International Centre for Radio Astronomy Research

COSMOLOGY

Dr Alan Duffy

THE UNIVERSITY OF WESTERN AUSTRALIA

Achieve International Excellence

So what is cosmology?

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The study of the Universe on large scales to determine its origin, evolution and, ultimately, fate…

So what is cosmology?

The study of the Universe on large scales to determine its origin, evolution and, ultimately, fate…

Or, to misquote Douglas Adams;

Not much about **Life**, *mostly it's* **the Universe and Everything** *in it*

Powers of Ten

Image credit: IMAX

What do we know of the Universe?

What do we know of the Universe?

The Universe is expanding

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The Universe is made of Dark Matter, Dark Energy and Baryons (atoms)

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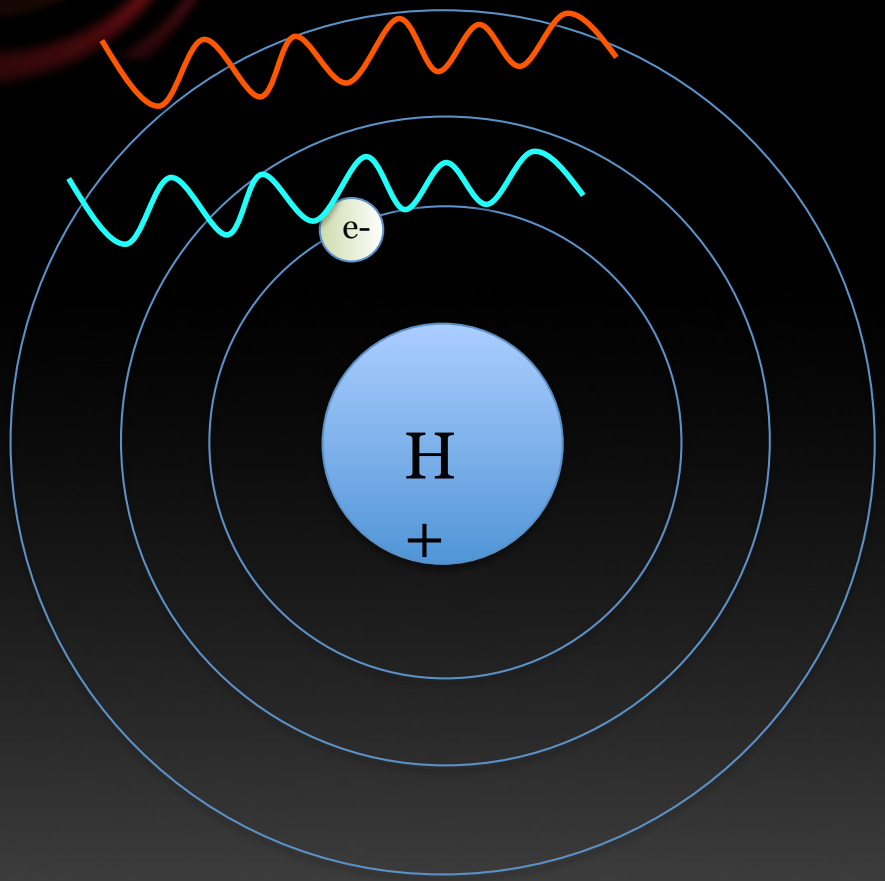
So how did we discover these facts?

The expanding Universe…

How do we know it's expanding?



