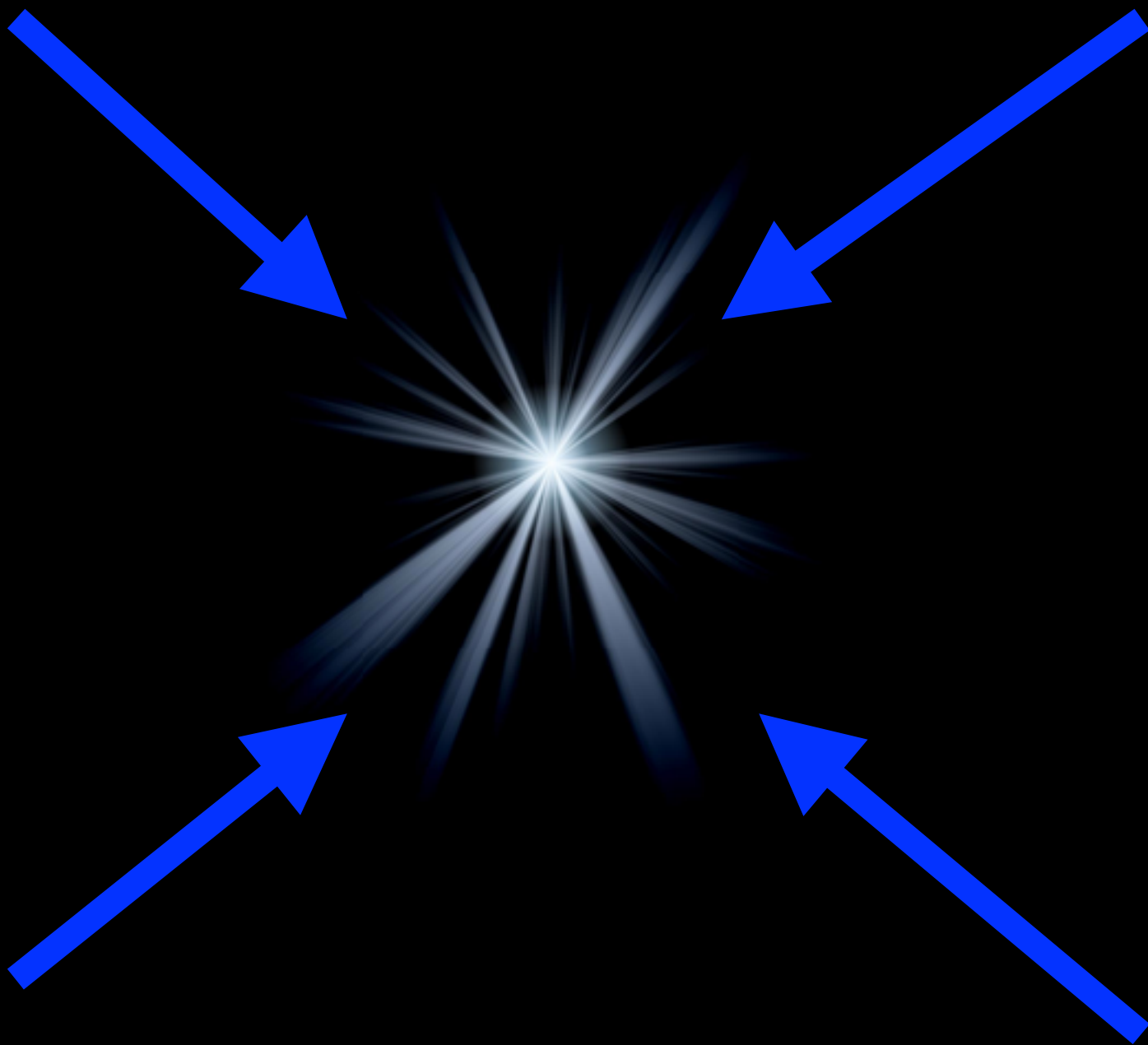
Now



Later





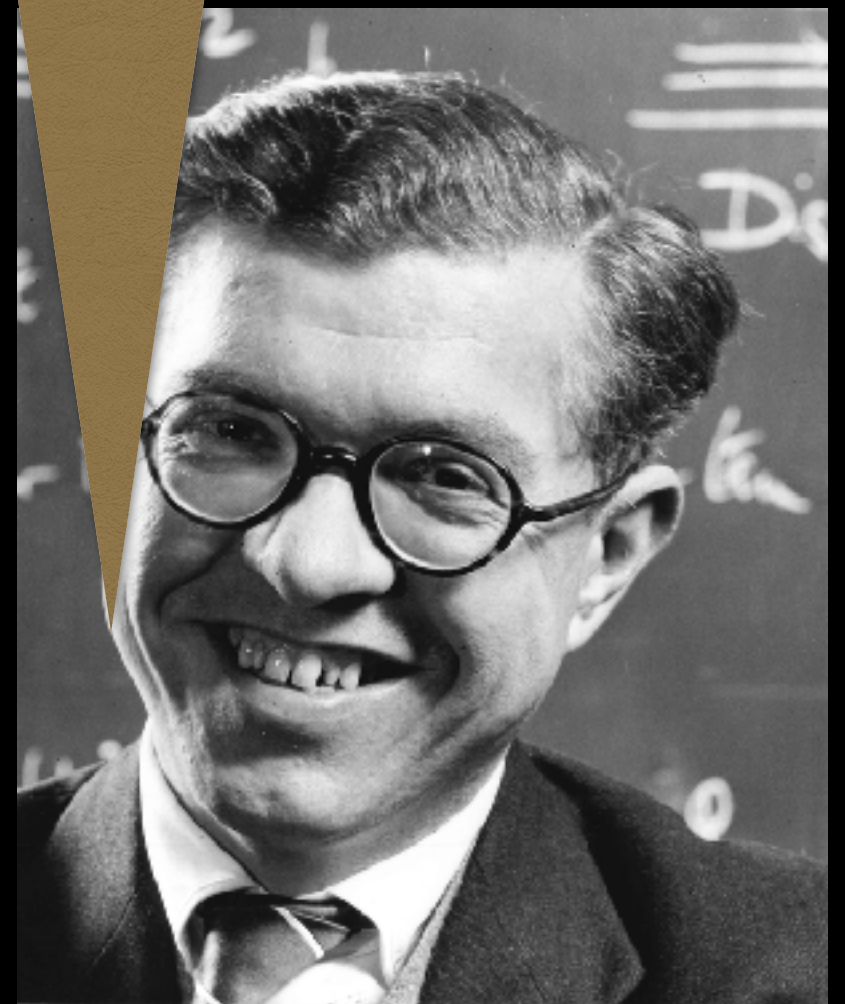


... did the Universe have a beginning?

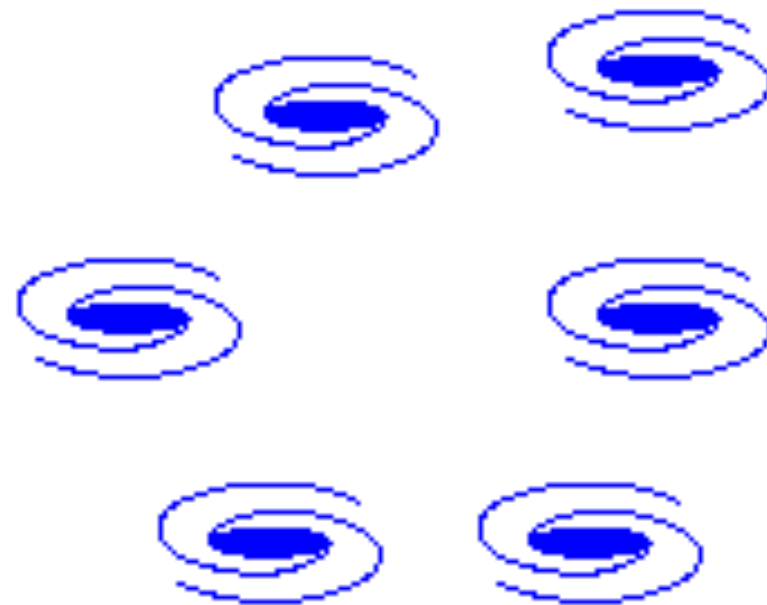




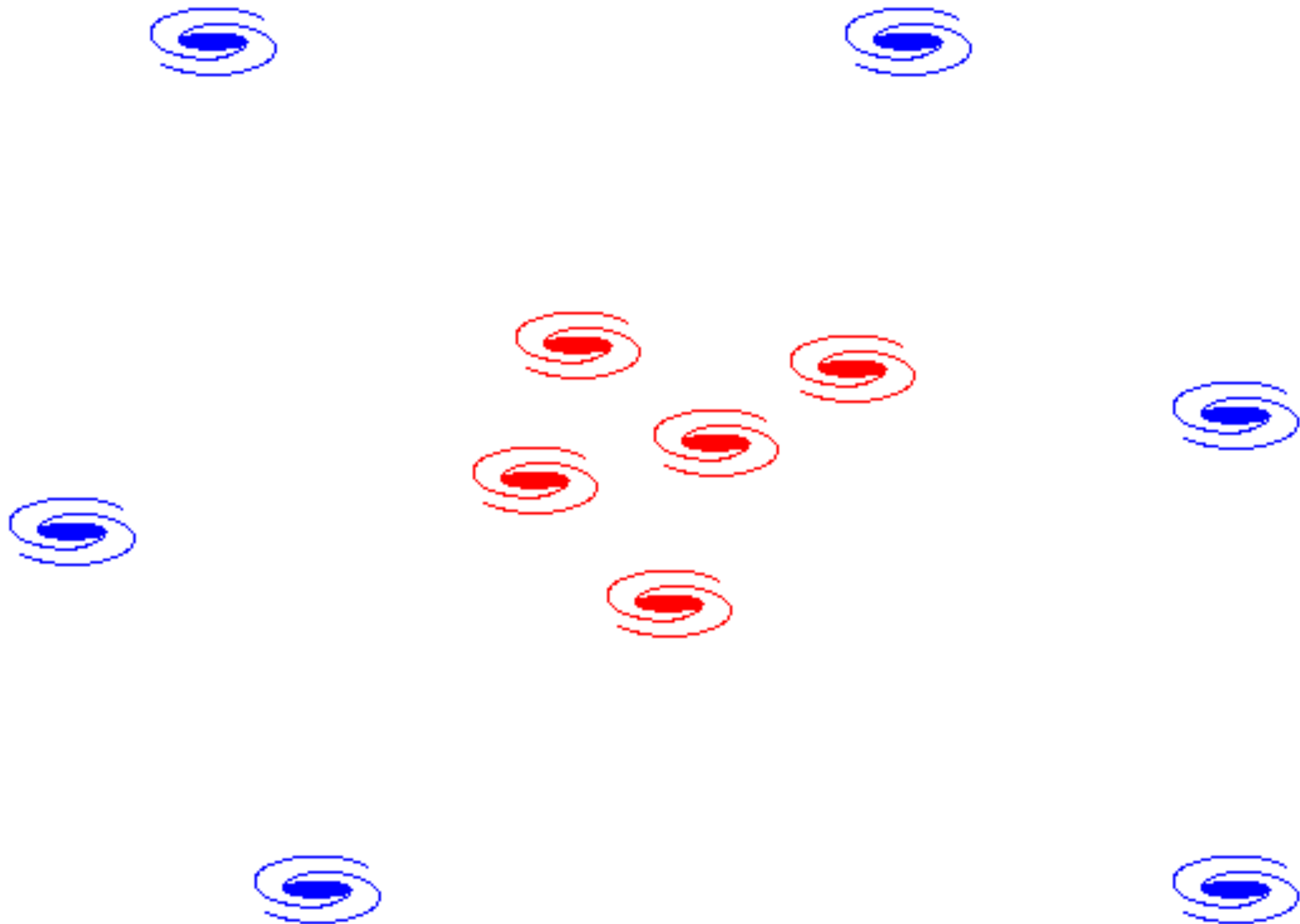
[...] the hypothesis that all the matter in the universe was created in one “big bang” at a particular time in the remote past.



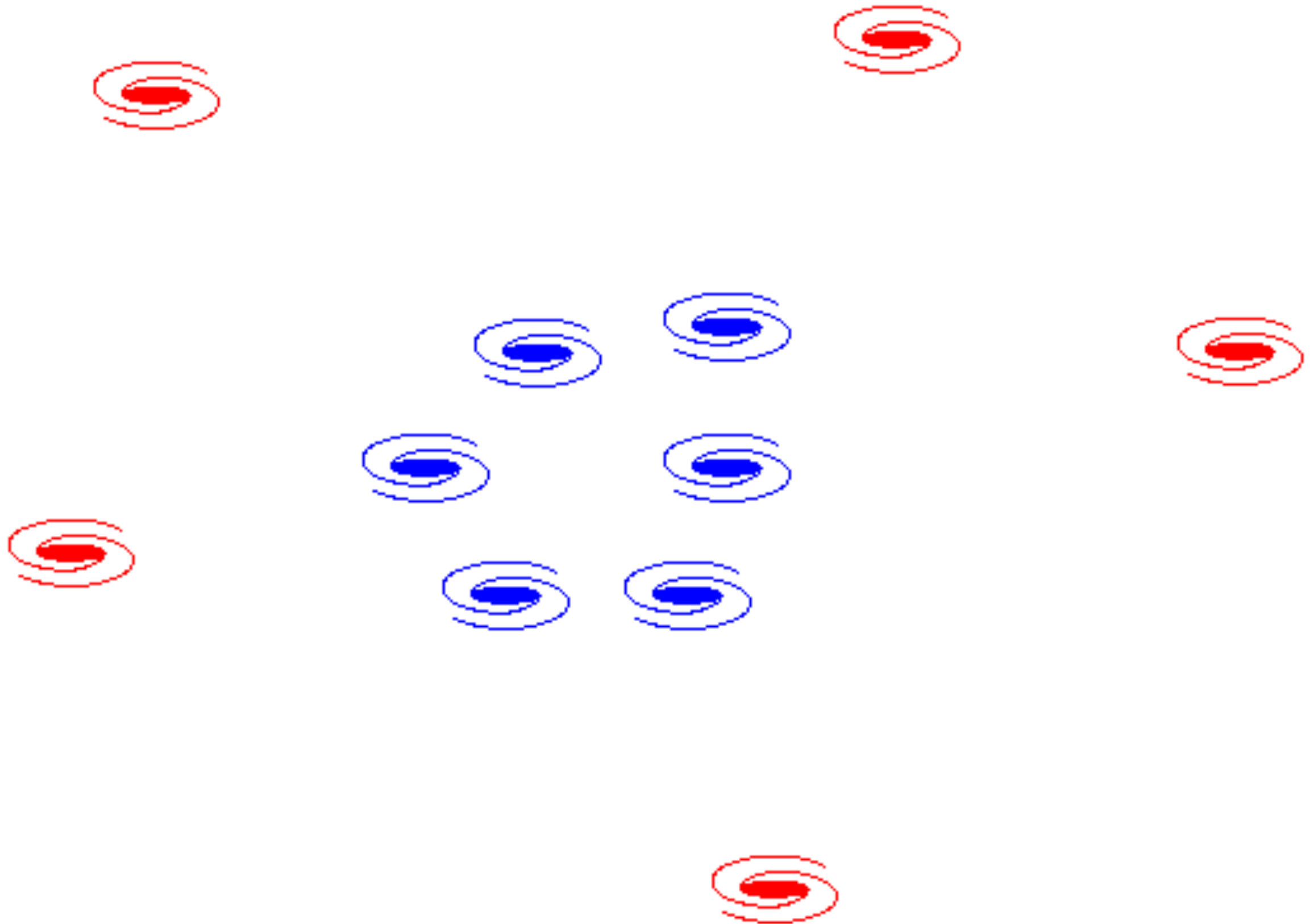
A UNIVERSE WITHOUT A BIG BANG?



A UNIVERSE WITHOUT A BIG BANG?

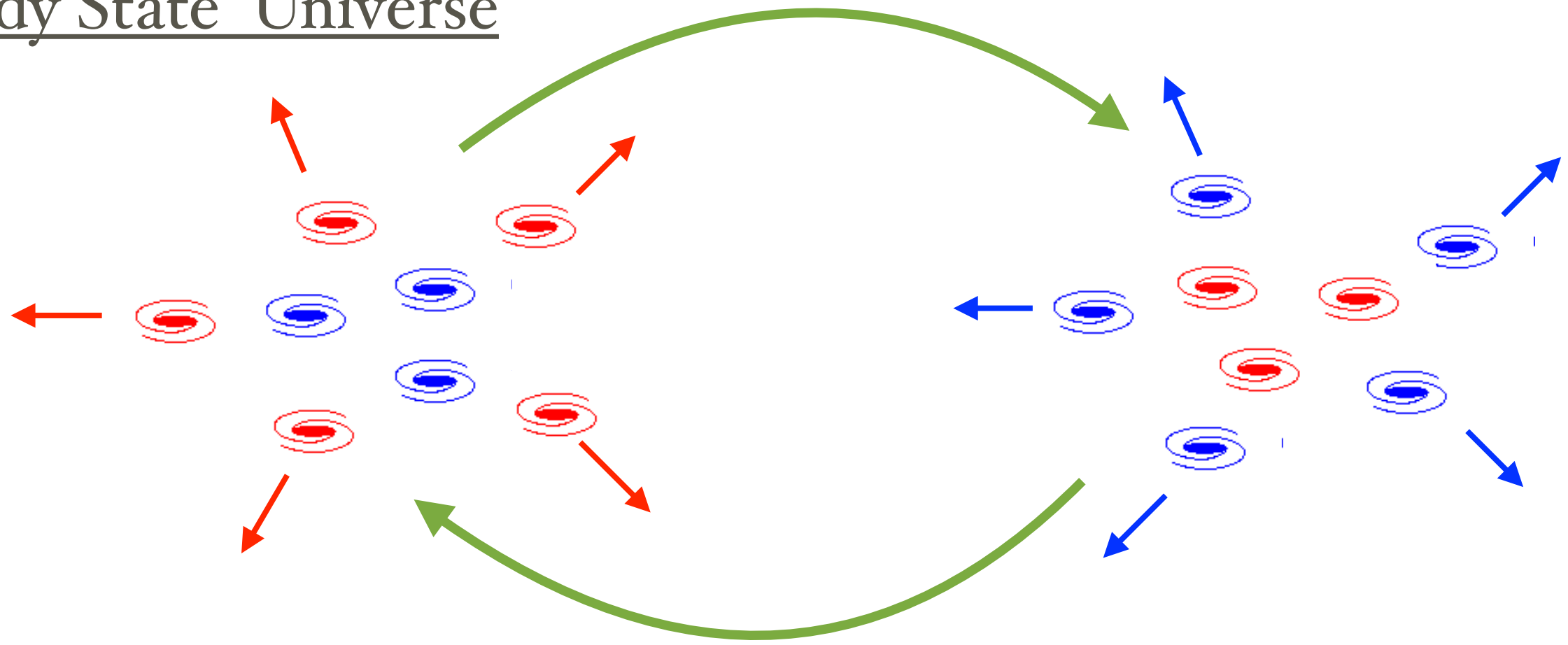


A UNIVERSE WITHOUT A BIG BANG?