With thanks to
Kirsten Gottschalk

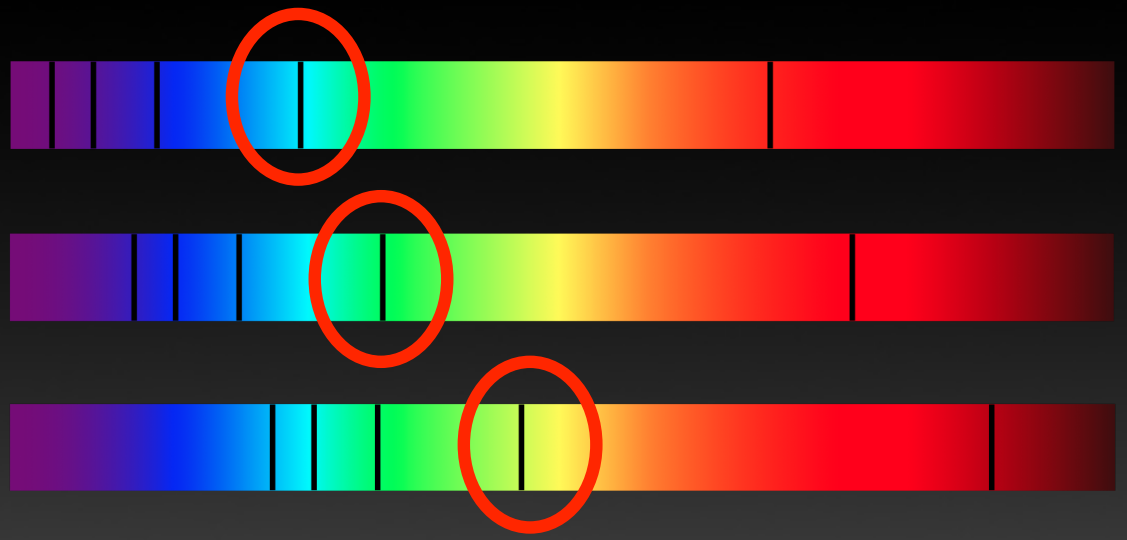
The expanding Universe…

The expanding Universe…

At rest

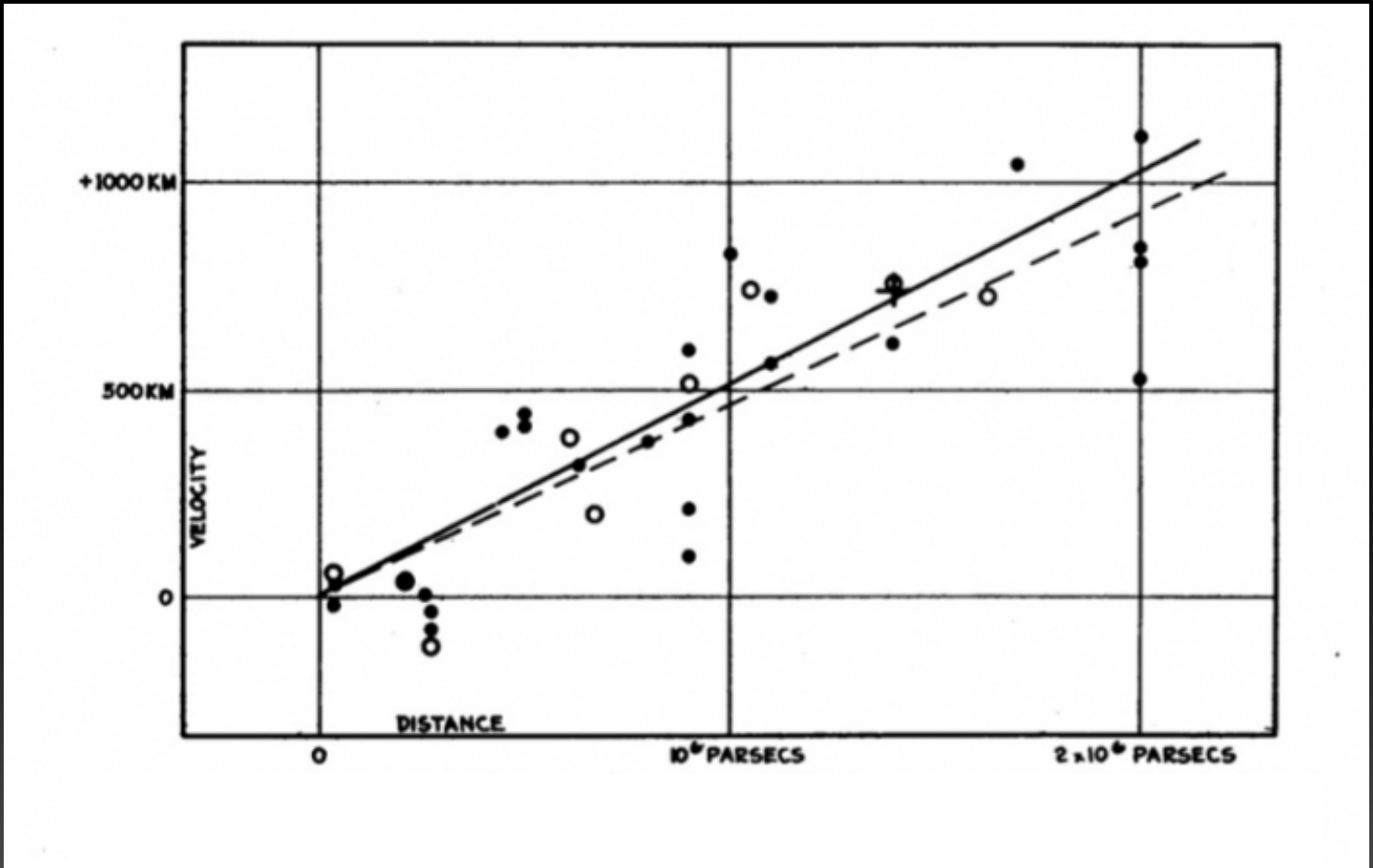
The expanding Universe…

The expanding Universe…



The expanding Universe… Hubble

Velocity [km/s]