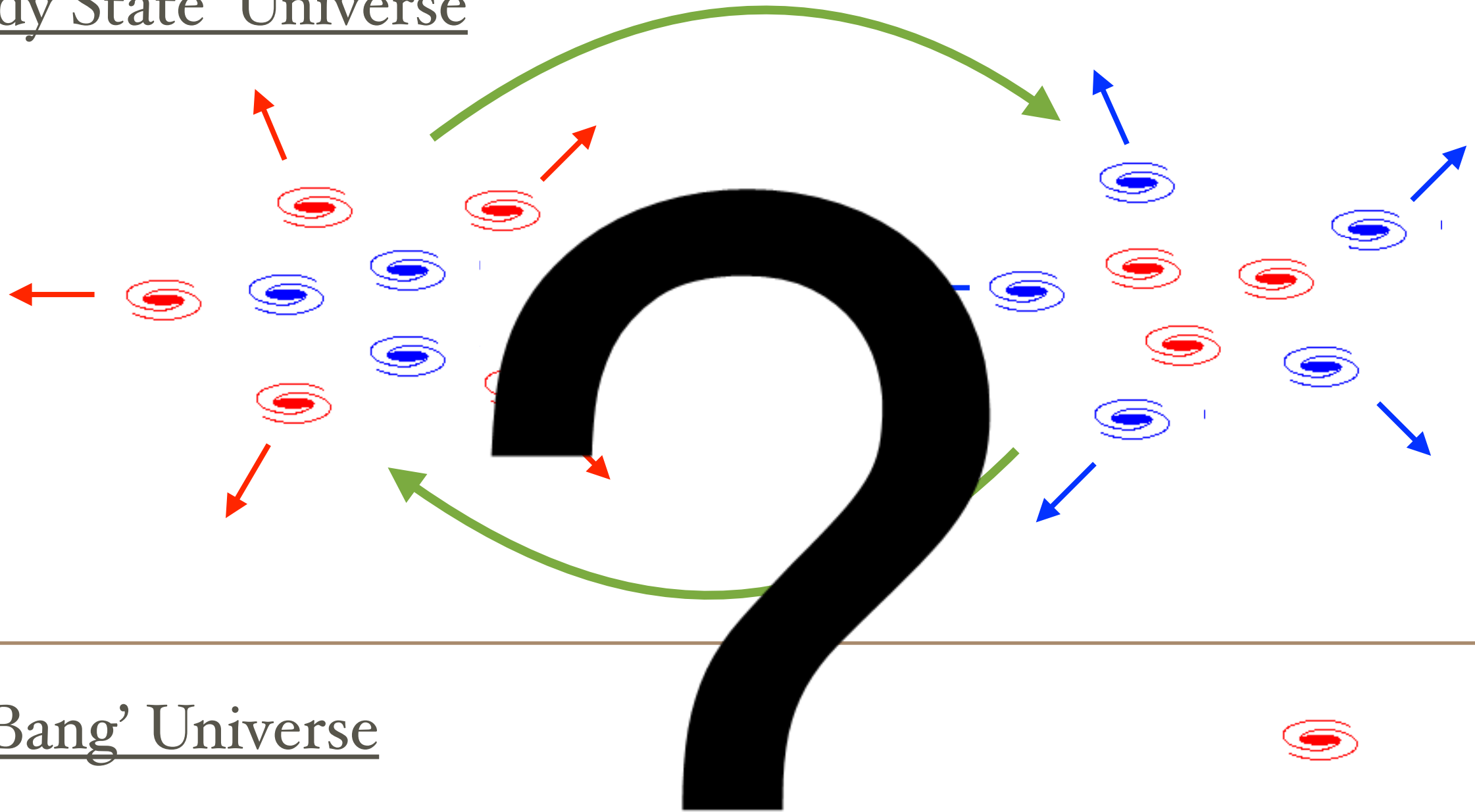


‘Steady State’ Universe

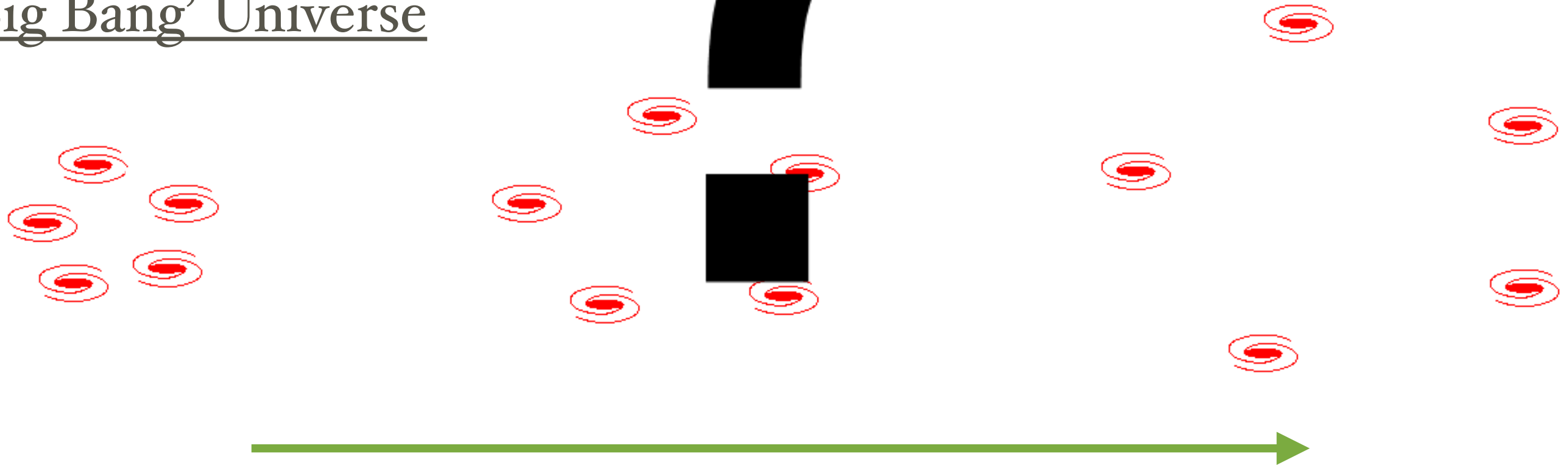
'Steady State' Universe



'Steady State' Universe



'Big Bang' Universe





Time



Hot
+
Dense

Time

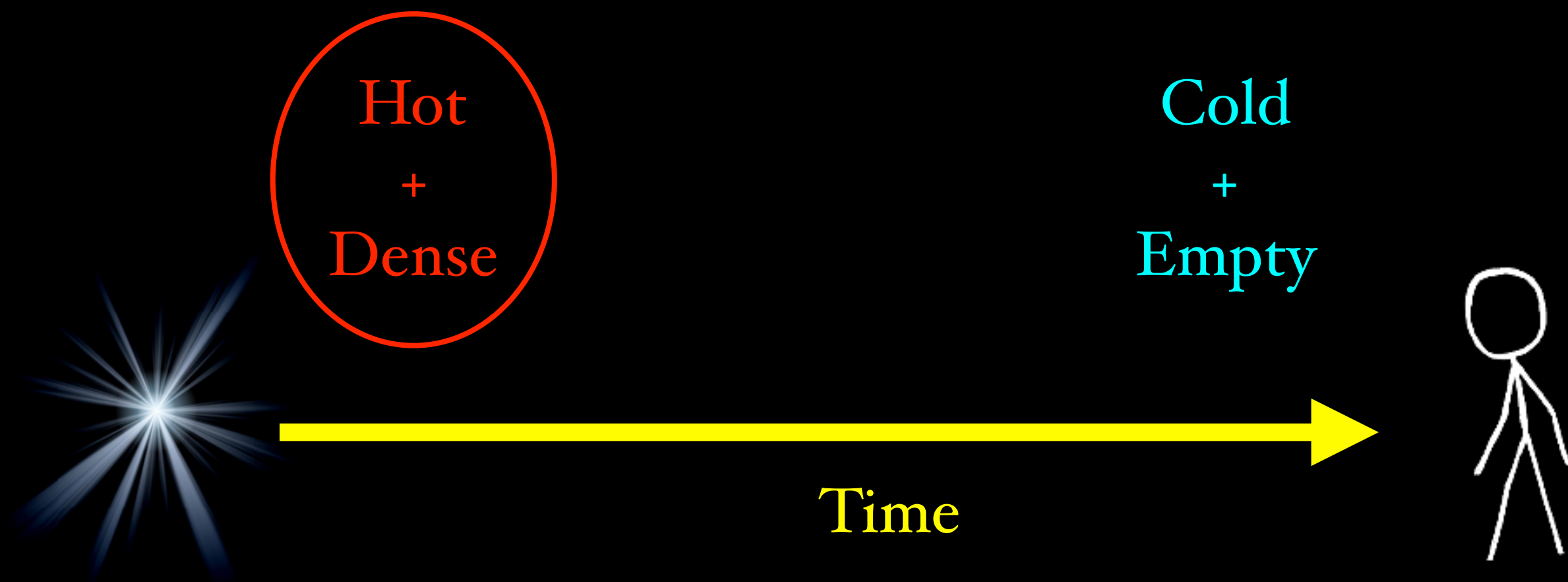


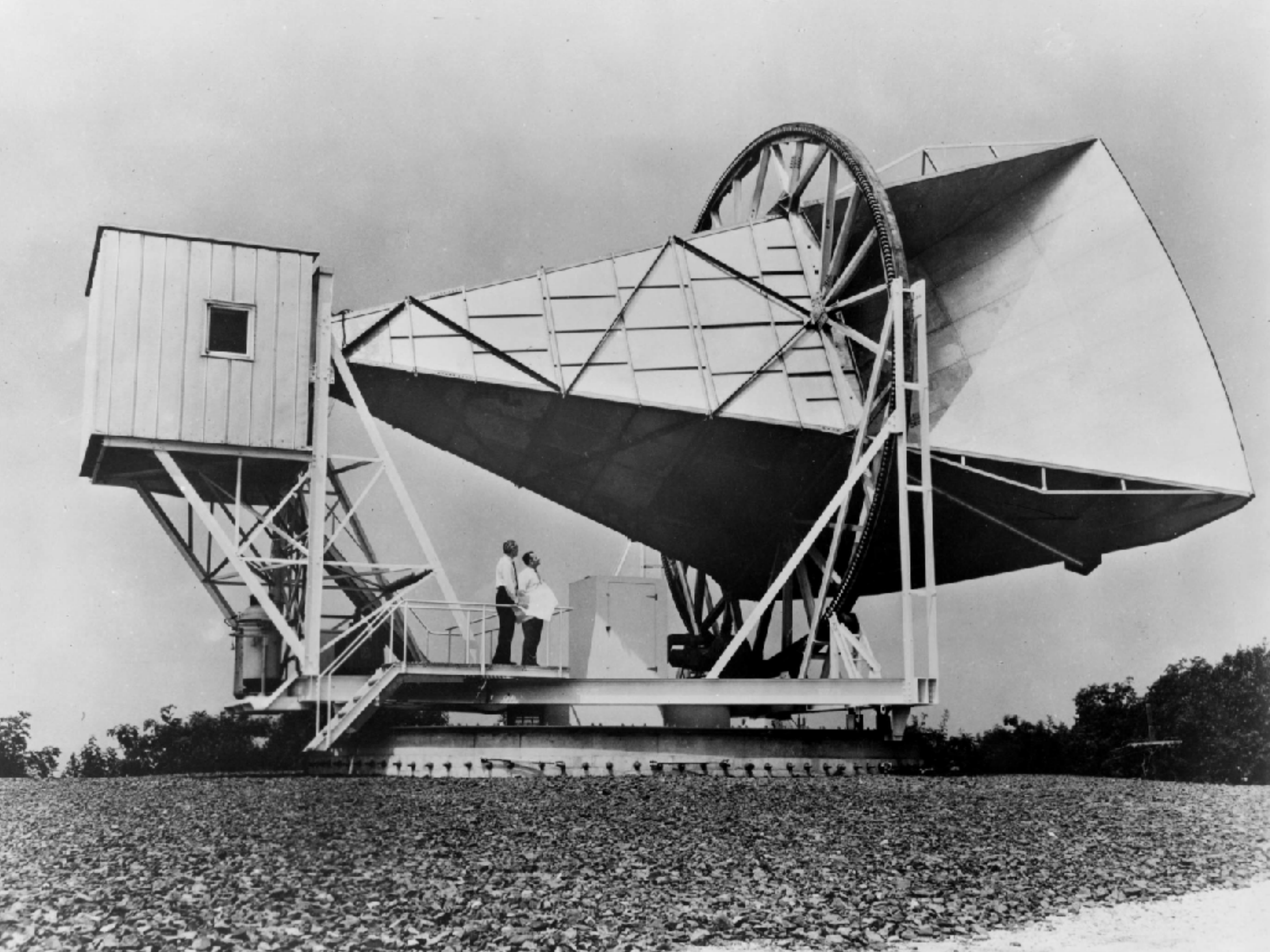
Hot
+
Dense

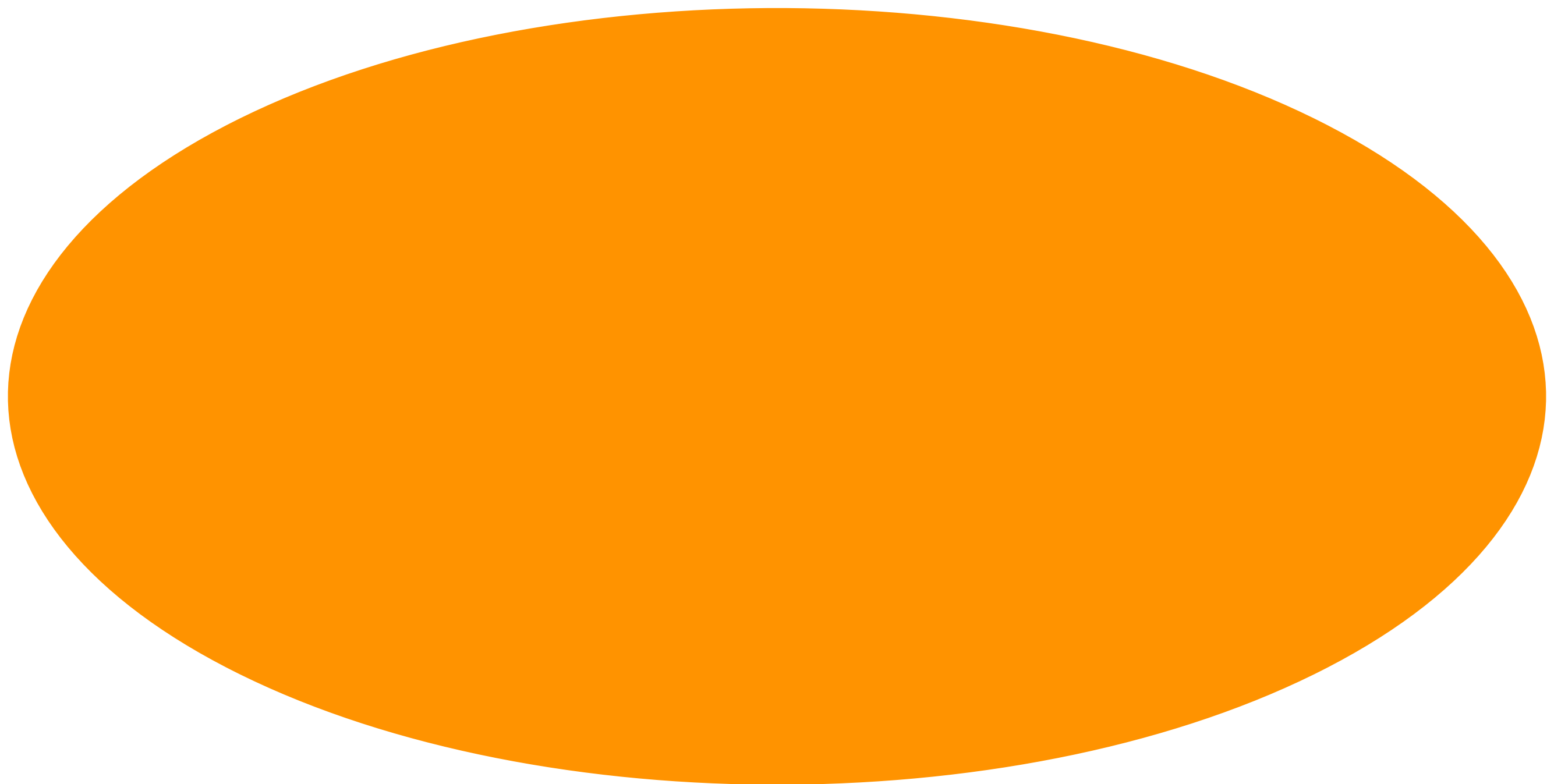
Cold
+
Empty

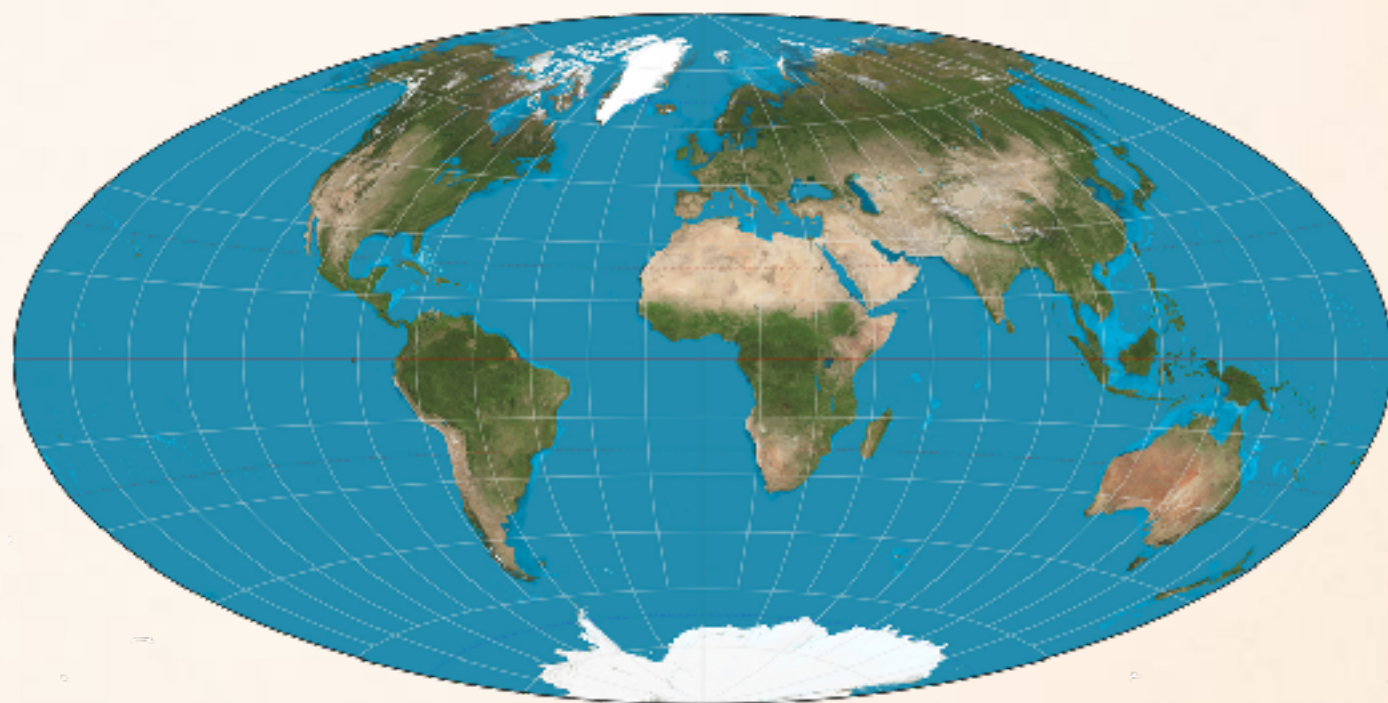
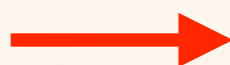
Time



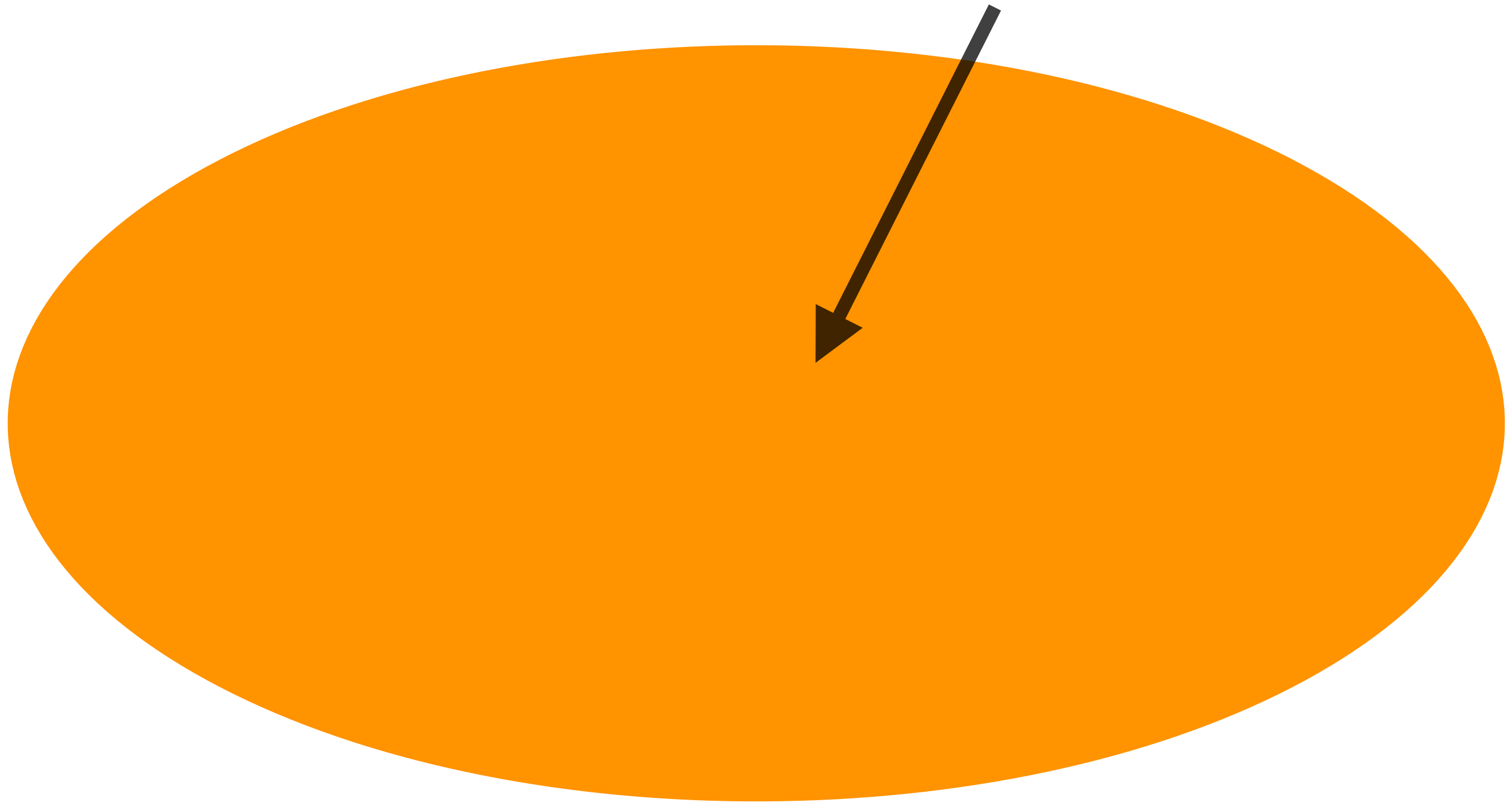


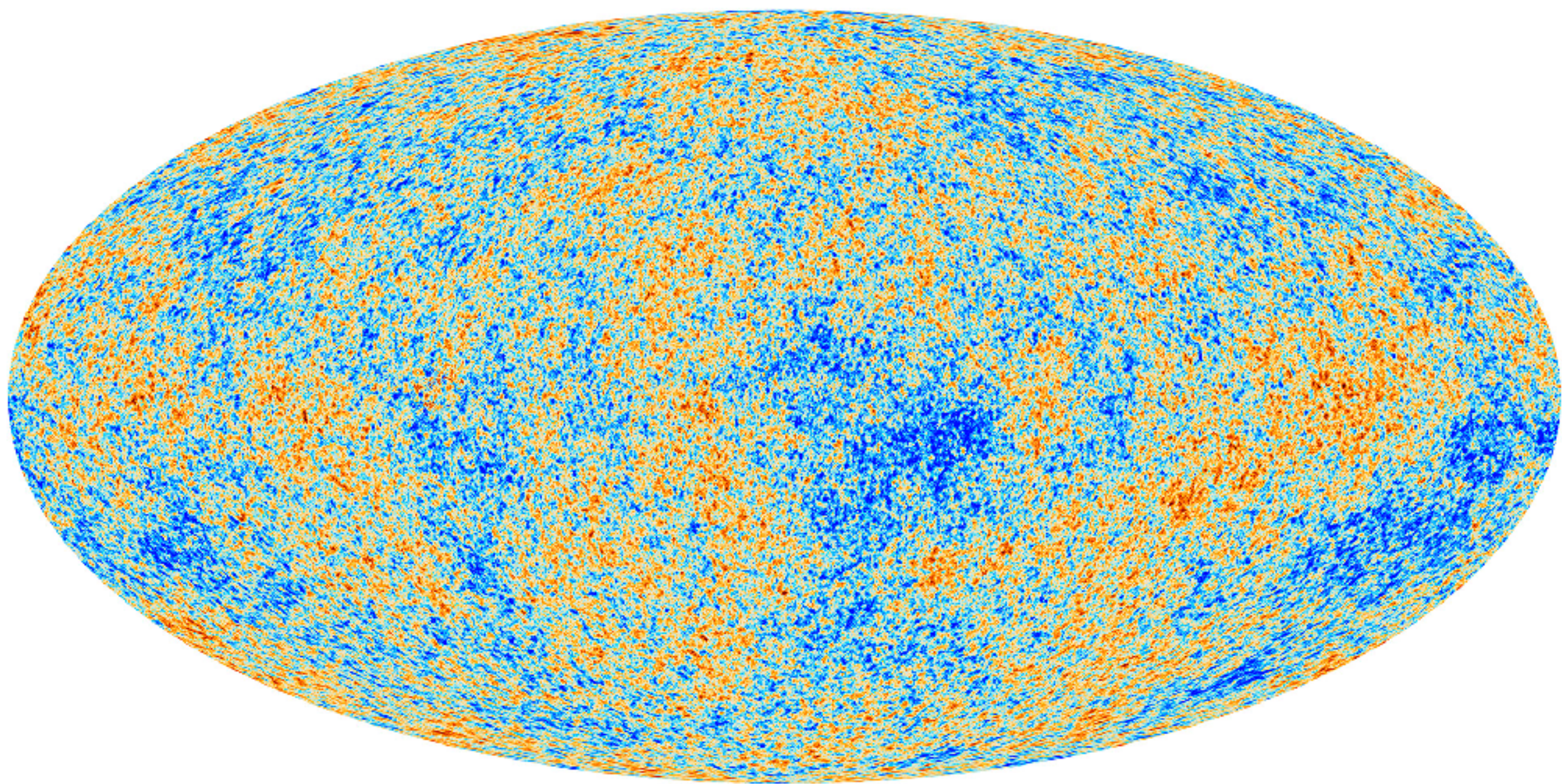




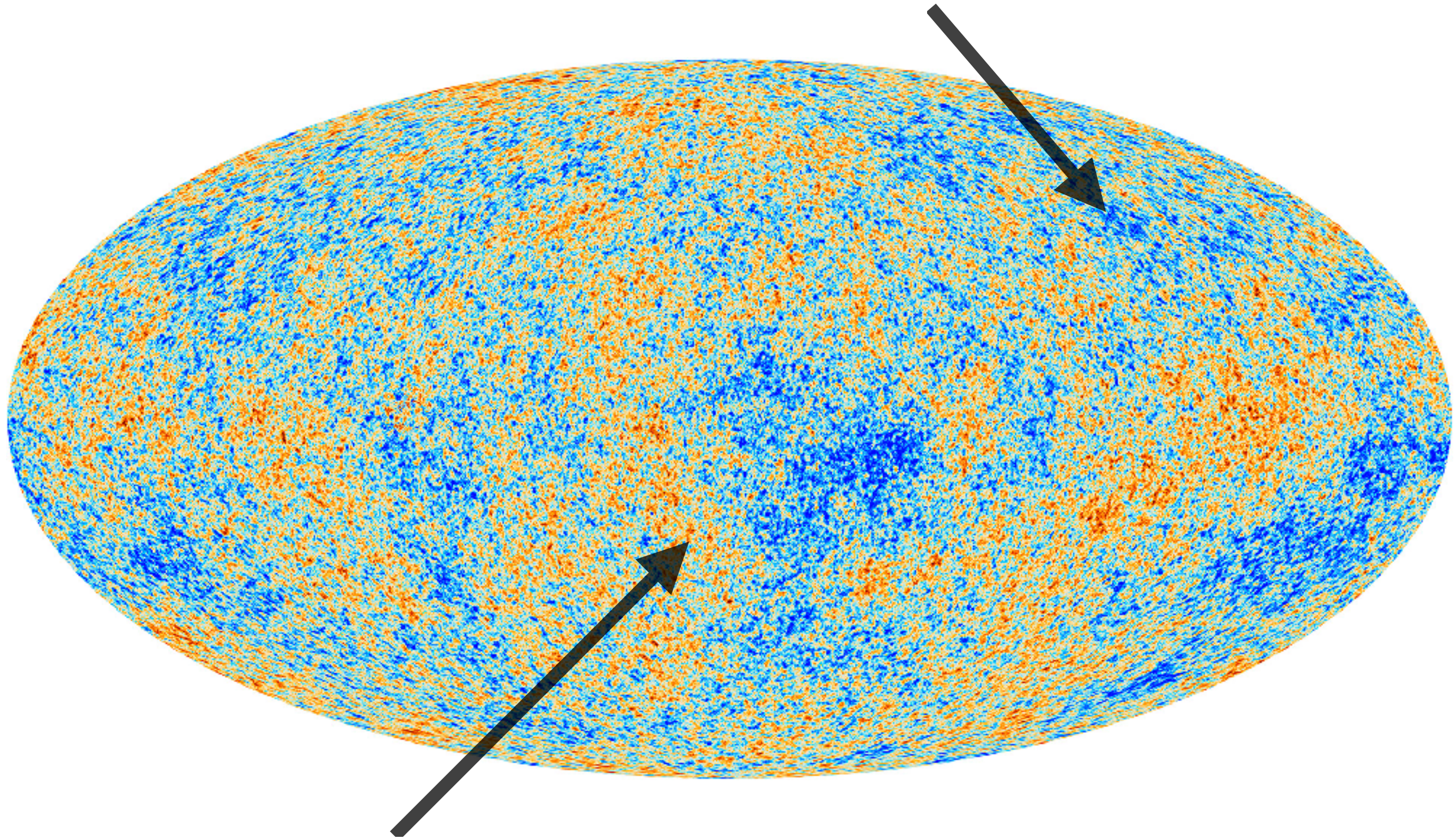


Temperature = 2.728 K

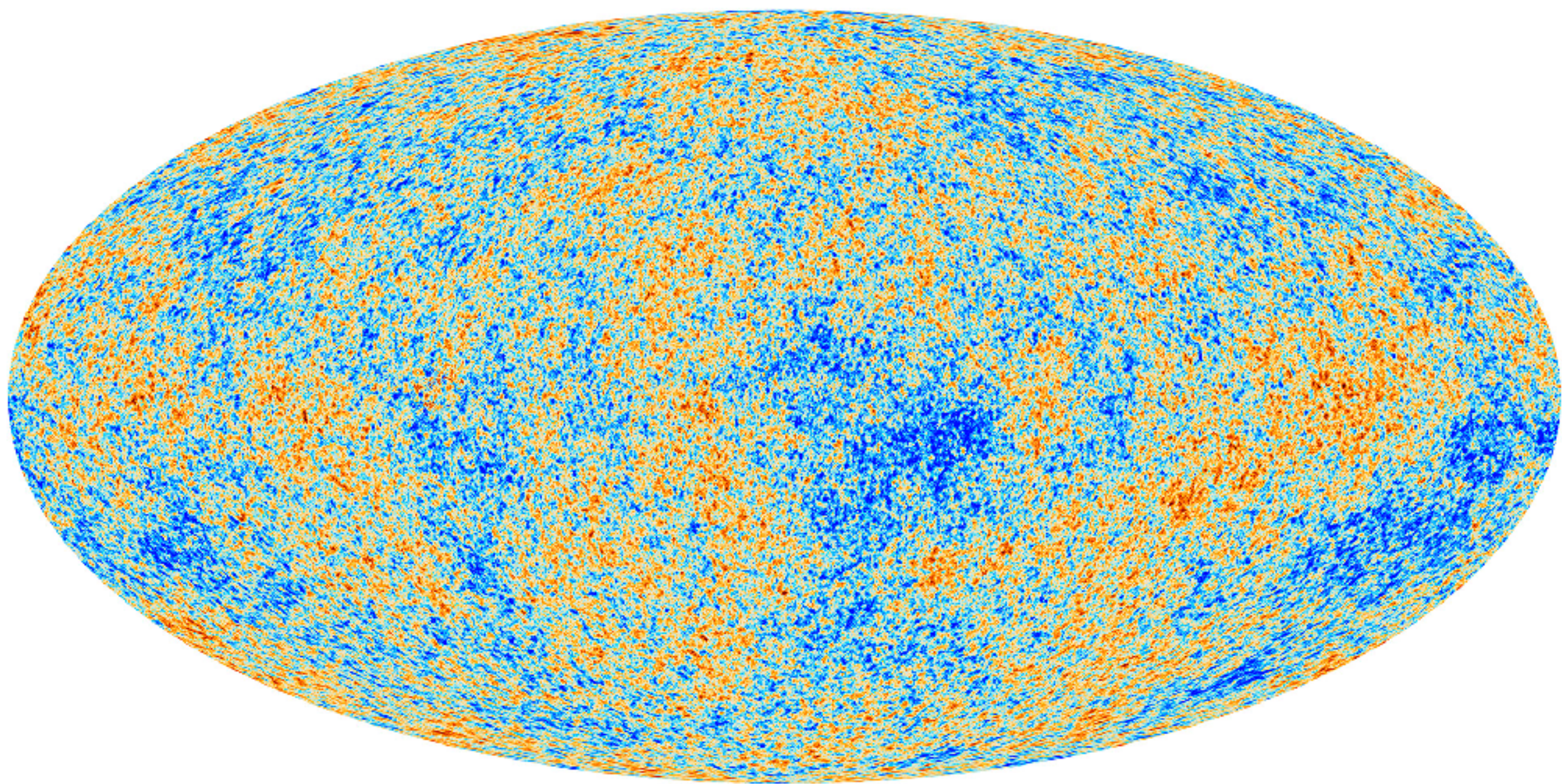




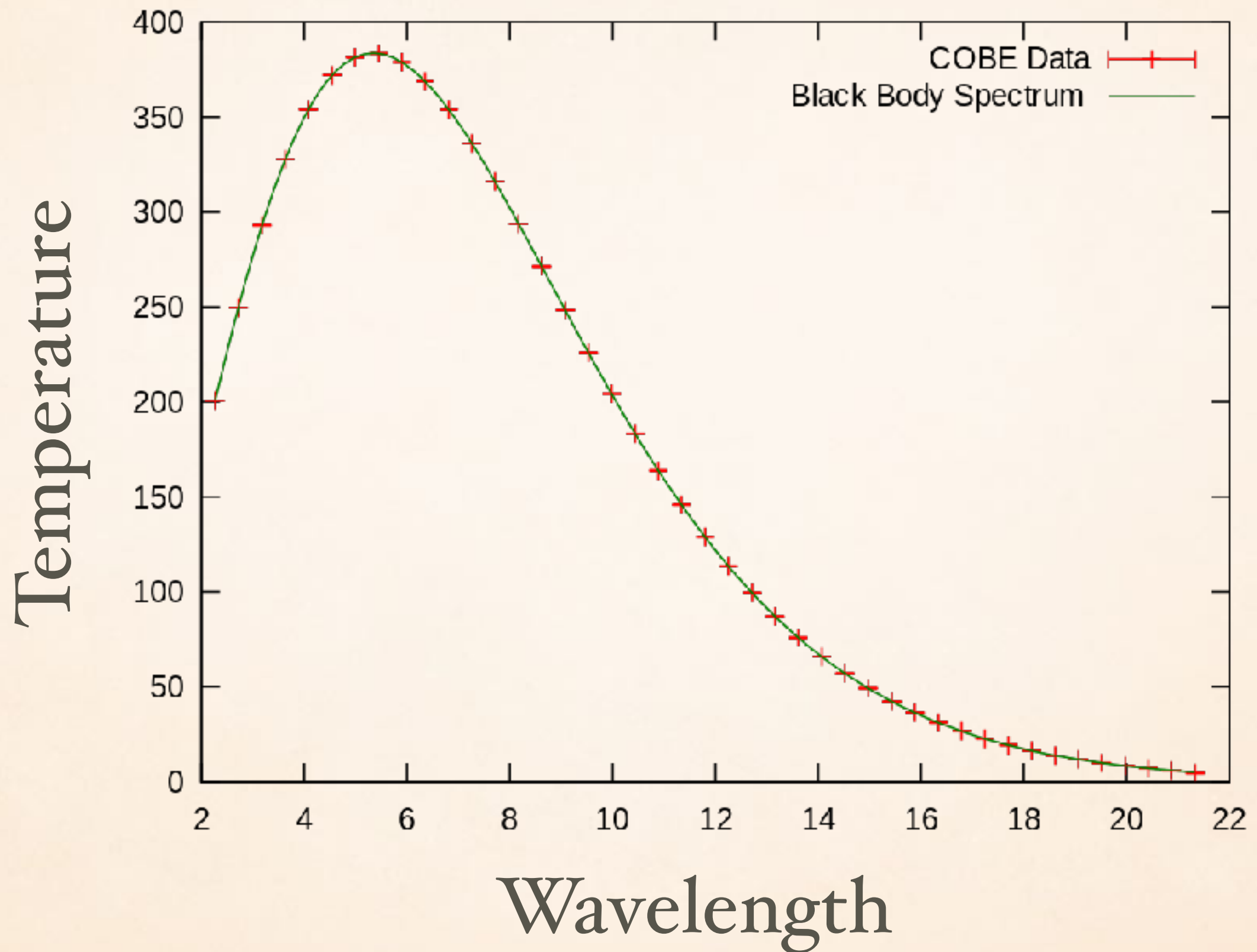
Temperature = 2.72901 K



Temperature = 2.72902 K



Cosmic Microwave Background Spectrum from COBE



A UNIVERSE FIT FOR LIFE?

In an expanding Universe, there is a direct link
between age and size

... an **OLDER** Universe is a **BIGGER** Universe

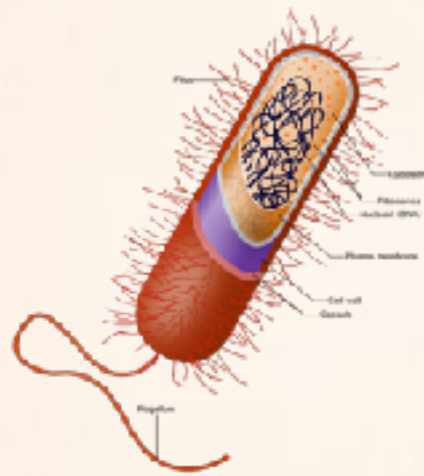
A UNIVERSE FIT FOR LIFE?

A UNIVERSE FIT FOR LIFE?



‘Simple’ life takes
~5-10 billion years

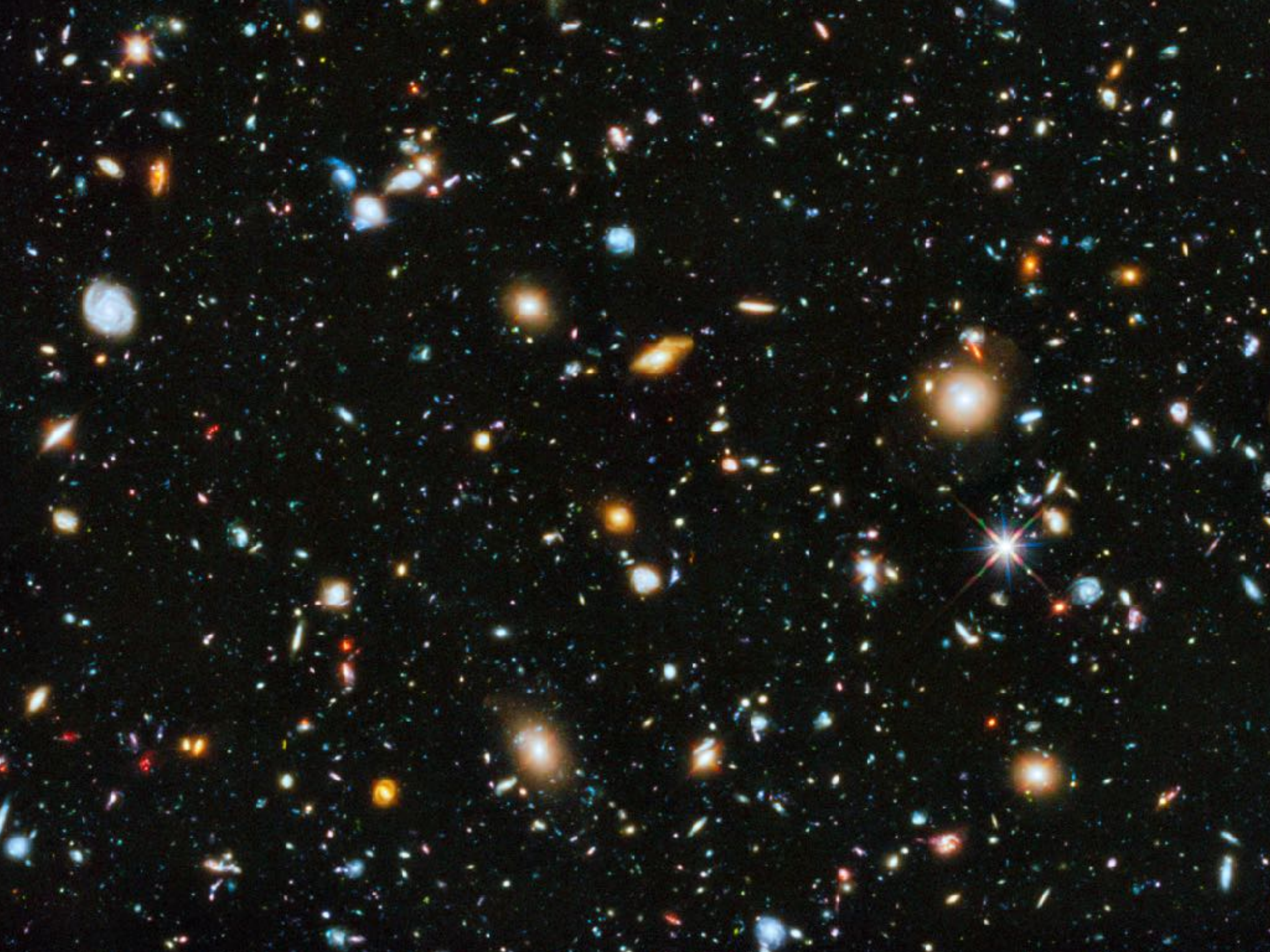
A UNIVERSE FIT FOR LIFE?