Distance [pc]

Image credit: Edwin Hubble, Proceedings of the National Academy of Sciences, vol. 15 no. 3, pp.168-173

The expanding Universe… Hubble

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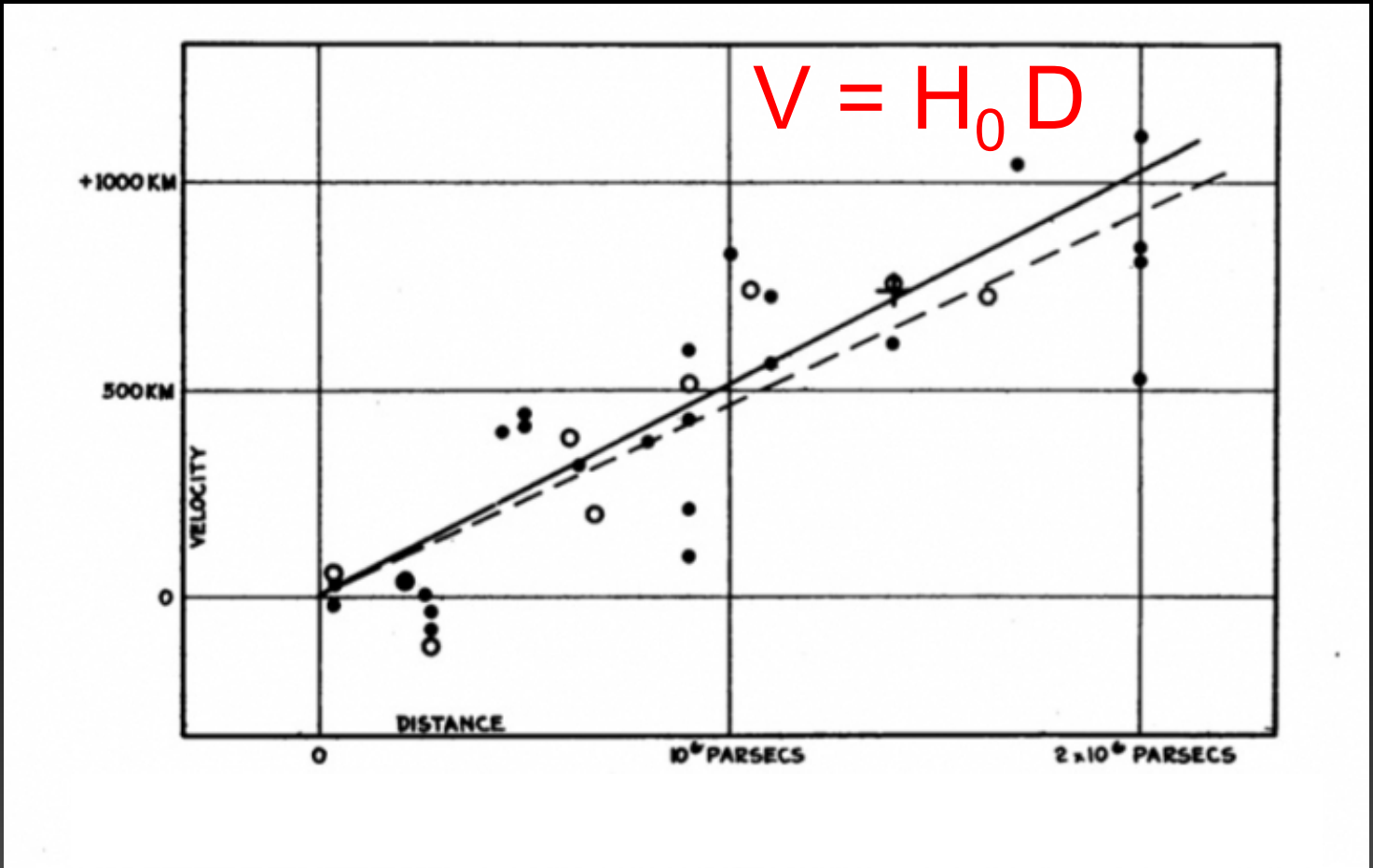

Distance [pc]

Image credit: Edwin Hubble, Proceedings of the National Academy of Sciences, vol. 15 no. 3, pp.168-173

The expanding Universe… Hubble

We can determine the age of the Universe using H_0

The expanding Universe… Hubble

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The Hubble time $t_H = 1/ H_0$

The expanding Universe… Hubble

We can determine the age of the Universe using H_0

The Hubble time $t_H = 1/ H_0 \sim 1/ 70$ [km/s /Mpc]

The expanding Universe… Hubble

We can determine the age of the Universe using H_0

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$\sim$ 13.8 billion years

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What happens if H_0 is wrong…?