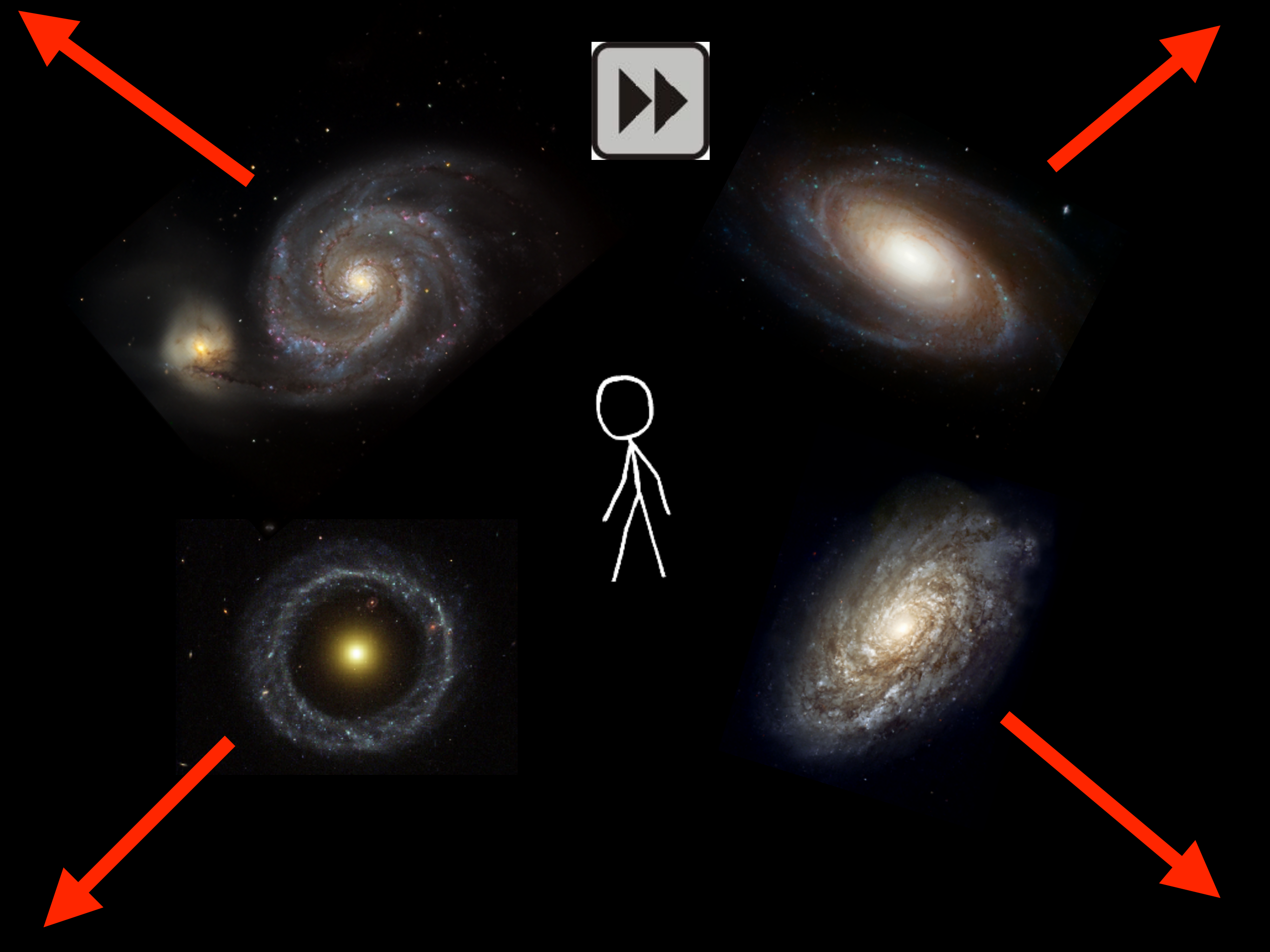


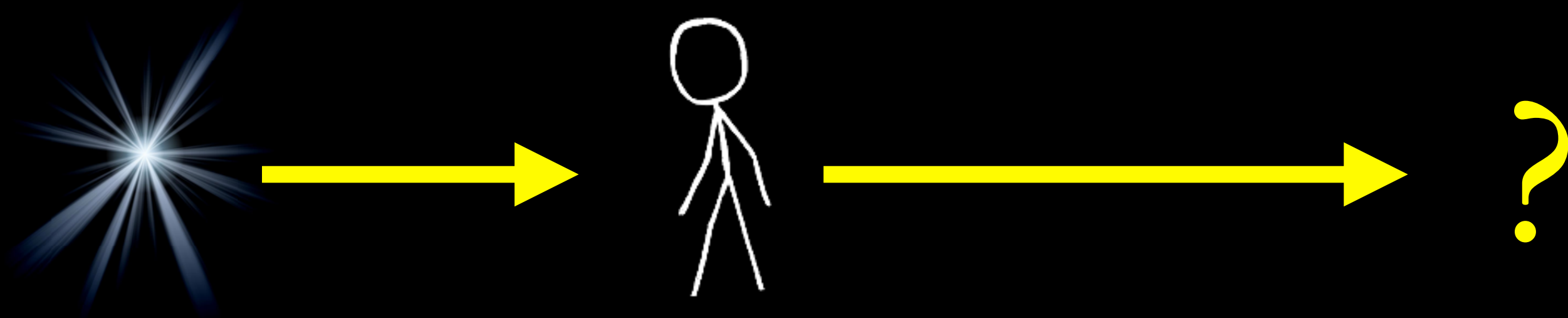
‘Simple’ life takes
~5-10 billion years

‘Sophisticated’ life
takes ~13 billion
years











0



13.7 billion years



100 billion years

THE FUTURE OF THE UNIVERSE

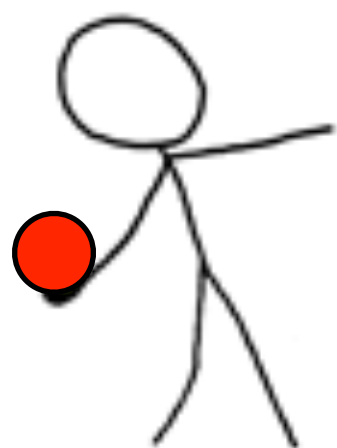
- ❖ We know (from observation) that galaxies are moving apart...
- ❖ But gravity should be pulling everything together!
- ❖ So... is the expansion **slowing down?**



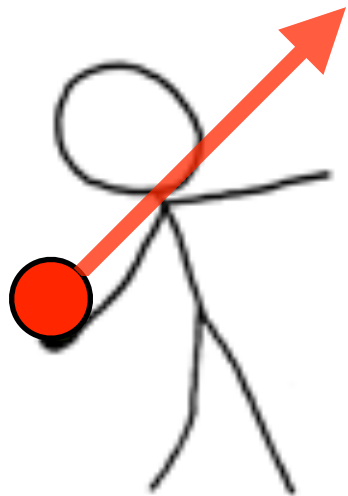


Thought
experiment...

A simple line drawing of a stick figure is positioned at the bottom left. A series of three small circles leads from the figure's head to a large, cloud-shaped thought bubble. Inside the bubble, the words "Thought experiment..." are written in a serif font.

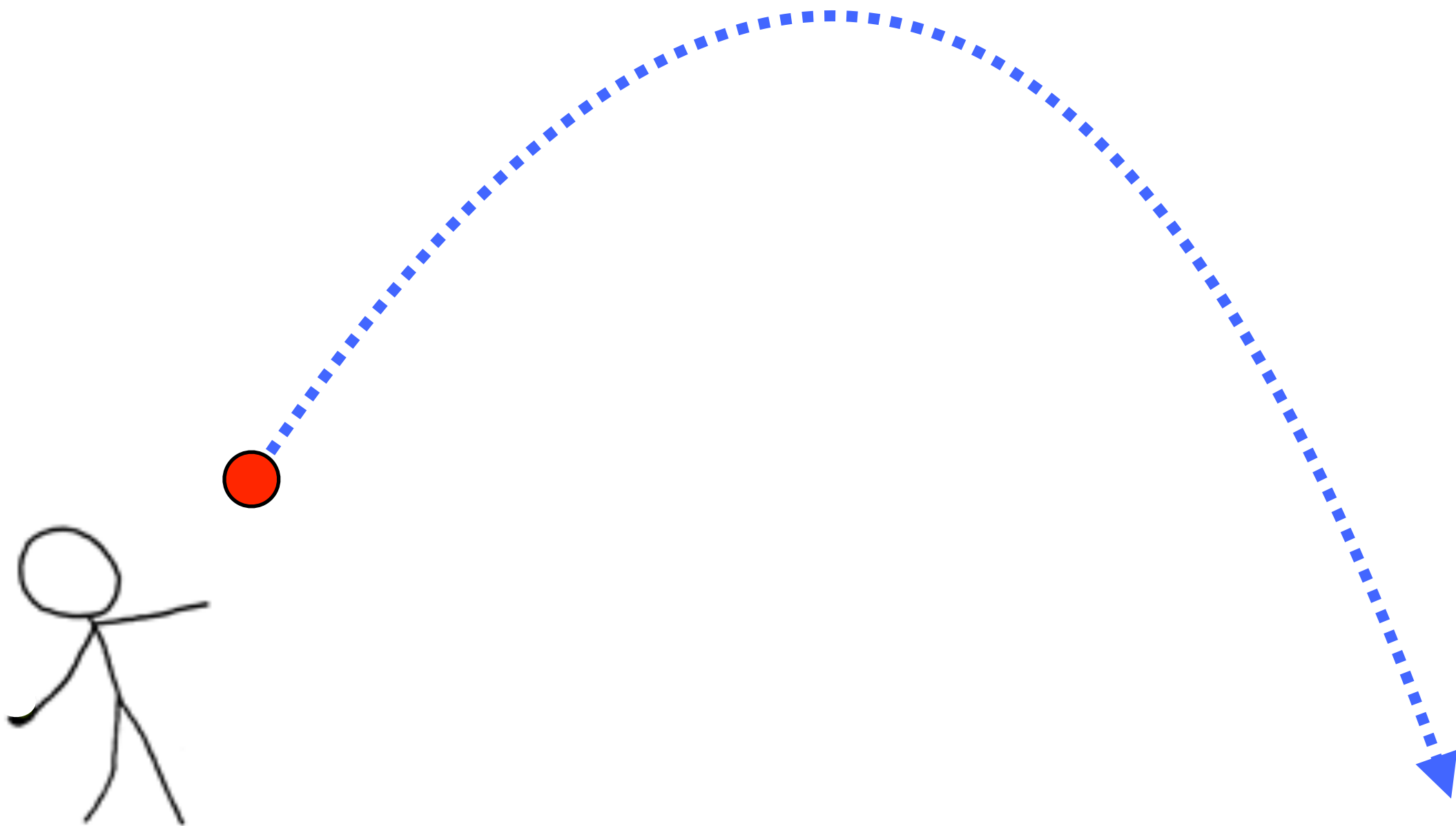


What happens next depends on
how hard you threw the ball...



What happens next depends on
how hard you threw the ball...

With a normal throw, the ball is pulled to Earth by gravity



What happens next depends on
how hard you threw the ball...



With a strong enough (Superman!) throw,
the ball escapes into space...

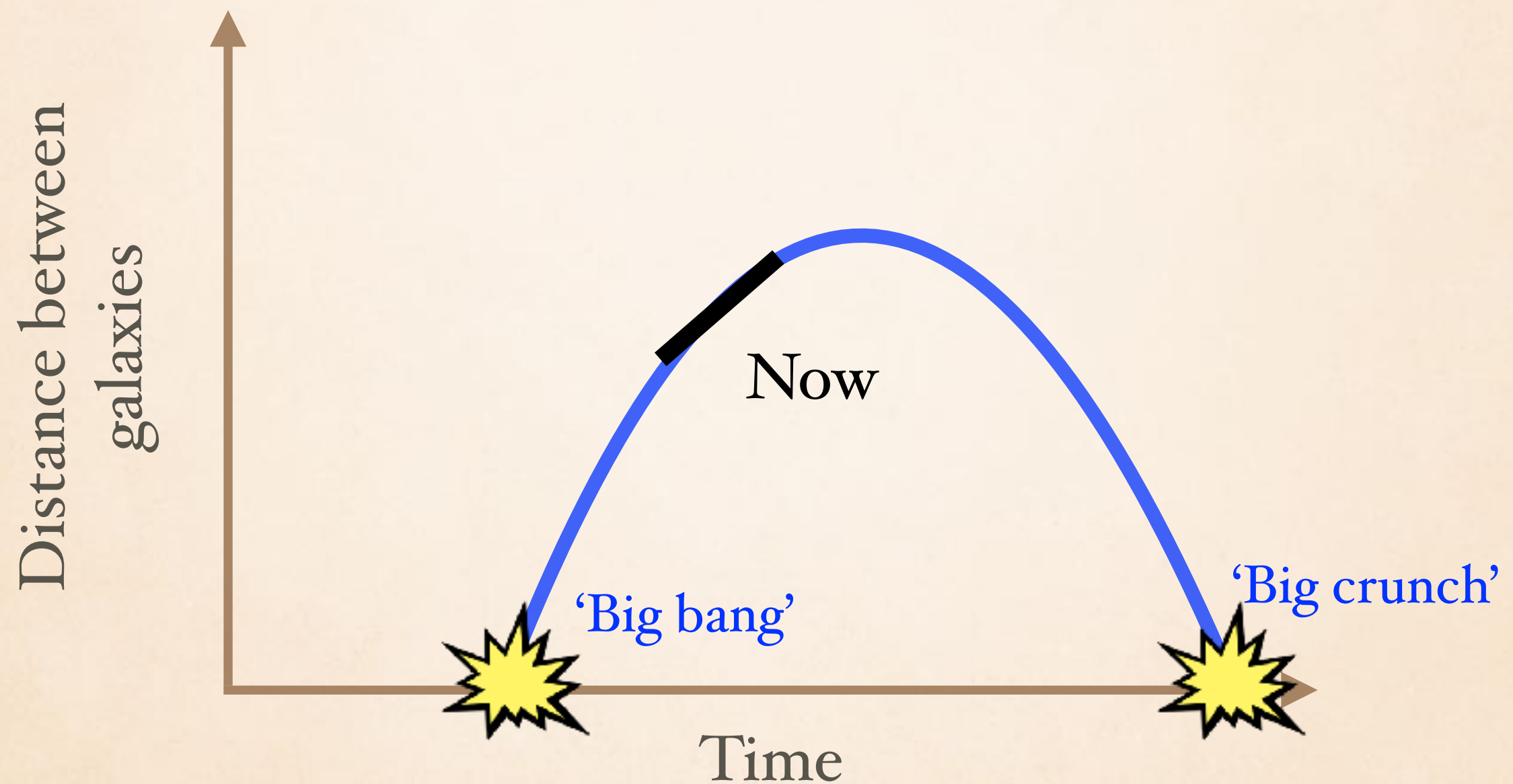
THE EVOLUTION OF THE UNIVERSE



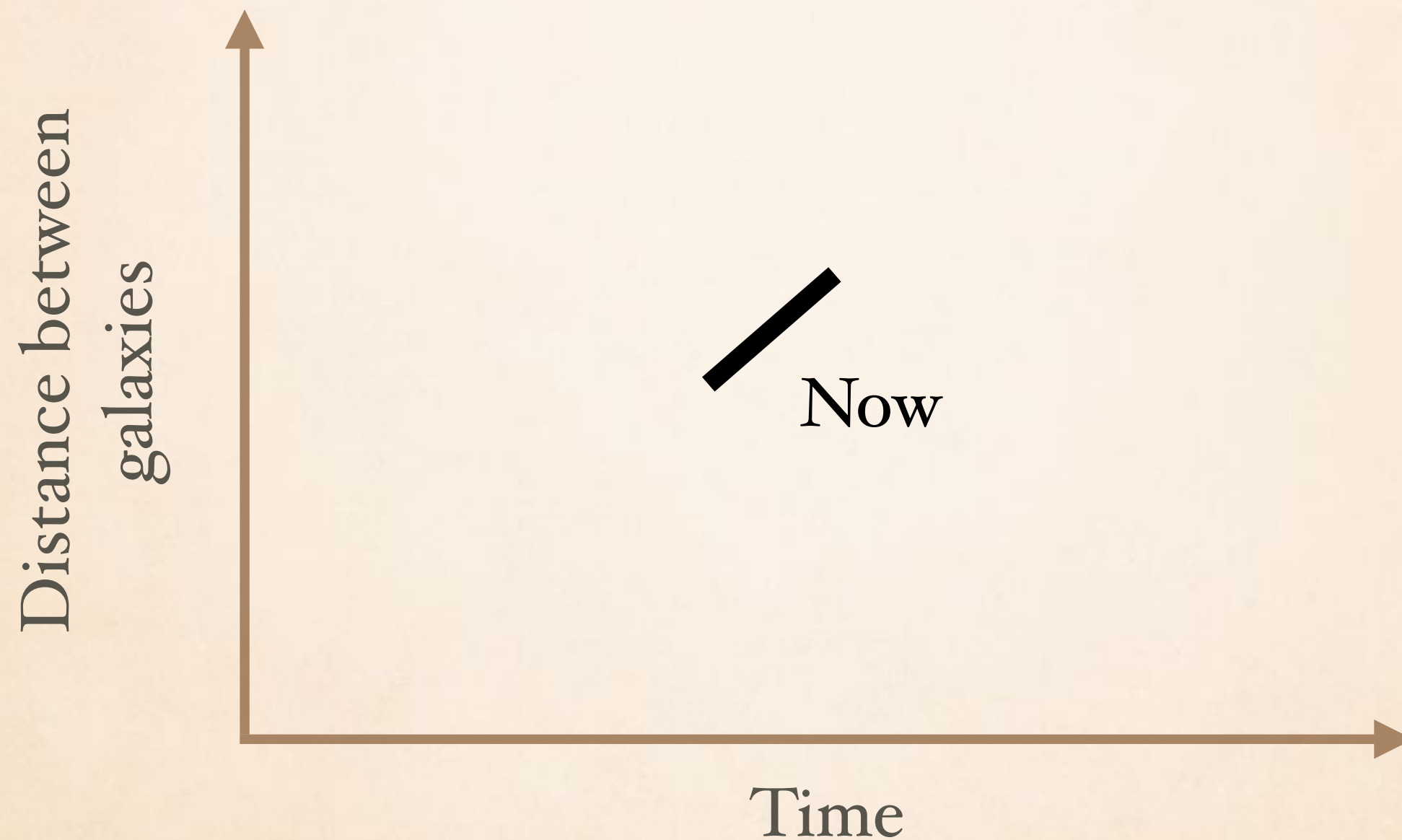
THE EVOLUTION OF THE UNIVERSE



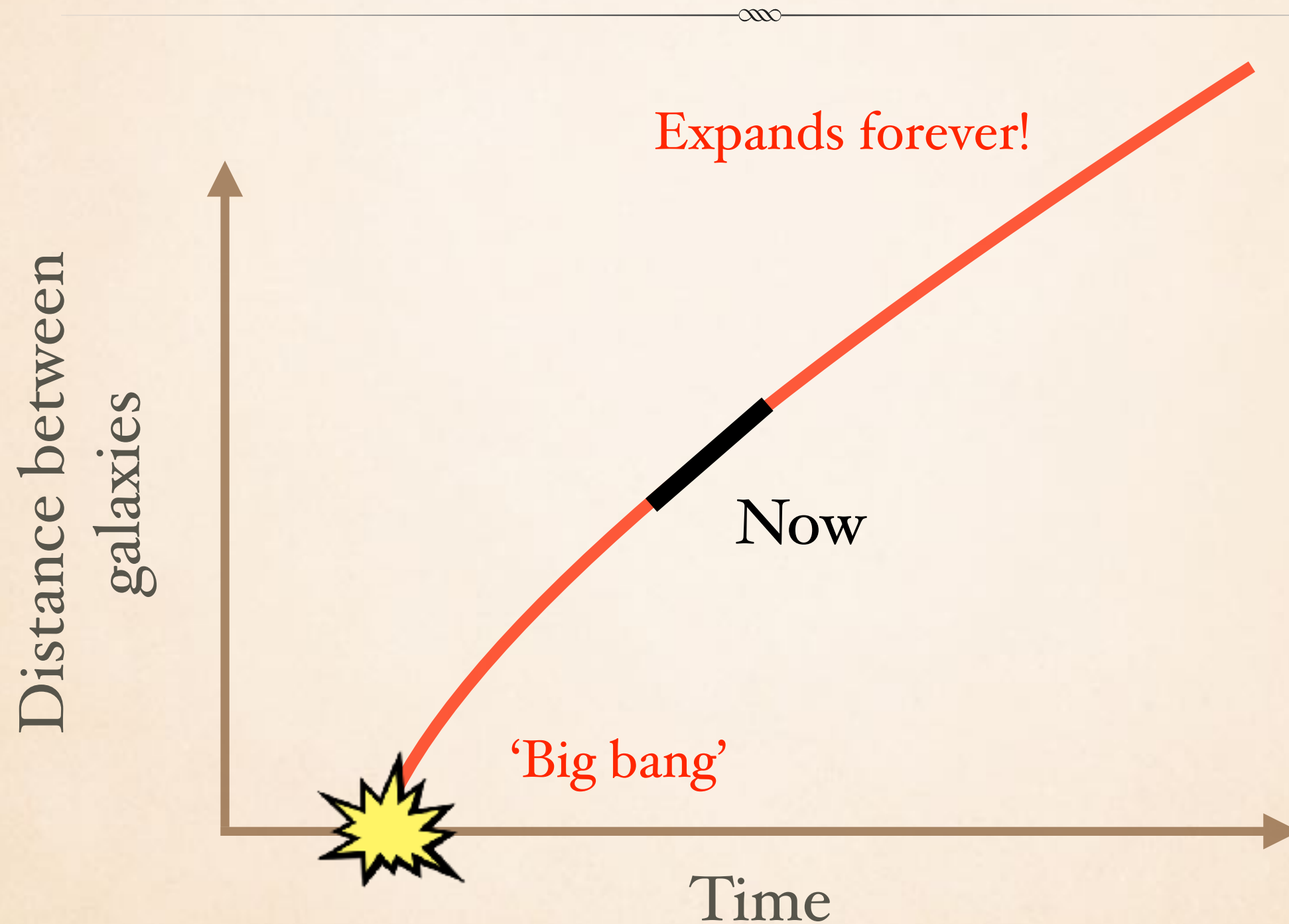
THE EVOLUTION OF THE UNIVERSE



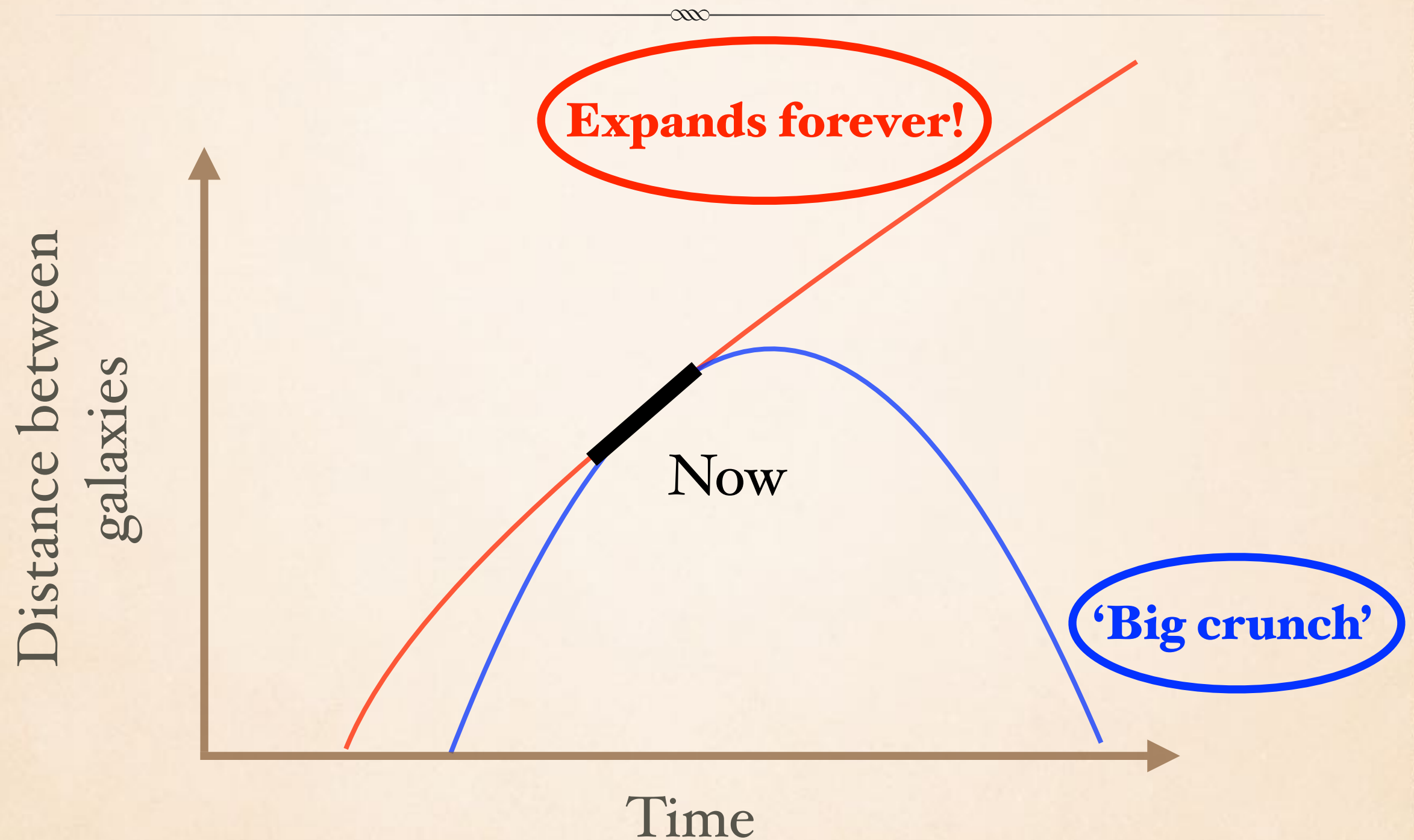
THE EVOLUTION OF THE UNIVERSE



THE EVOLUTION OF THE UNIVERSE



THE EVOLUTION OF THE UNIVERSE



THE EVOLUTION OF THE UNIVERSE

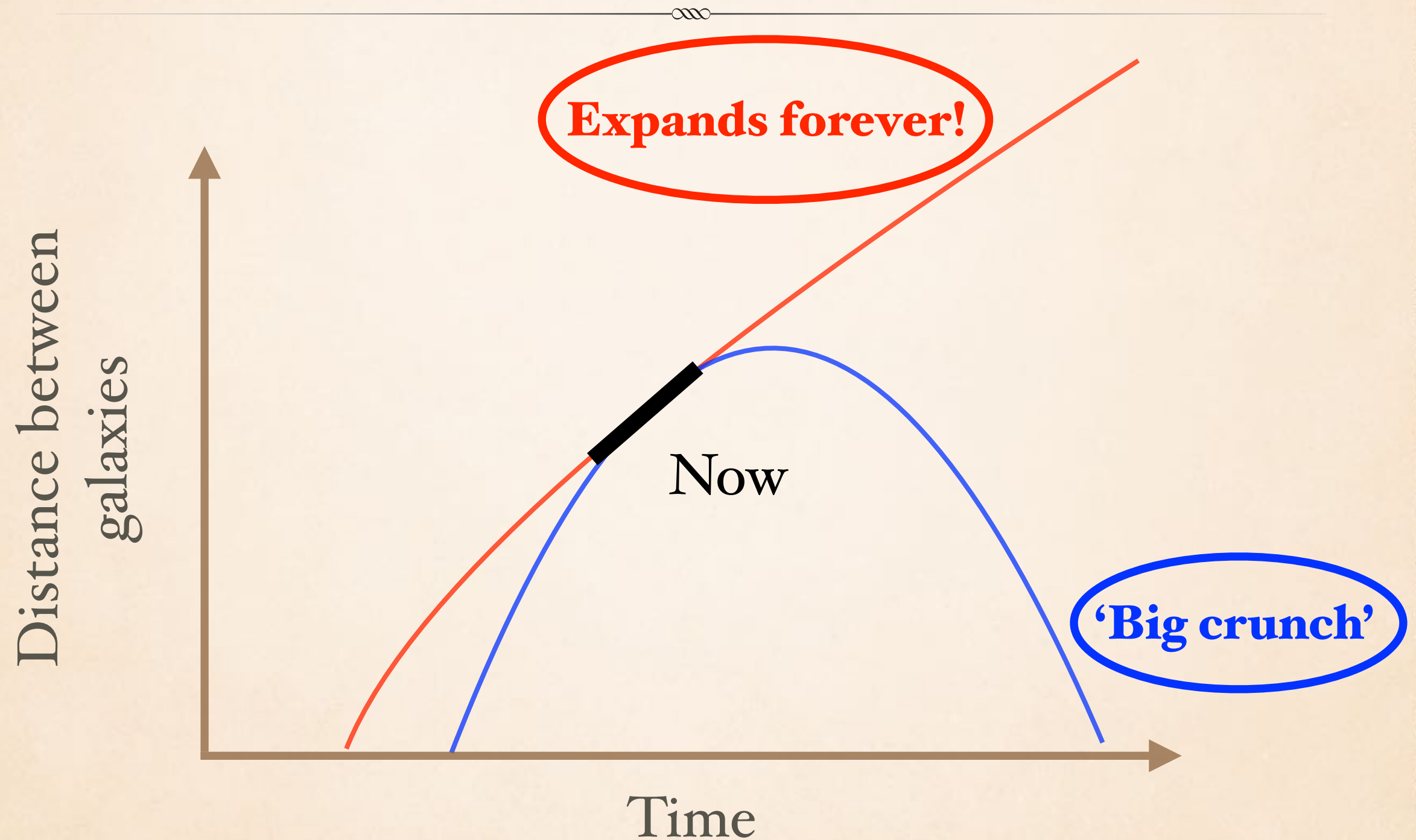
Two possibilities for the future of the Universe!

Expands forever!



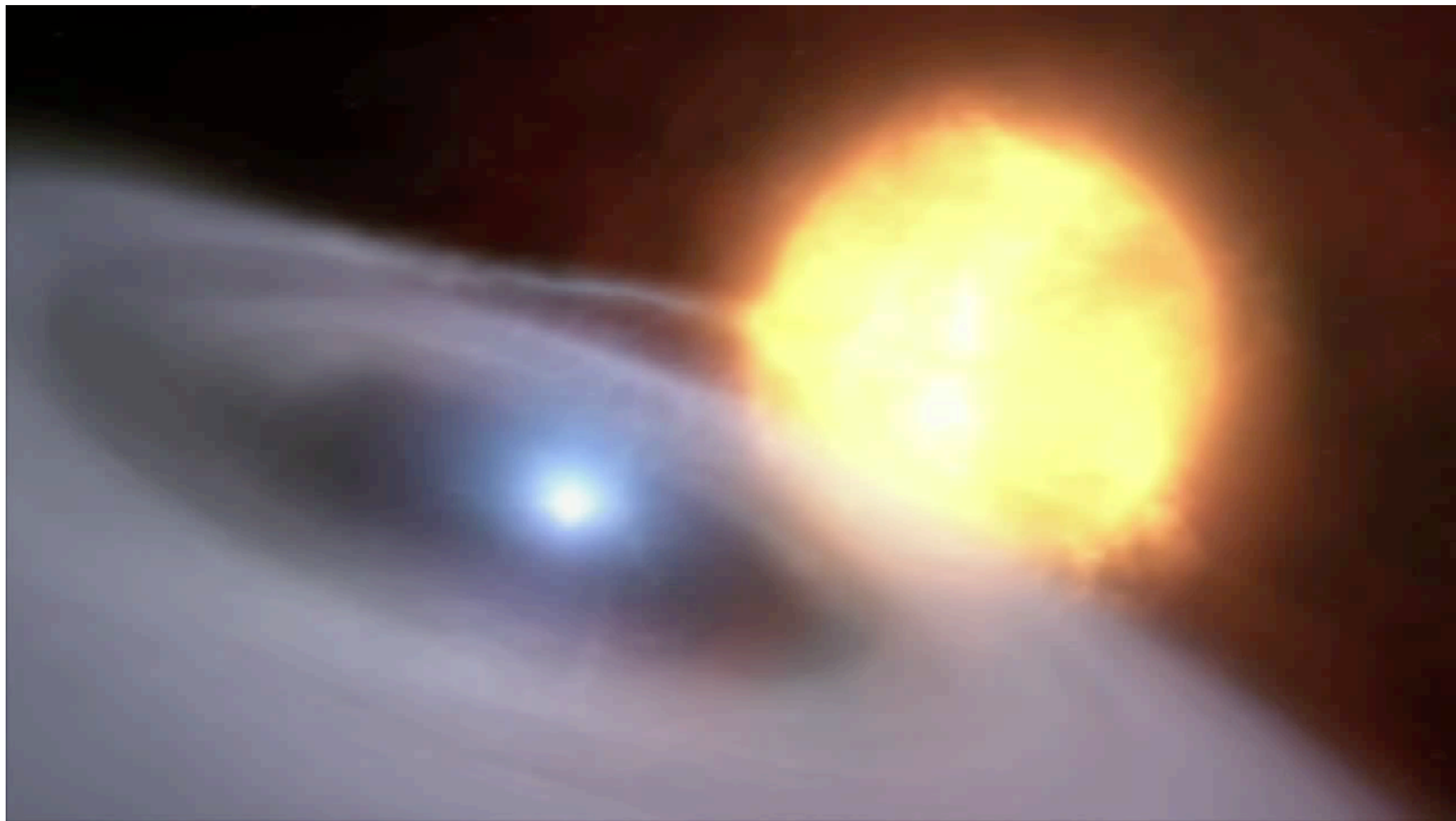
'Big crunch'

THE EVOLUTION OF THE UNIVERSE



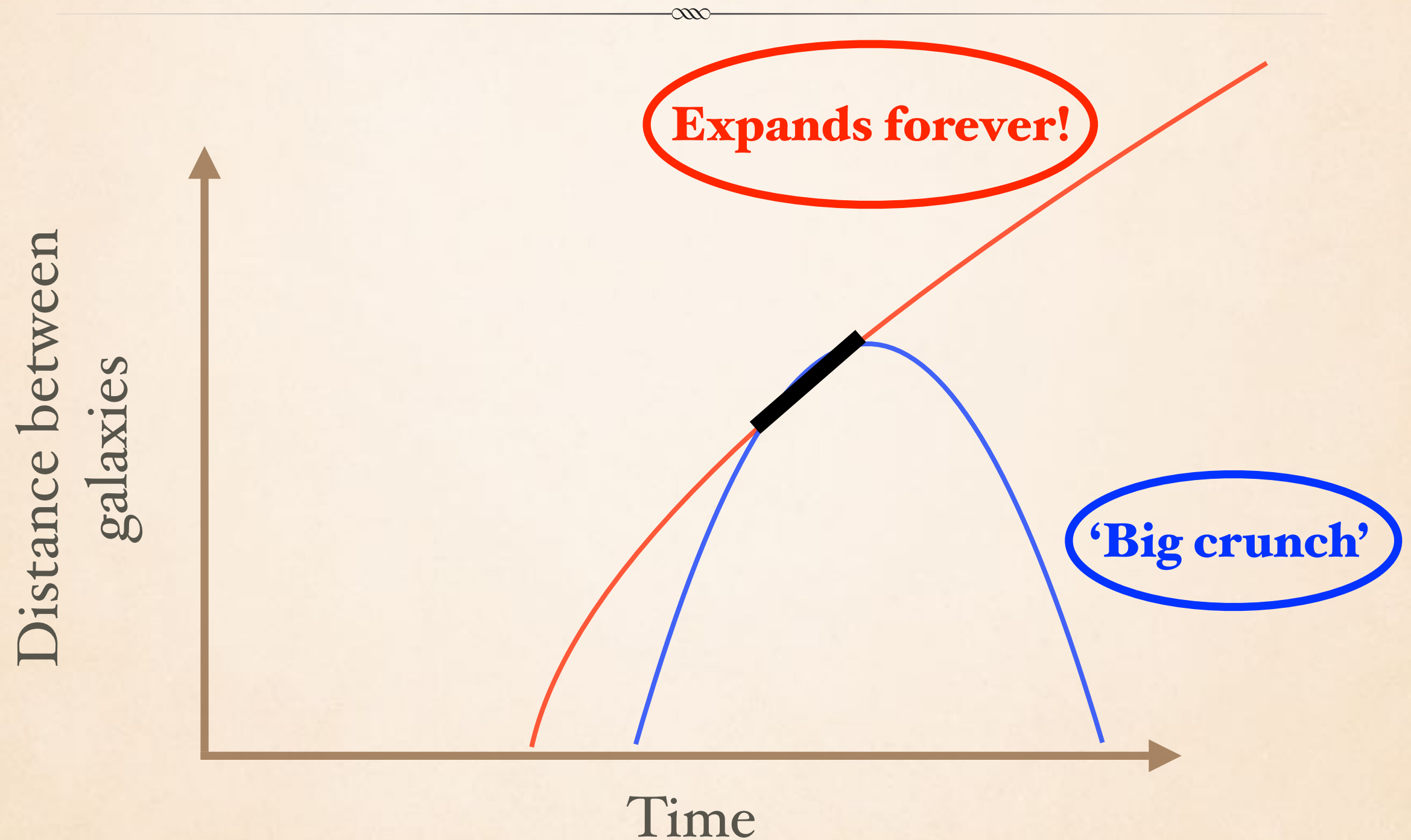
MEASURING THE UNIVERSE

- ❖ What we need to do is MEASURE the distances between galaxies...
- ❖ Luckily, nature has been kind and given us something we can use as a 'ruler'...
- ❖ A 'type IA supernova'