The expanding Universe… Hubble

If we go back in time, we see that all galaxies originate from a point of near zero size

The expanding Universe… Hubble

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Leads to a prediction of infinite density and temperature in the Early Universe…

The expanding Universe… Hubble

If we go back in time, we see that all galaxies originate from a point of near zero size

Image credit: CBS

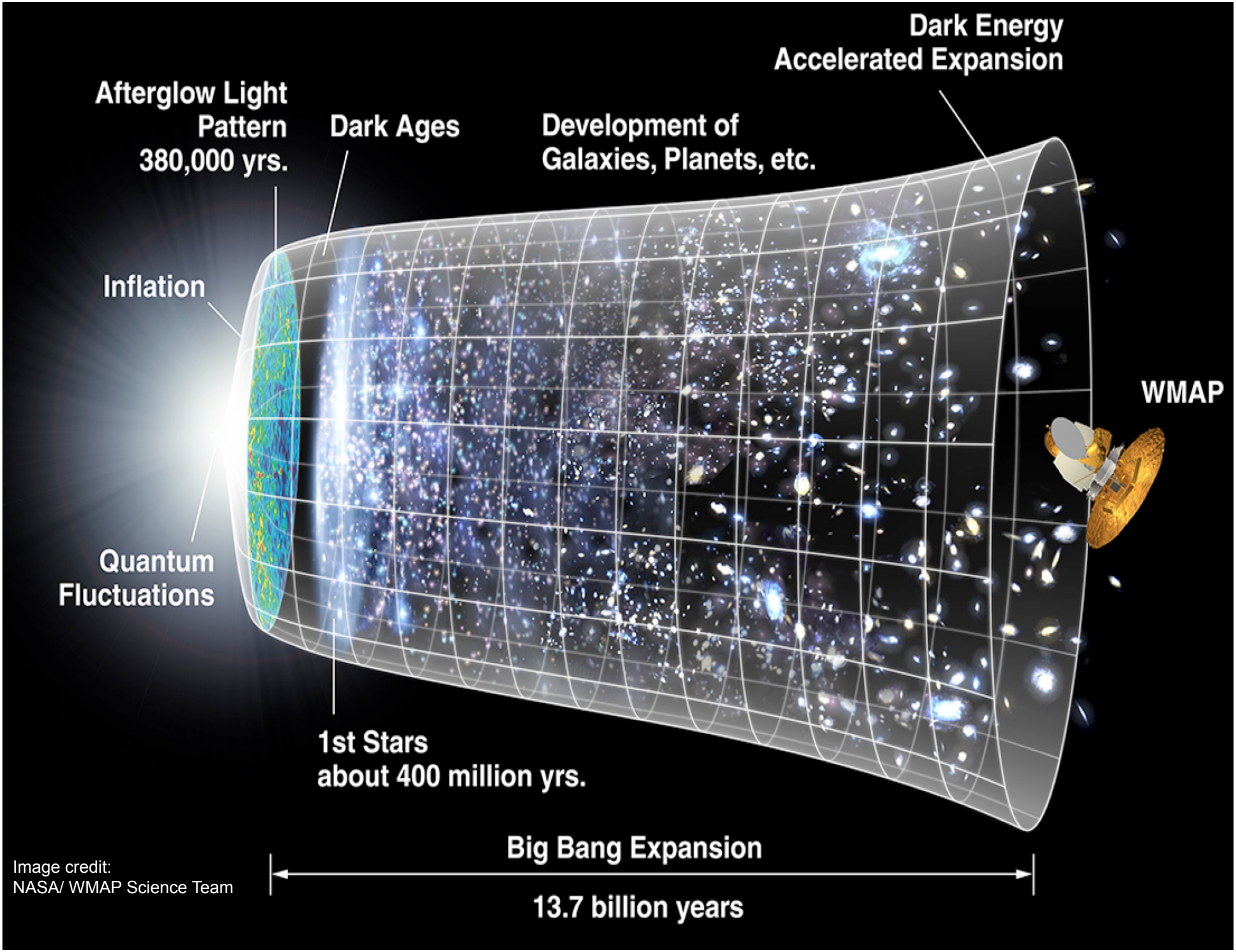
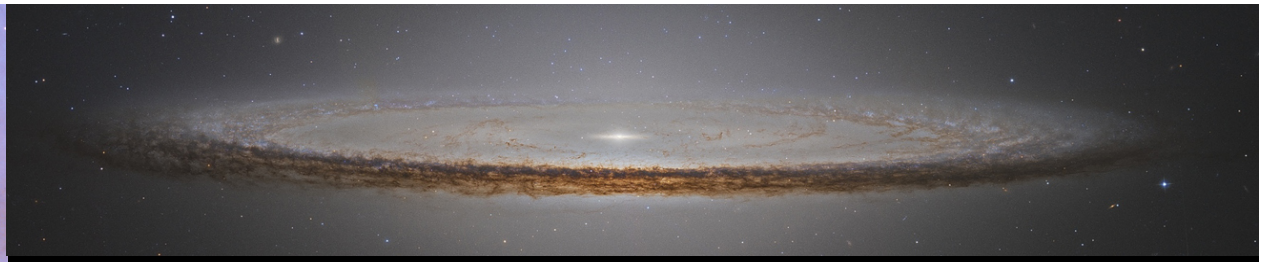


Image credit:
NASA/ WMAP Science Team

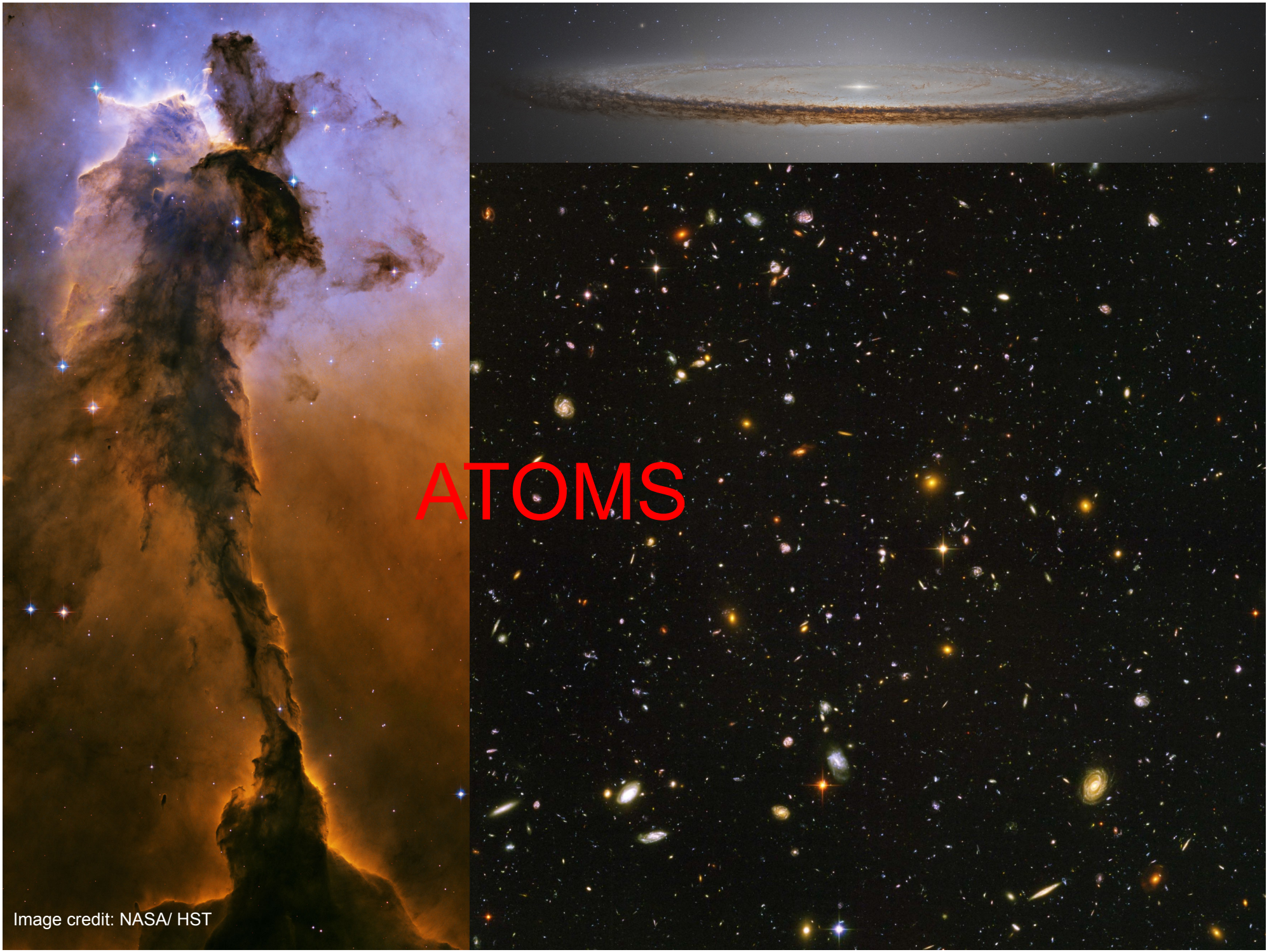
ATOMS

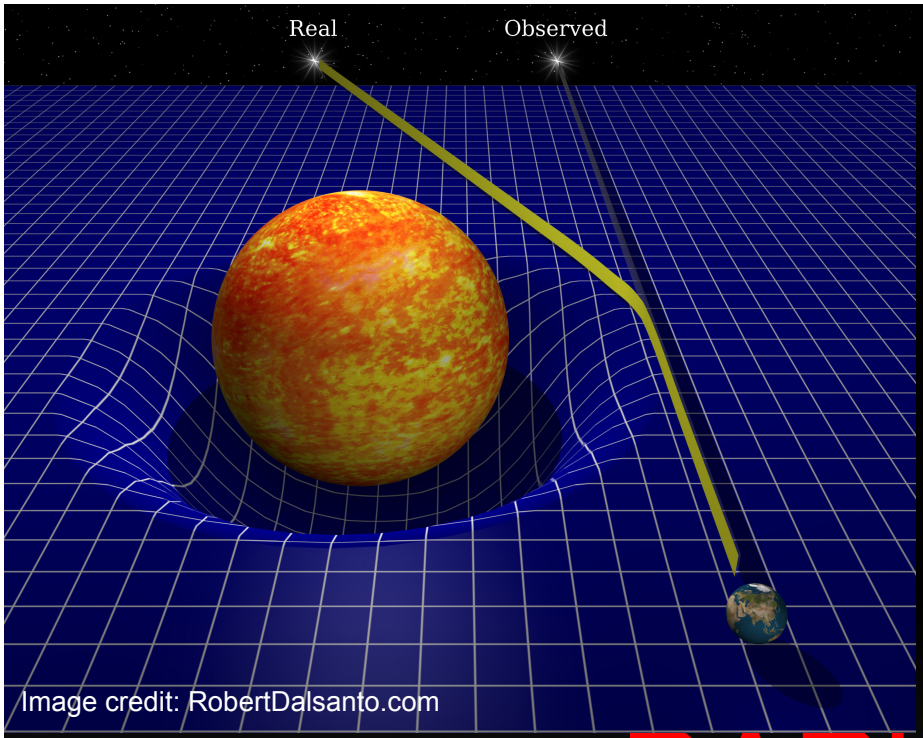