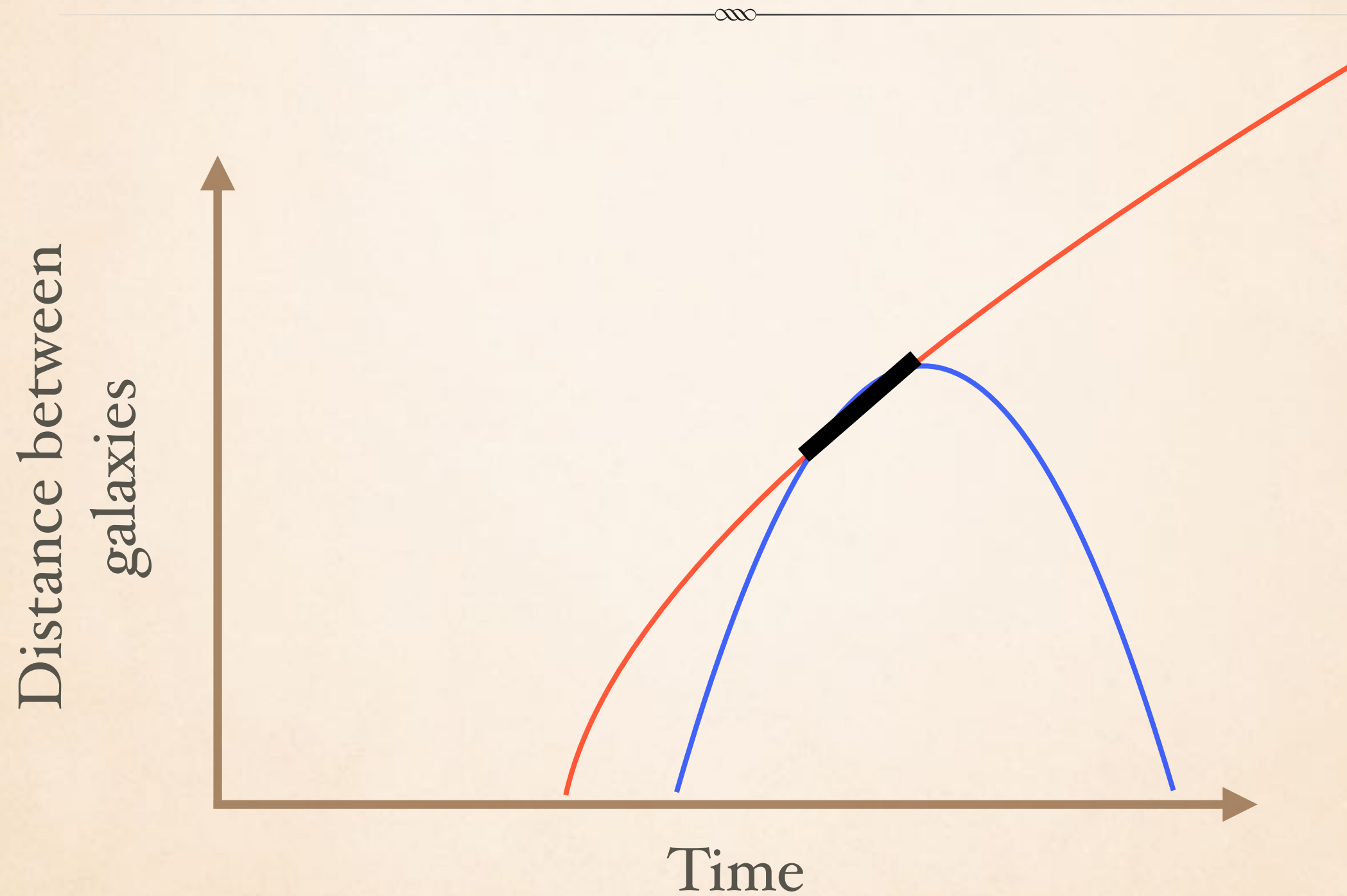




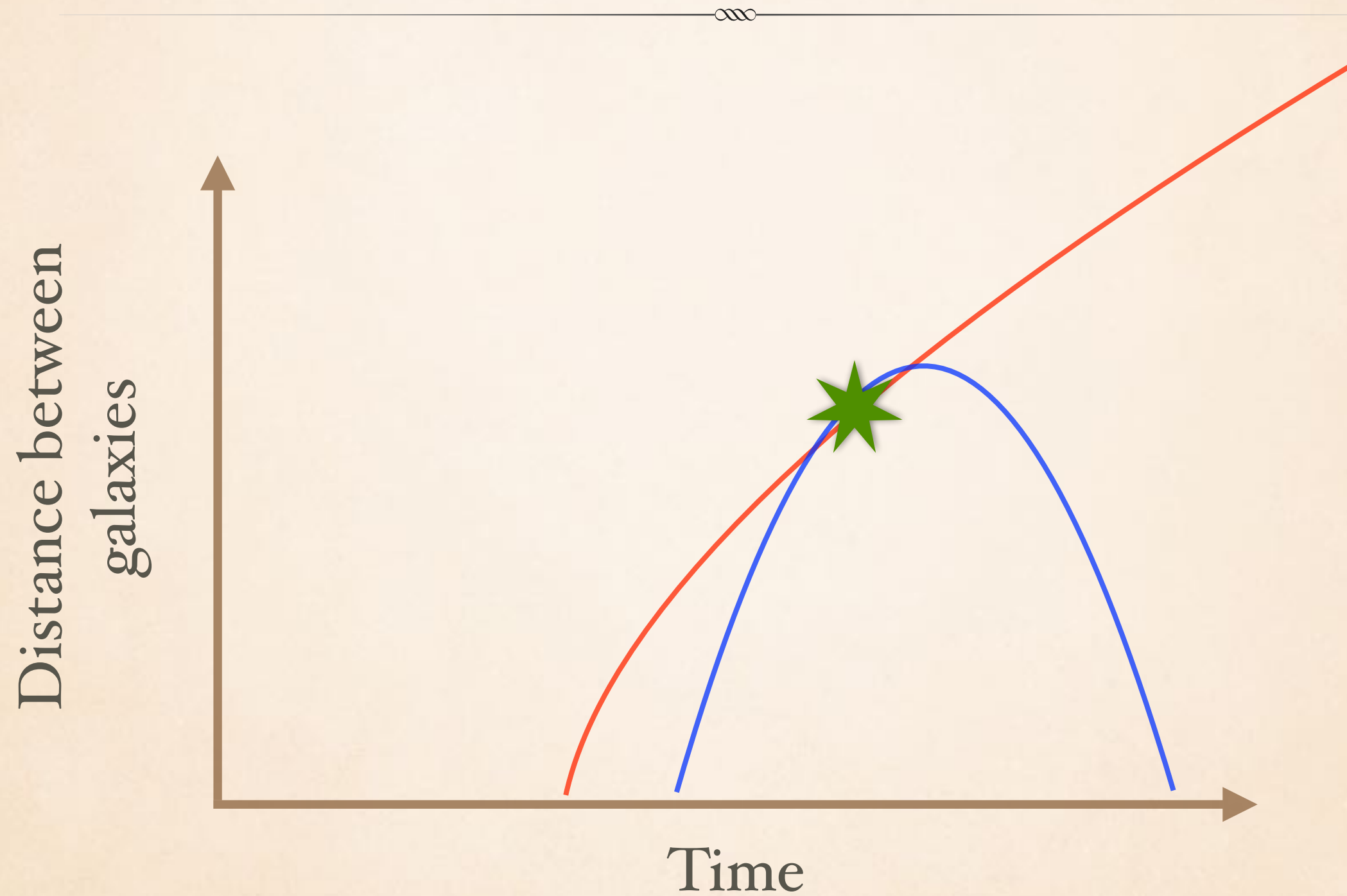
THE EVOLUTION OF THE UNIVERSE



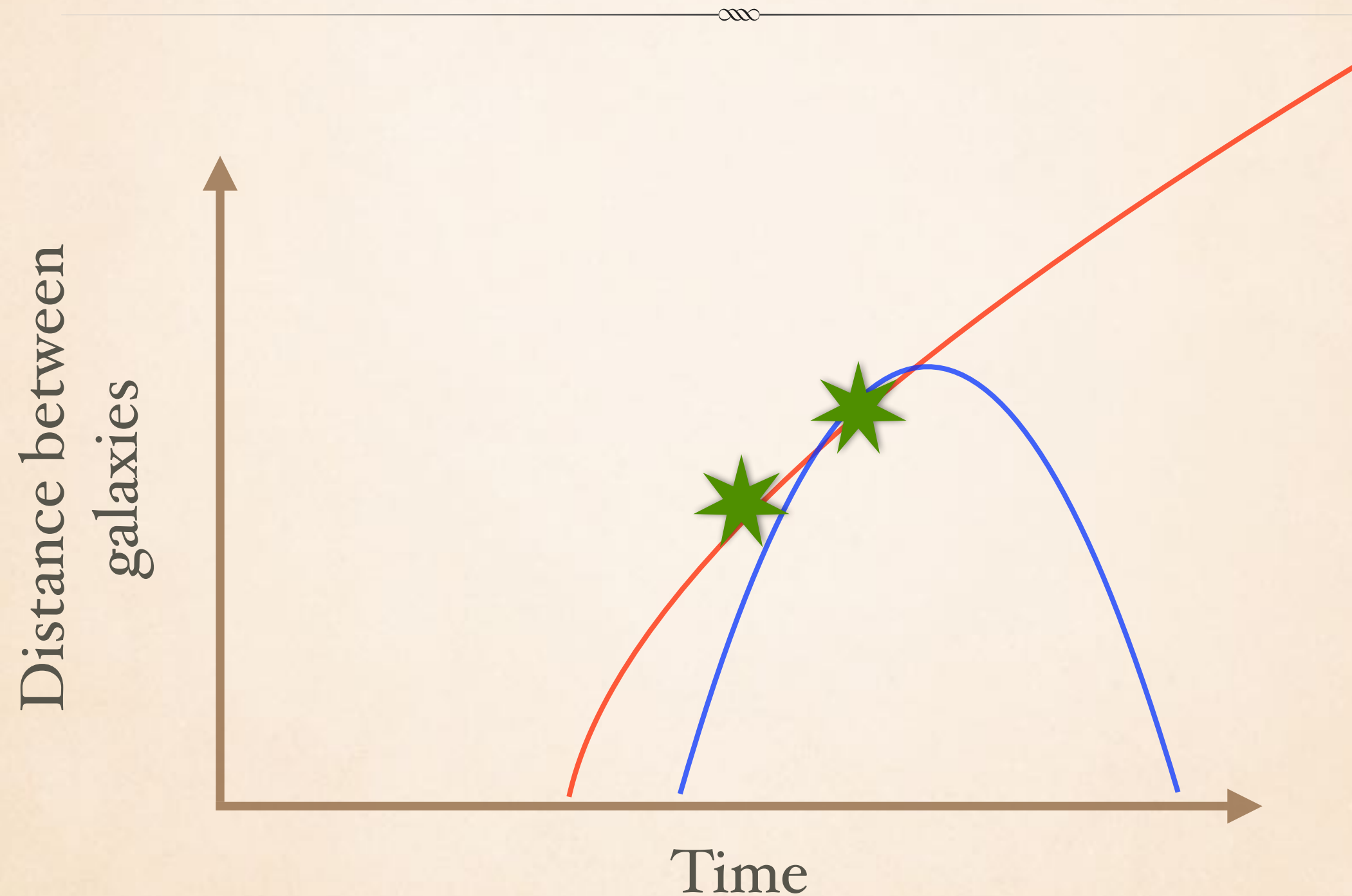
THE EVOLUTION OF THE UNIVERSE



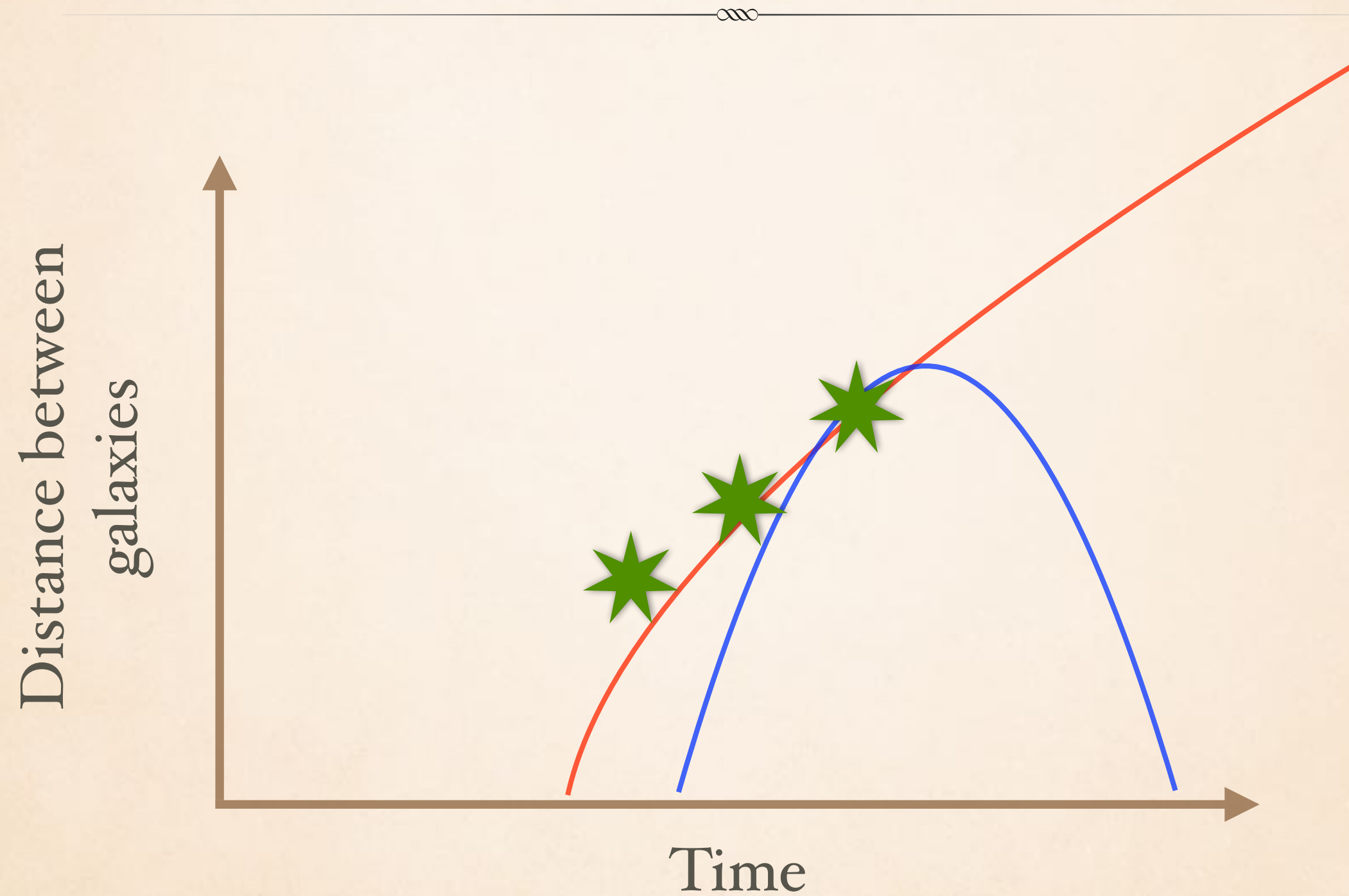
THE EVOLUTION OF THE UNIVERSE



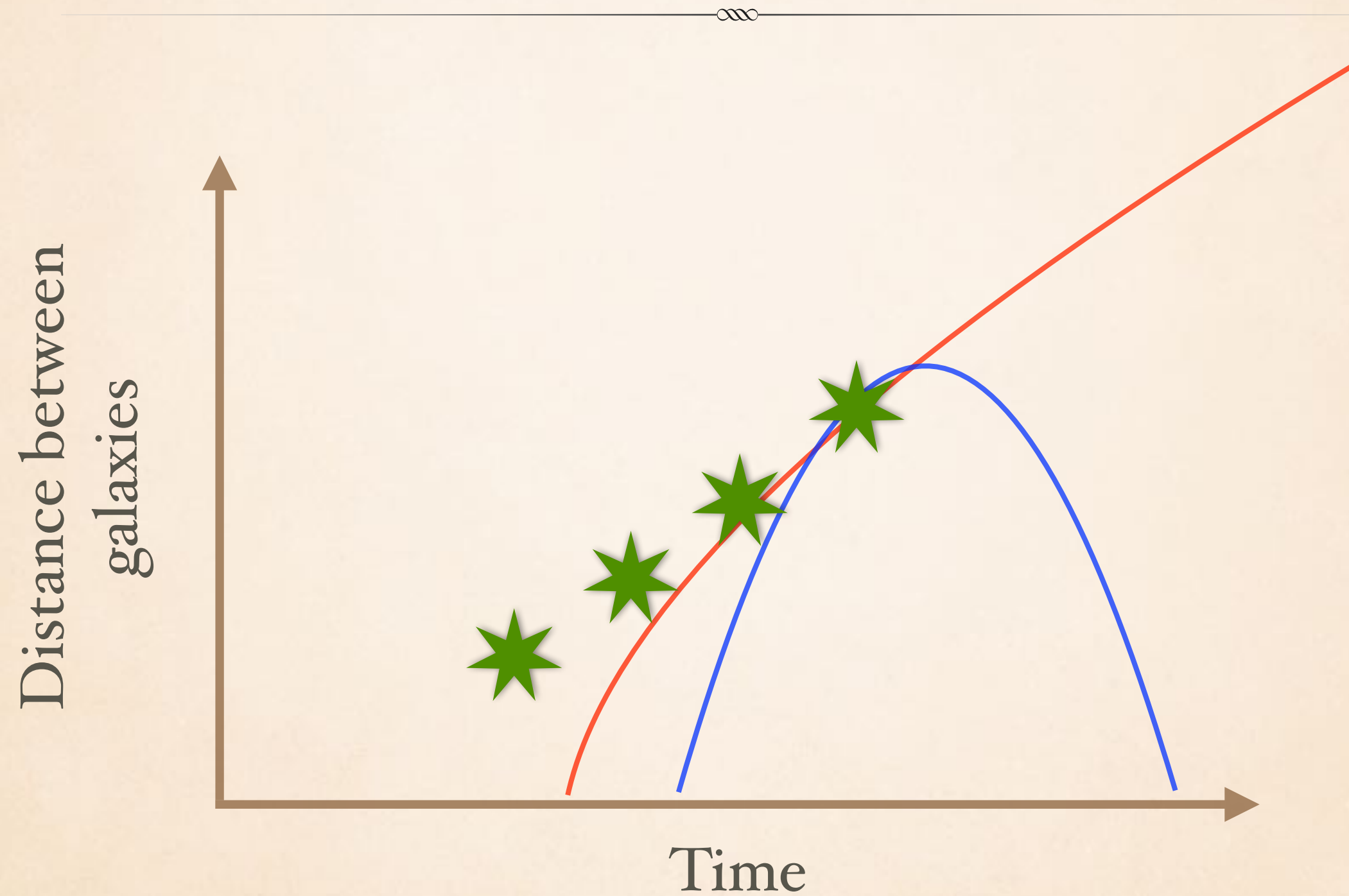
THE EVOLUTION OF THE UNIVERSE



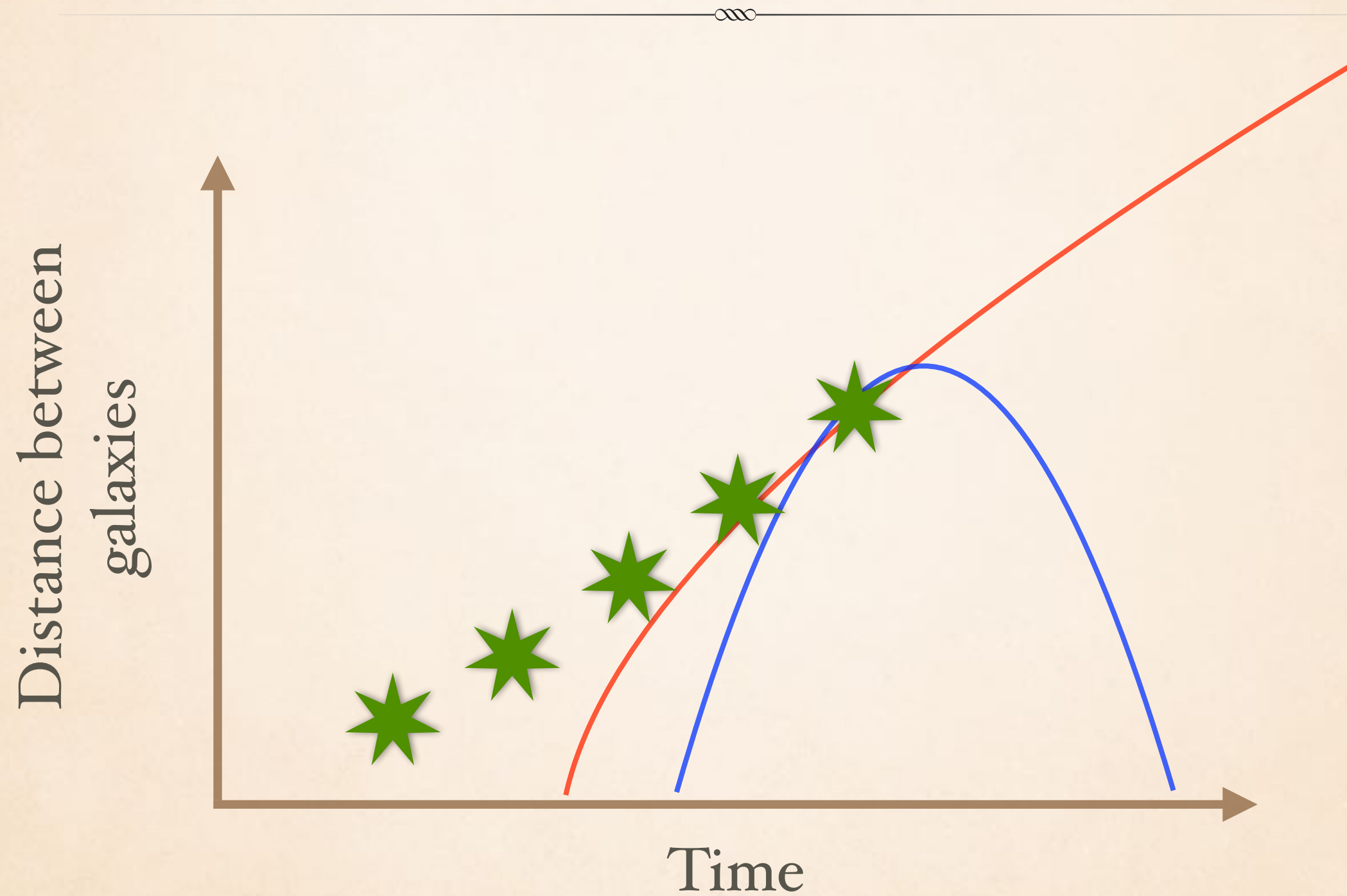
THE EVOLUTION OF THE UNIVERSE



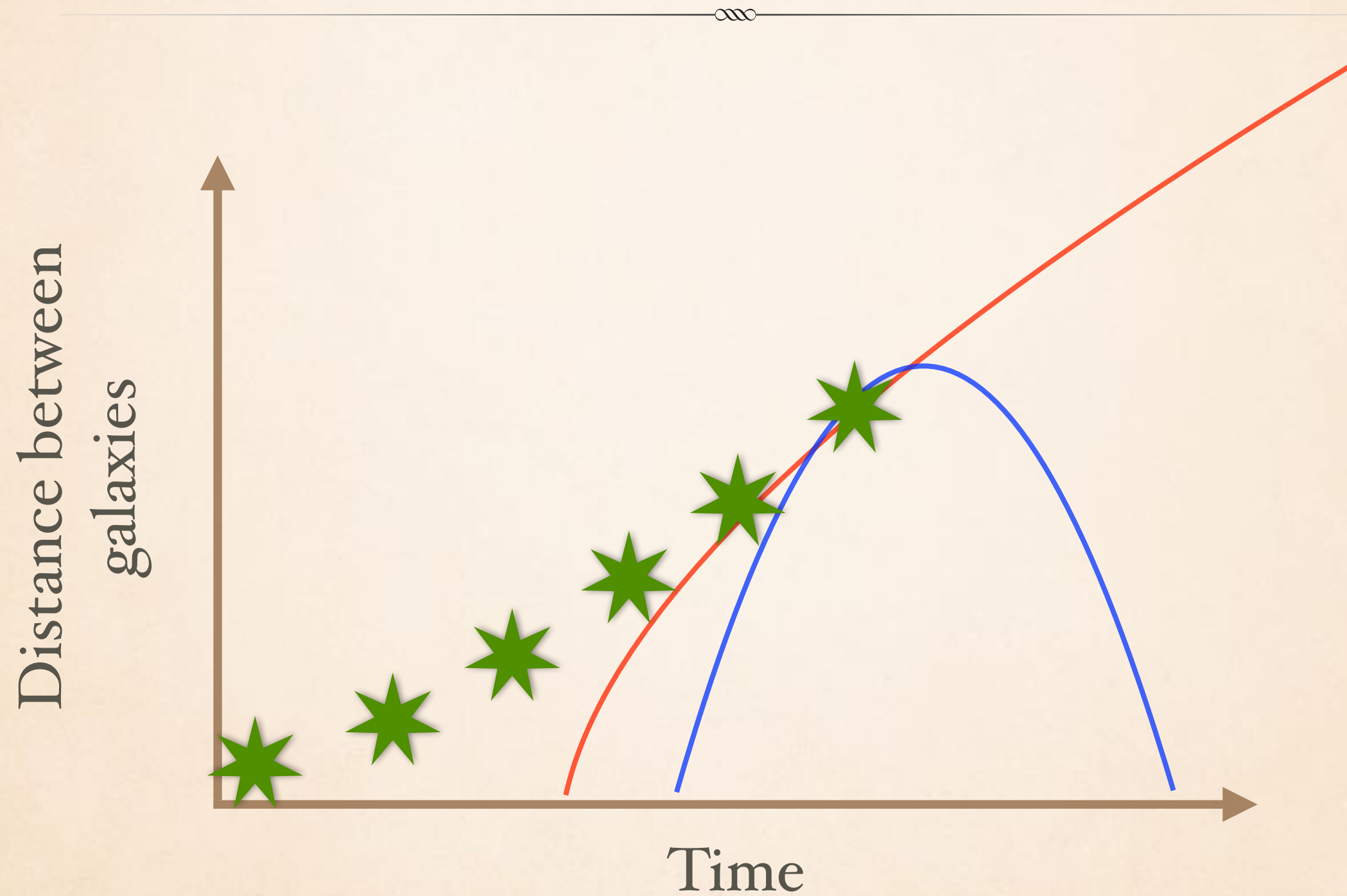
THE EVOLUTION OF THE UNIVERSE



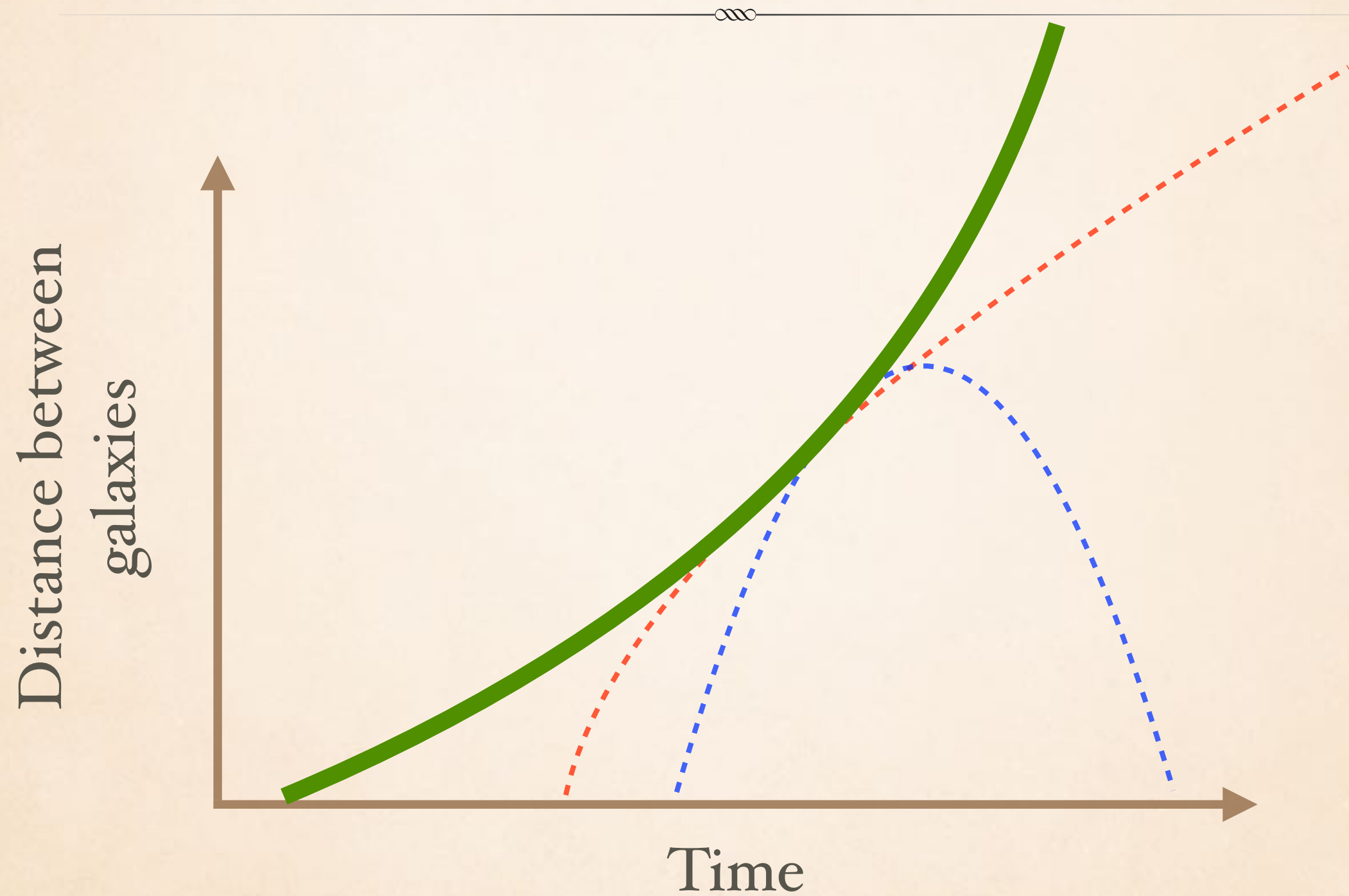
THE EVOLUTION OF THE UNIVERSE



THE EVOLUTION OF THE UNIVERSE



THE EVOLUTION OF THE UNIVERSE



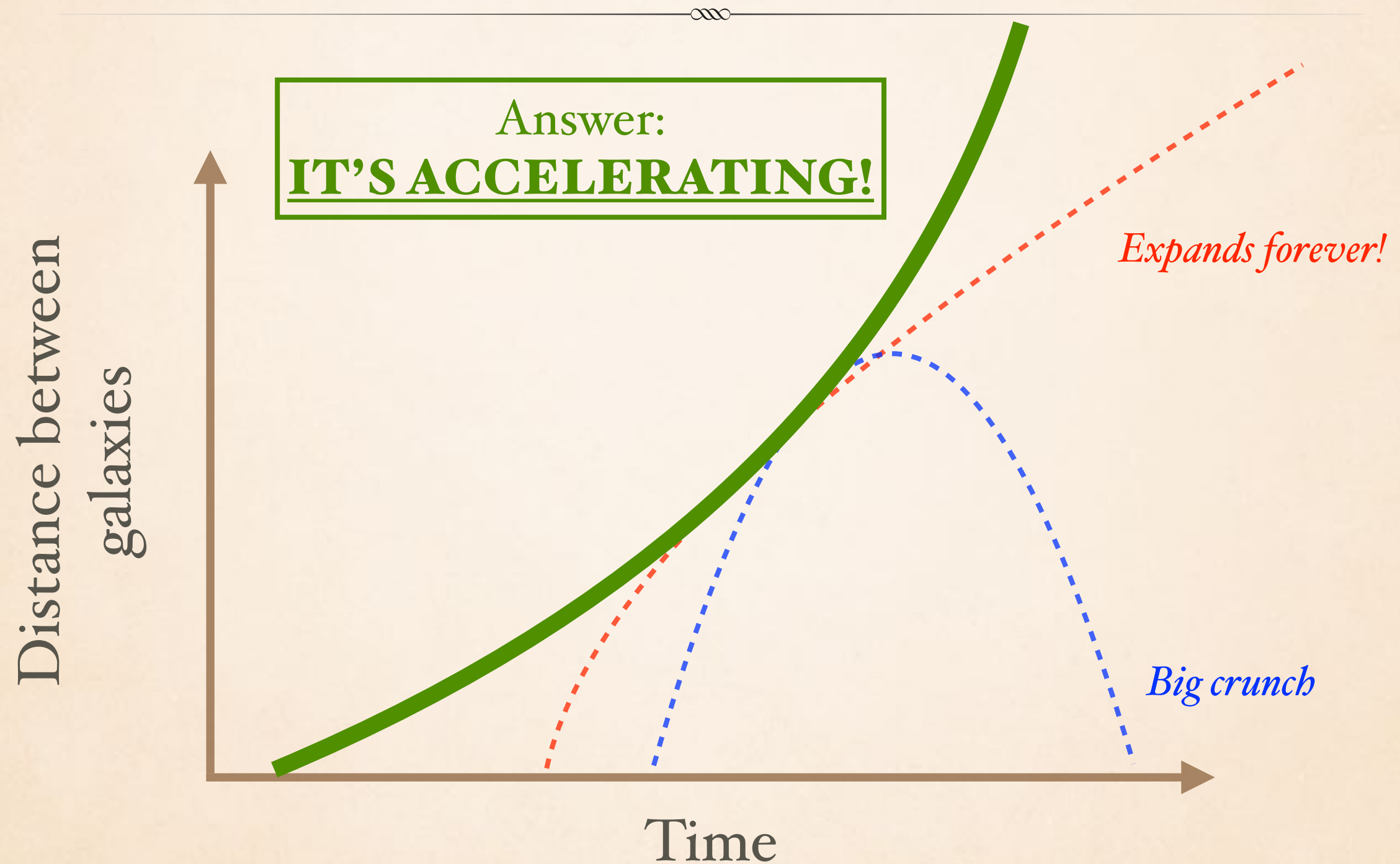
THE EVOLUTION OF THE UNIVERSE

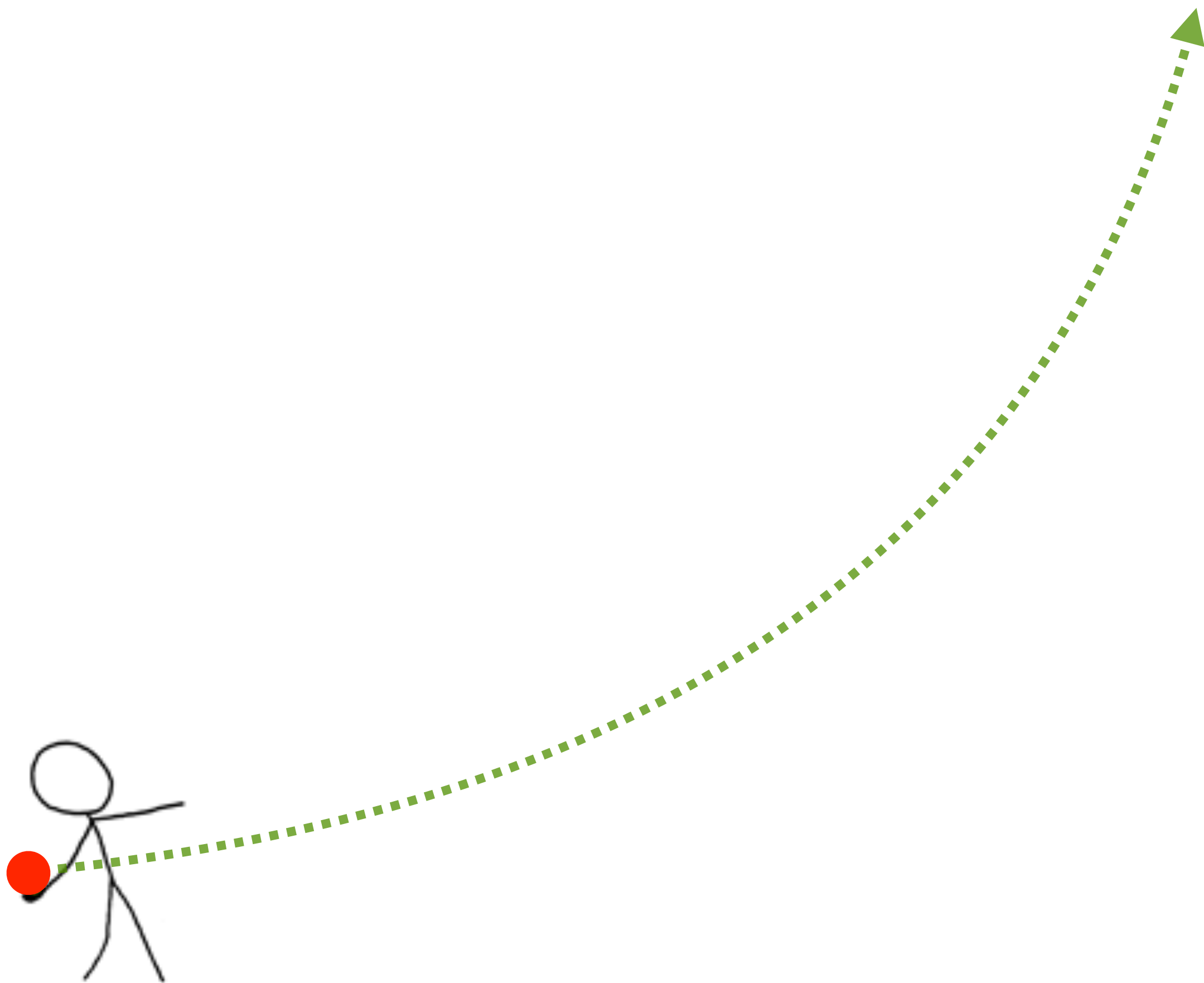