Image credit: NASA/ HST

Image credit: NASA/ HST



ATOMS


ATOMS
Image credit: NASA/ HST



DARK MATTER

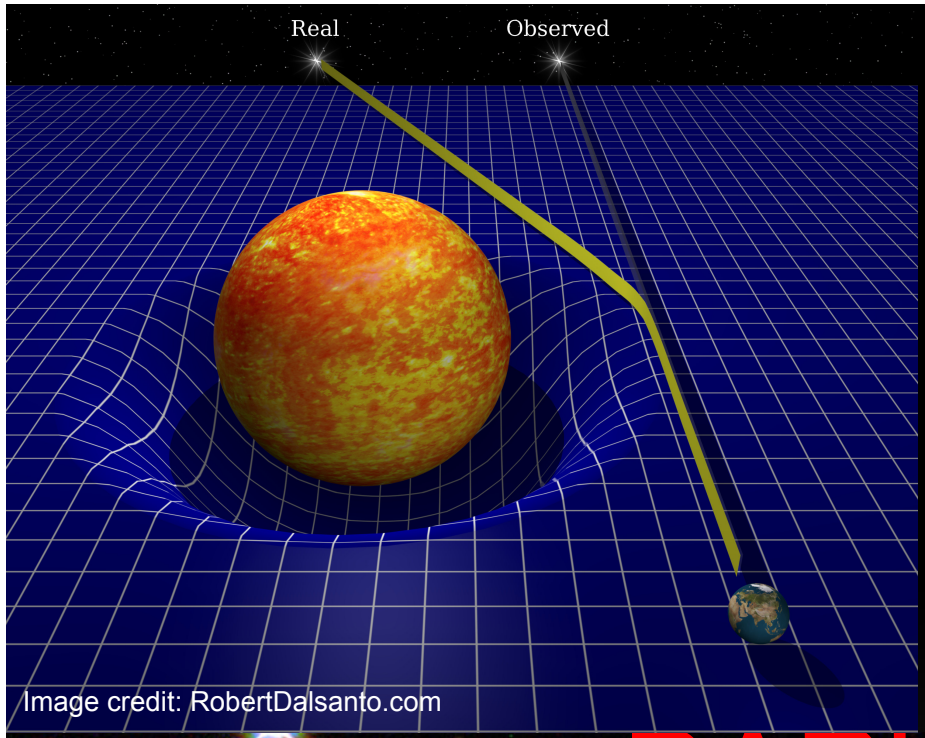
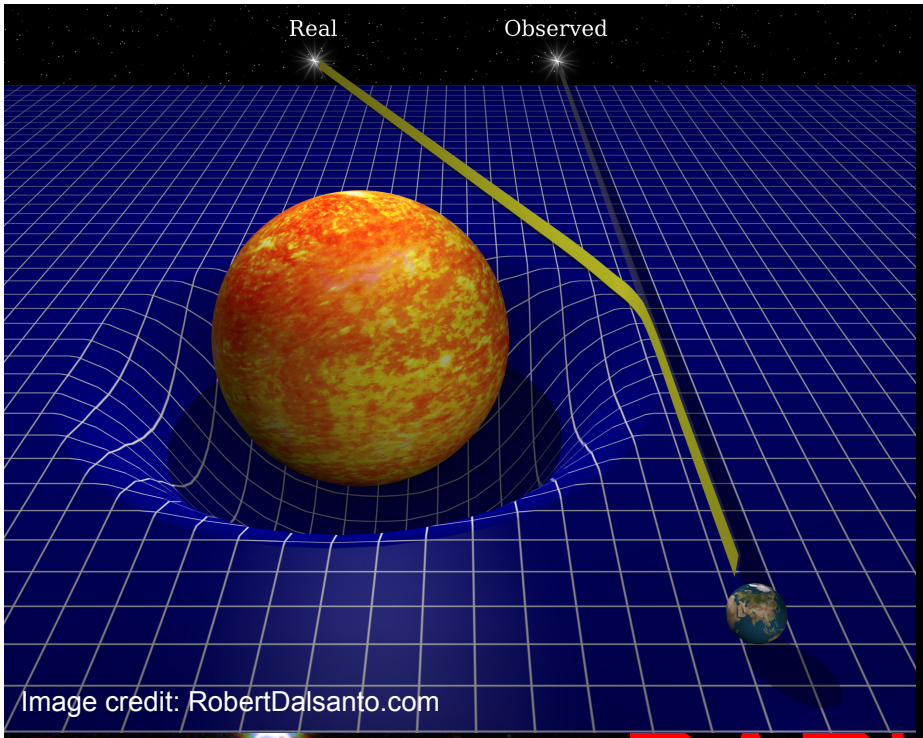
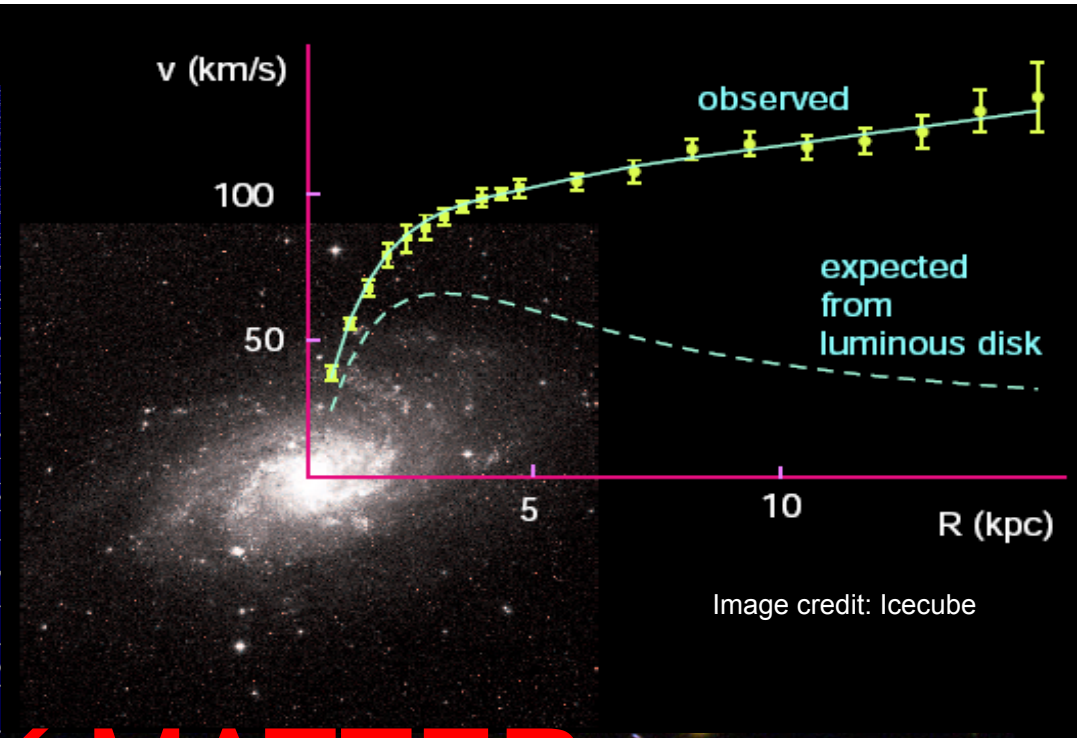