Expands forever!

'Big crunch'

The answer is... none of the above!

THE EVOLUTION OF THE UNIVERSE



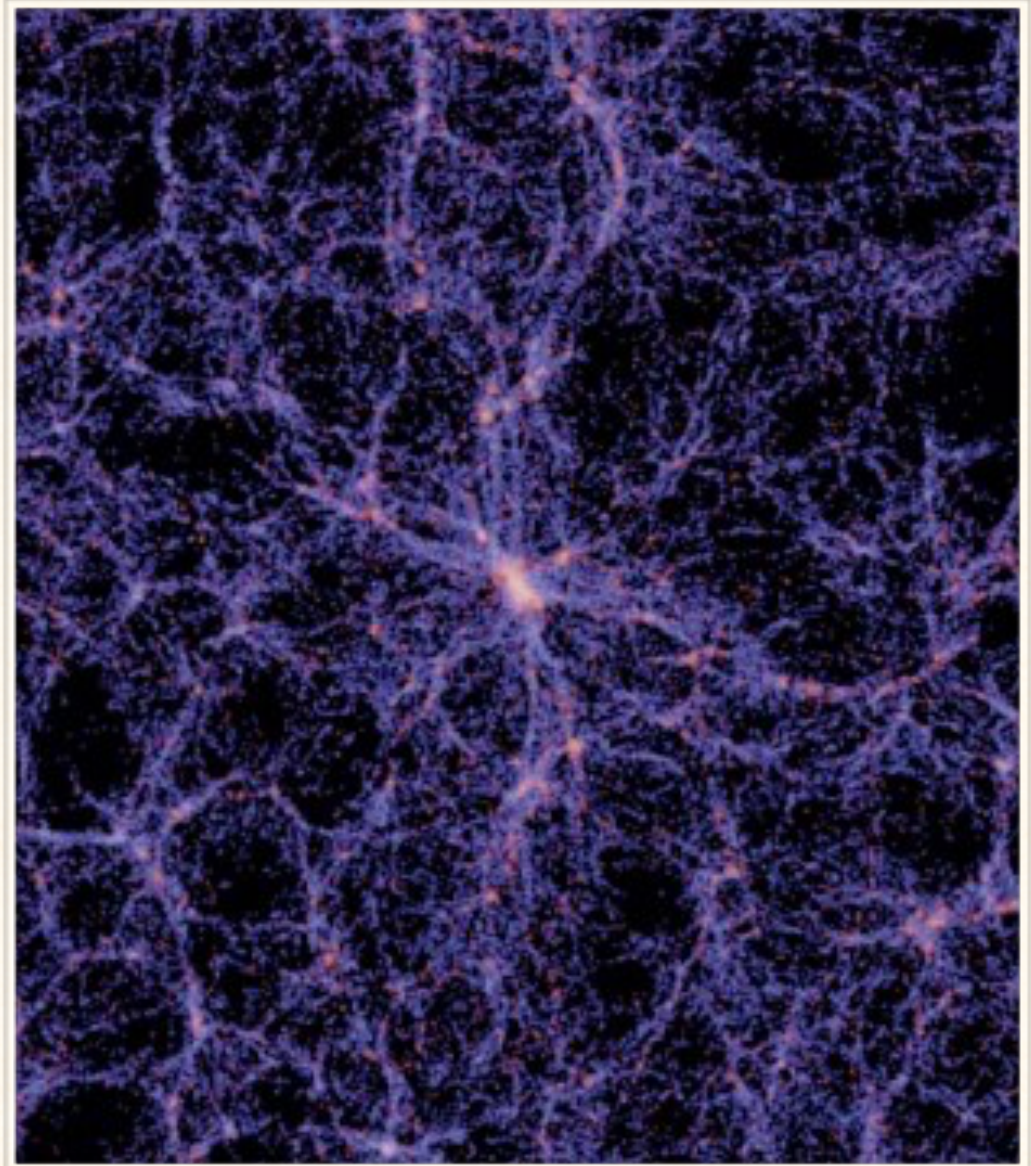




??

AN ACCELERATING UNIVERSE

- ❖ Completely contrary to all our predictions, the Universe's expansion is **speeding up!**
- ❖ Looks like some 'force' is pushing the Universe to expand faster and faster...



We call this effect
Dark Energy

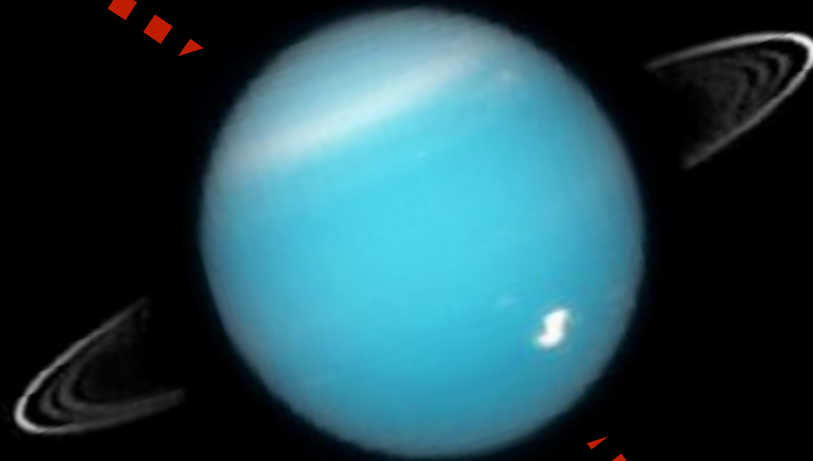
WHAT IS GOING ON?!

Normally, when your observations don't agree with your theory, there are two possible things going on:

- (1) You need to predict some kind of new object causing the weirdness
- (2) You need to modify your theory

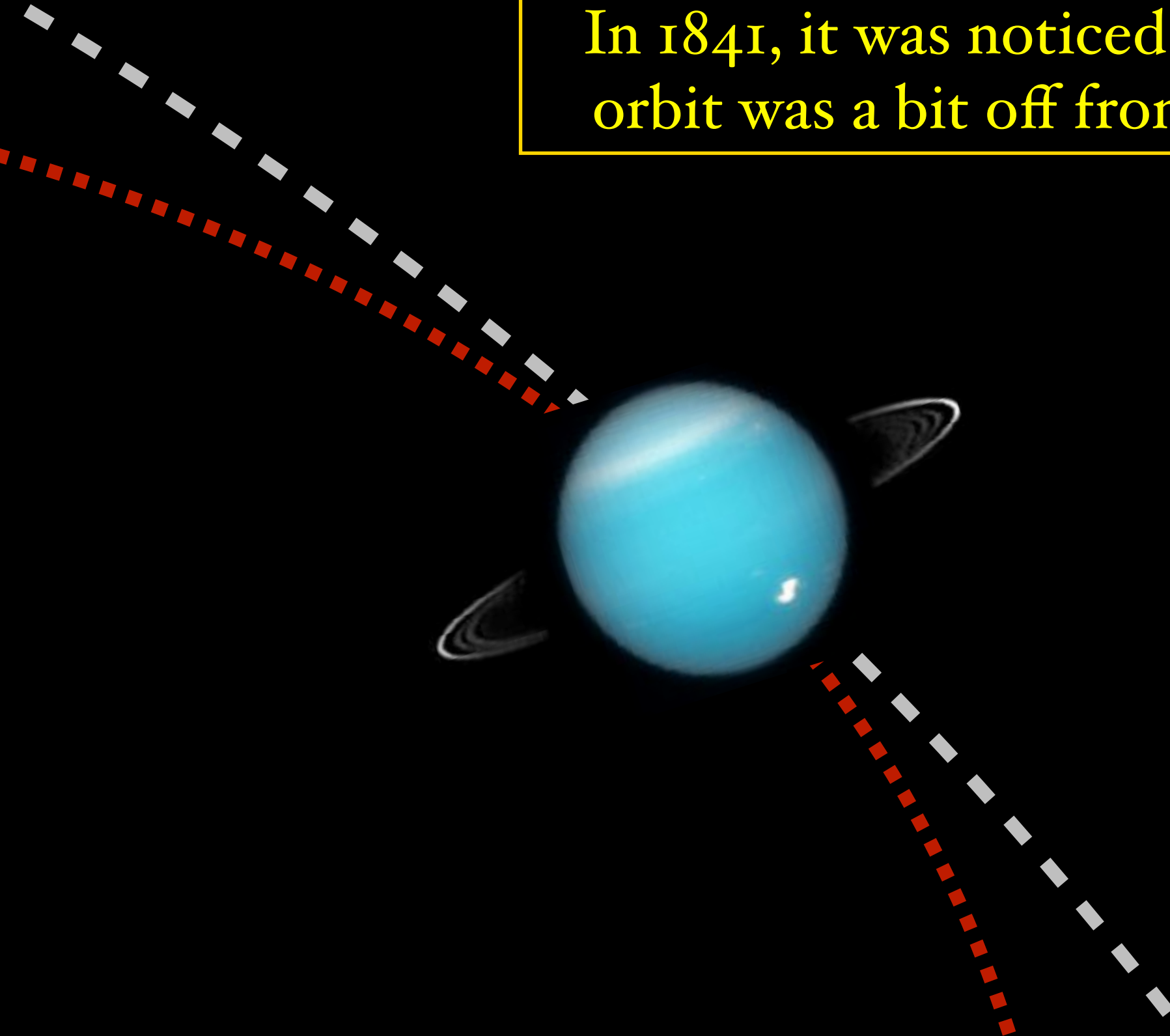
(I) New object?

In 1841, it was noticed that Uranus's orbit was a bit off from predictions



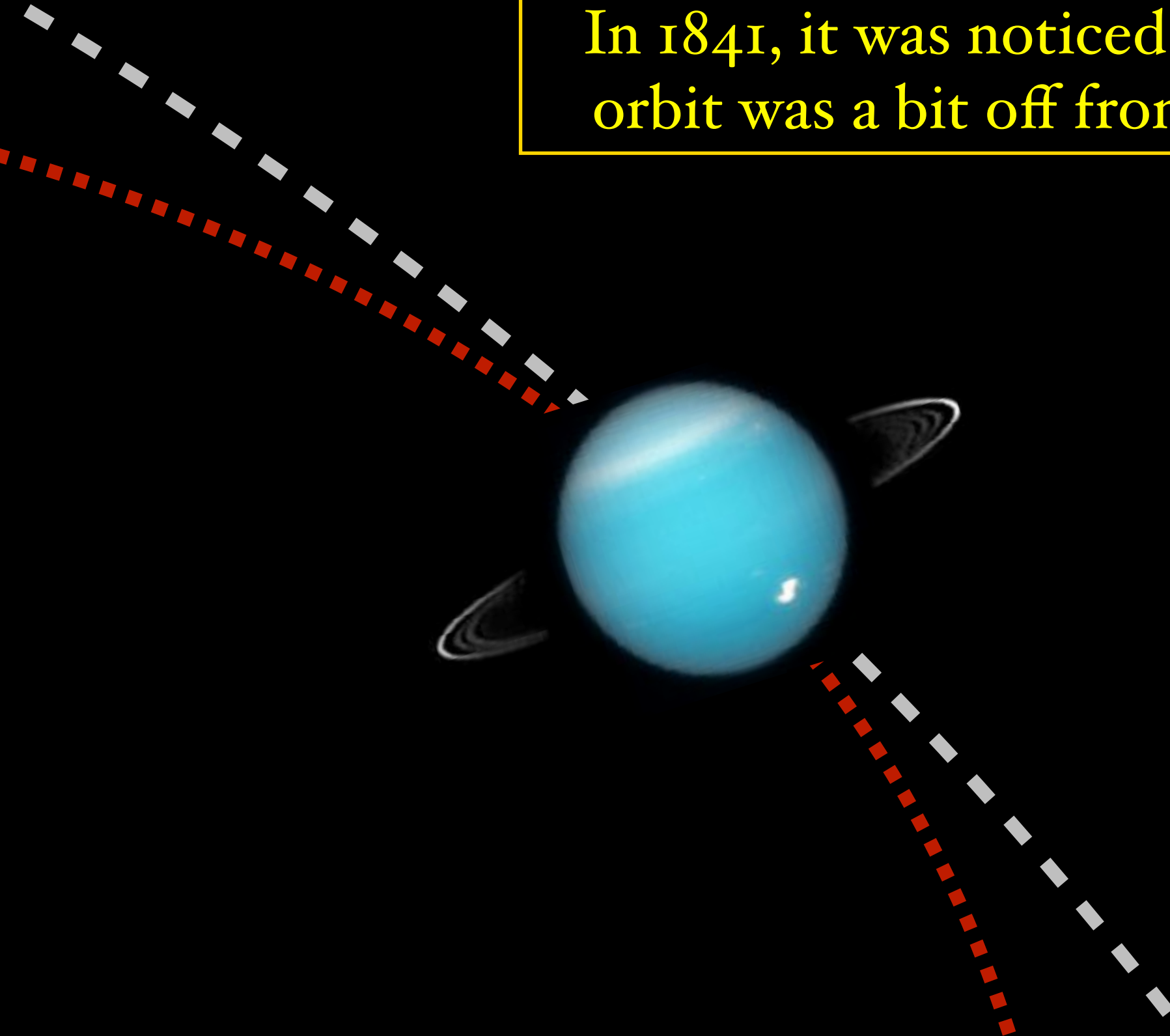
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(I) New object?

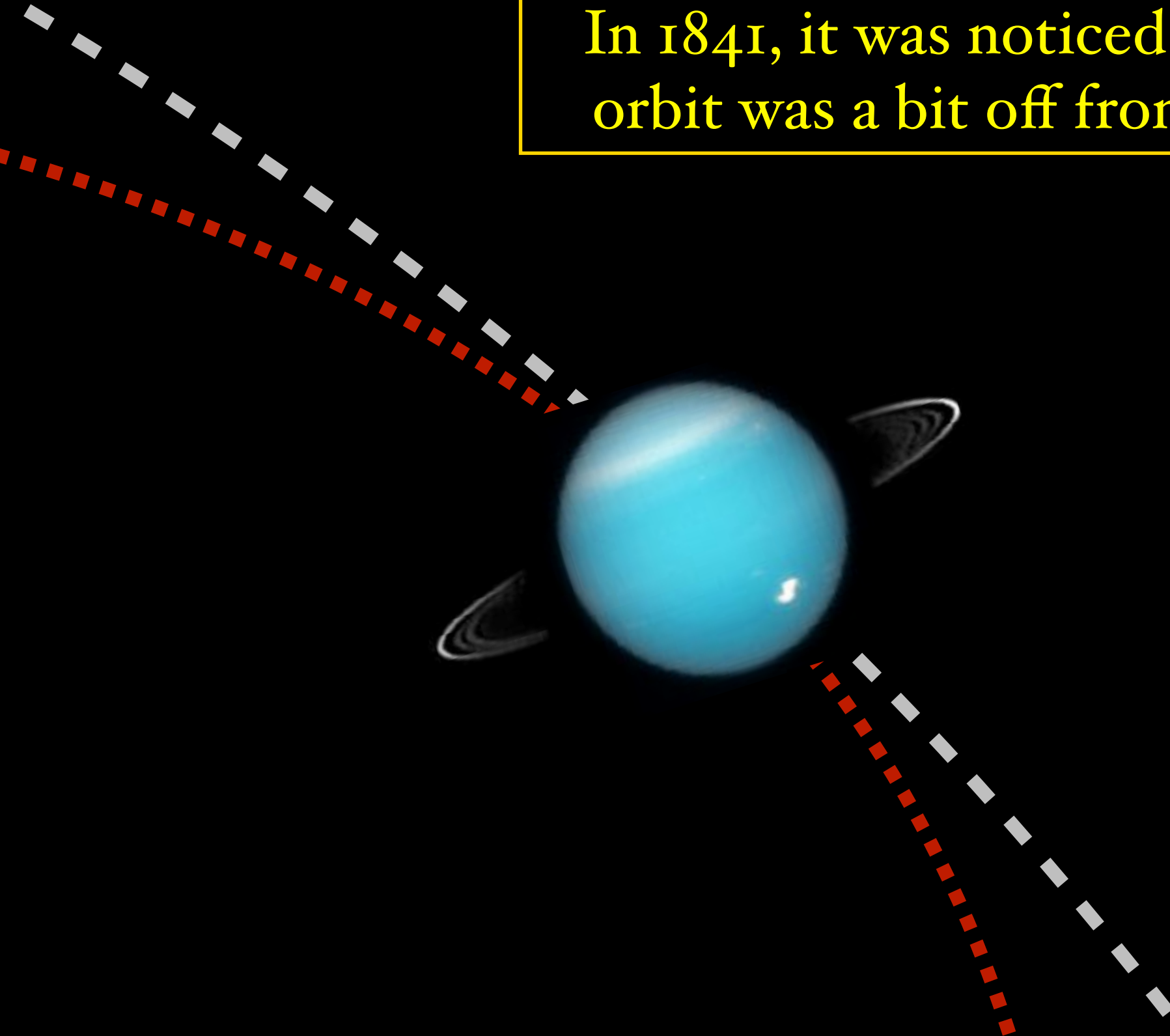
In 1841, it was noticed that Uranus's orbit was a bit off from predictions



(Alexis Bouvard)

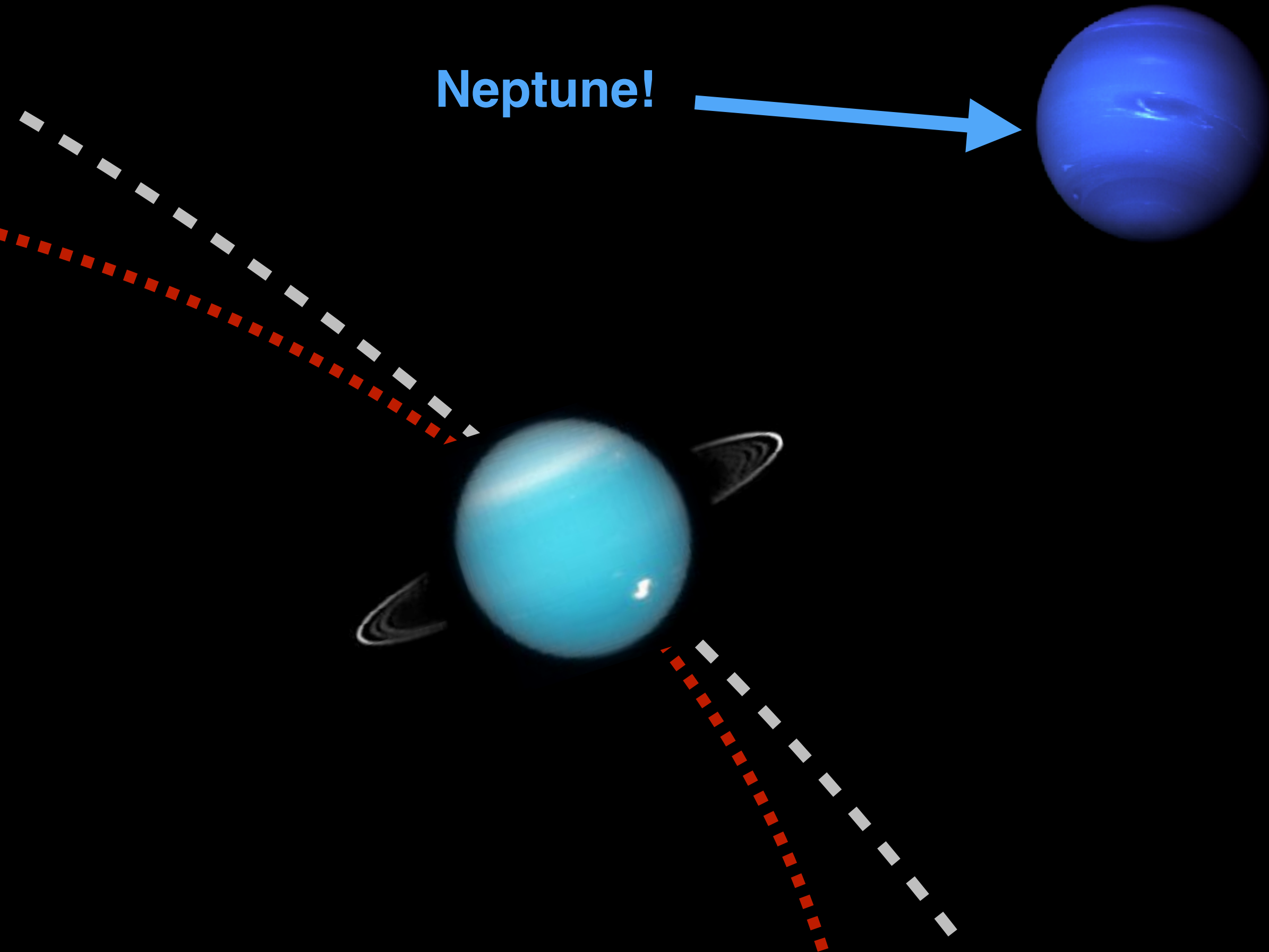
(I) New object?

In 1841, it was noticed that Uranus's orbit was a bit off from predictions



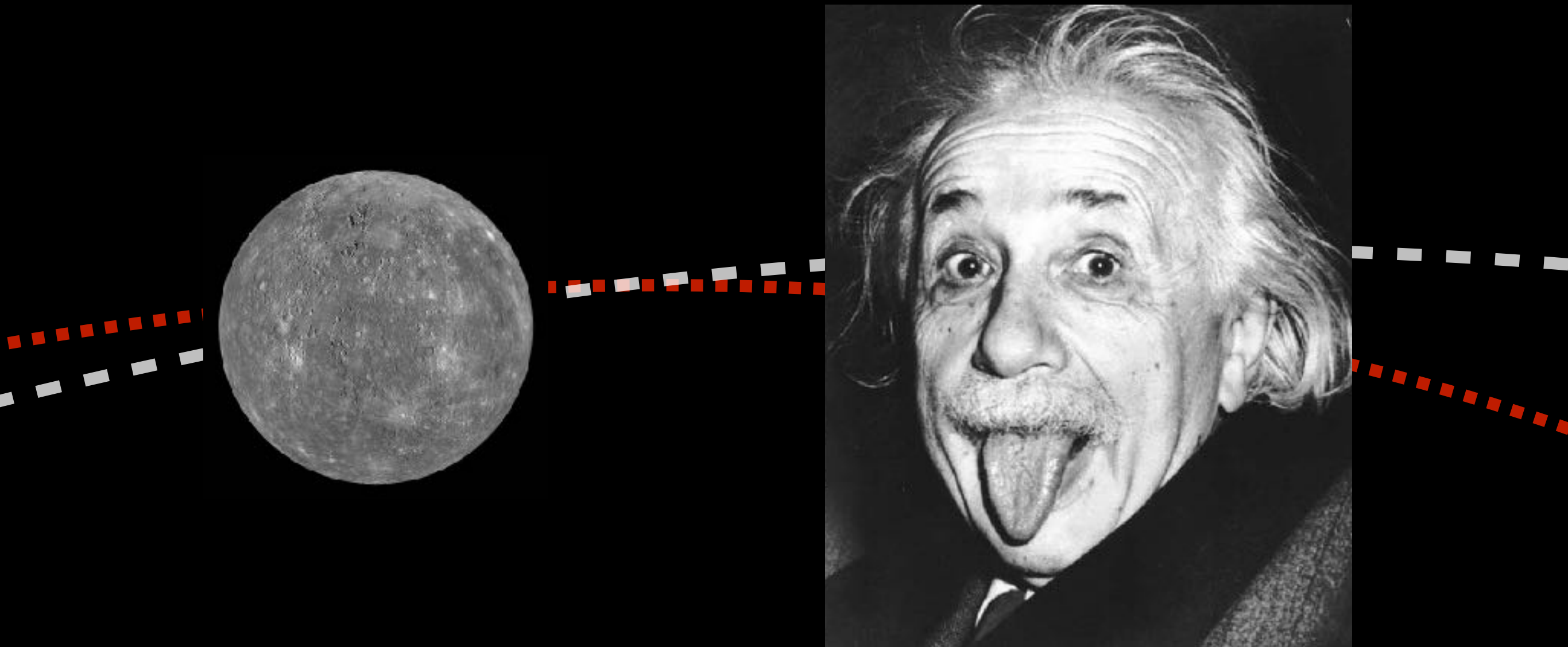
(1) New object?

Neptune!



(2) - Modify your theory...

In 1859, it was noticed that Mercury's orbit was a bit off from the predictions



SO... WHAT IS DARK ENERGY?

- (1) A new type of 'object', like an energy field pushing the Universe apart?
- (2) Or, do we just not understand gravity properly?

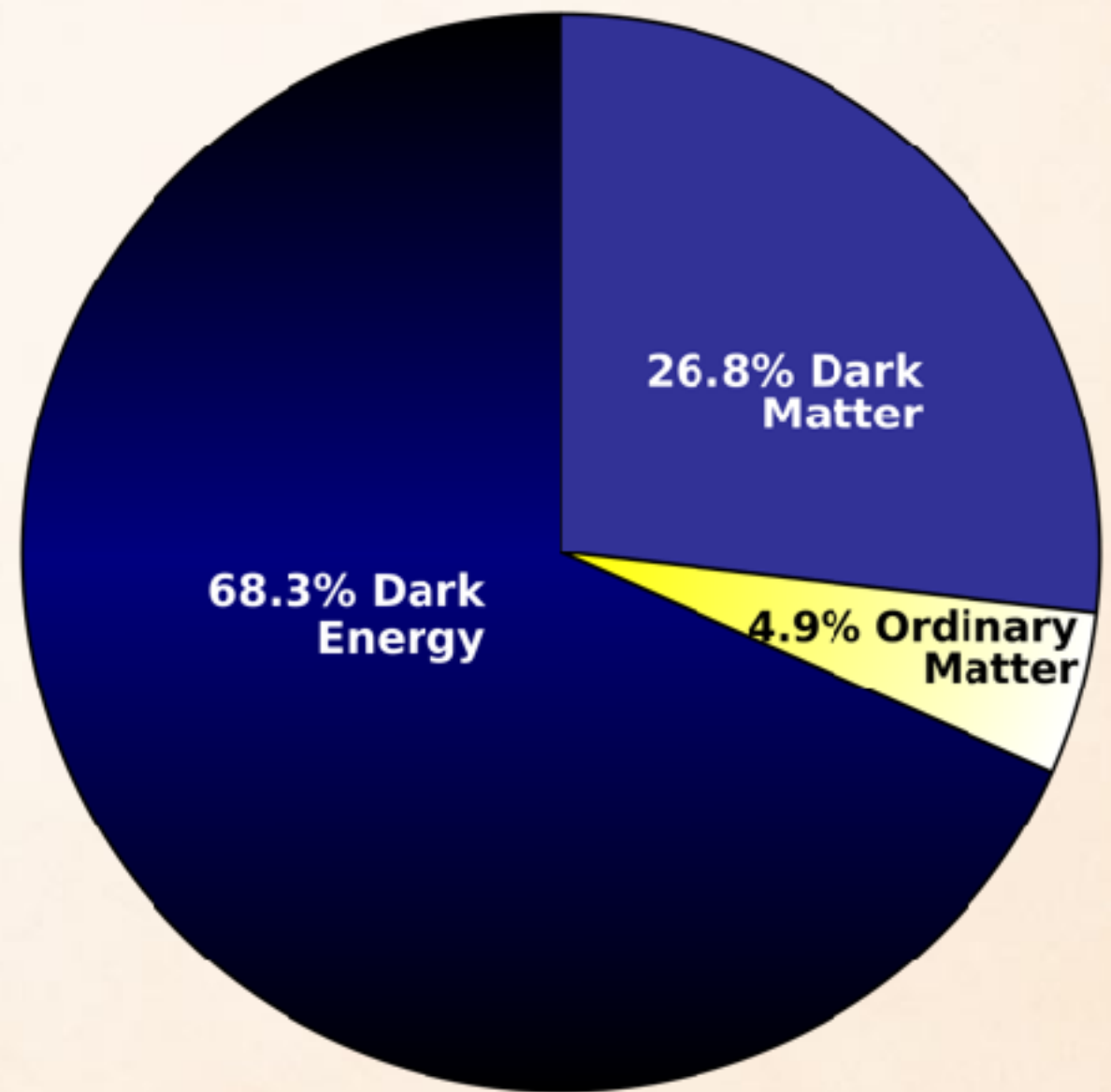
SO... WHAT IS DARK ENERGY?

- (1) A new type of 'object', like an energy field pushing the Universe apart?
- (2) Or, do we just not understand gravity properly?

The answer is... we don't know!

IT MAKES UP MOST OF THE UNIVERSE!

- ❖ About 70% of the Universe is Dark Energy
- ❖ 'Ordinary matter' (that makes up me, you, the Earth, the stars...) is just 5%!



A photograph of an iceberg floating in the ocean. The tip of the iceberg, which is above the water line, is small and jagged. The vast majority of the iceberg is submerged underwater, appearing much larger and more complex in shape. The water is a deep blue, and the sky is a lighter blue with some wispy clouds. Two text boxes are overlaid on the image: one in the top right corner and one in the bottom left corner.

5% 'normal' matter

95% mysterious
stuff (including Dark
Energy)