Image credit: RobertDalsanto.com

DARK MATTER

Image credit: NASA/ HST

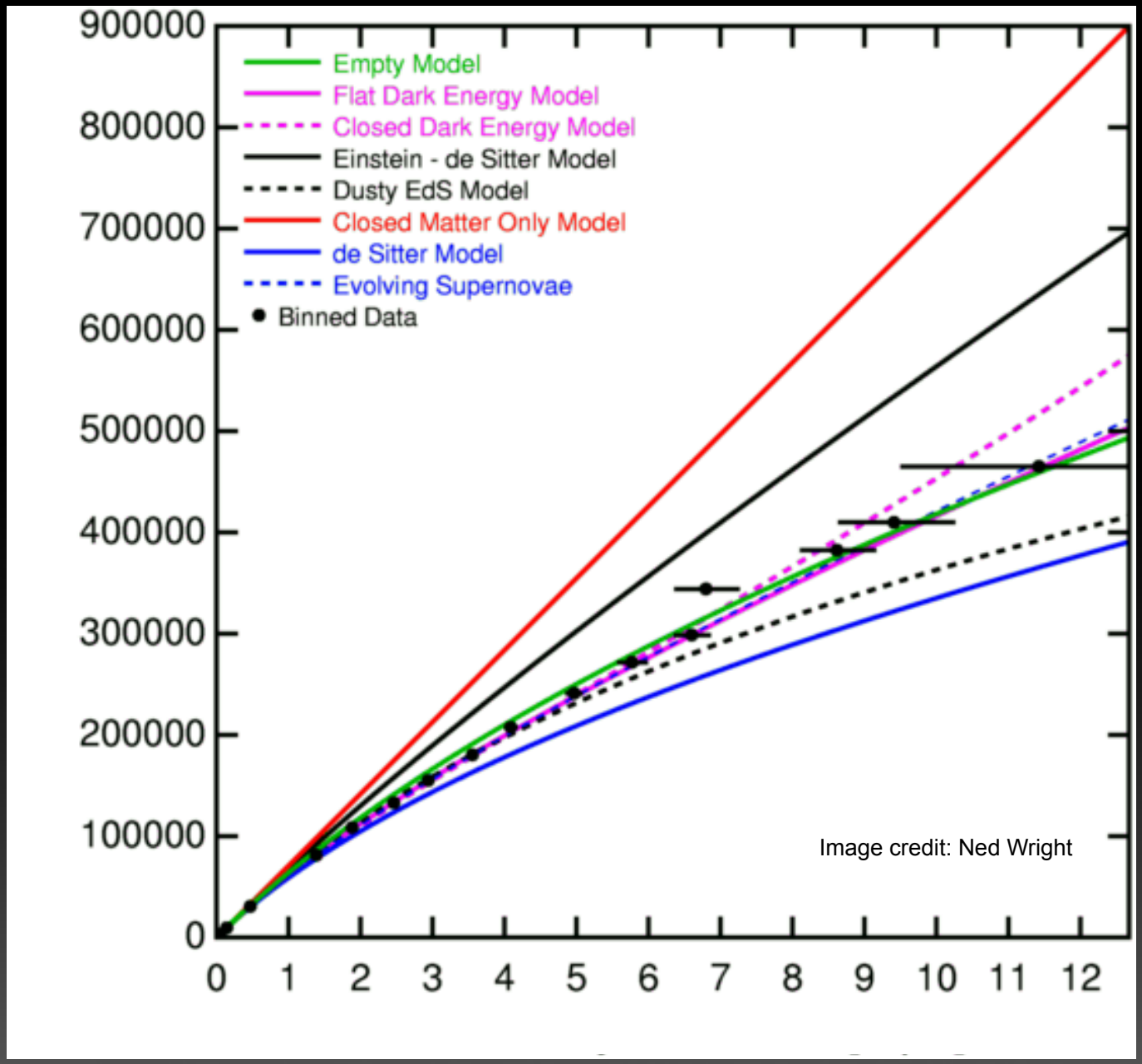

Real
Observed
Image credit: RobertDalsanto.com

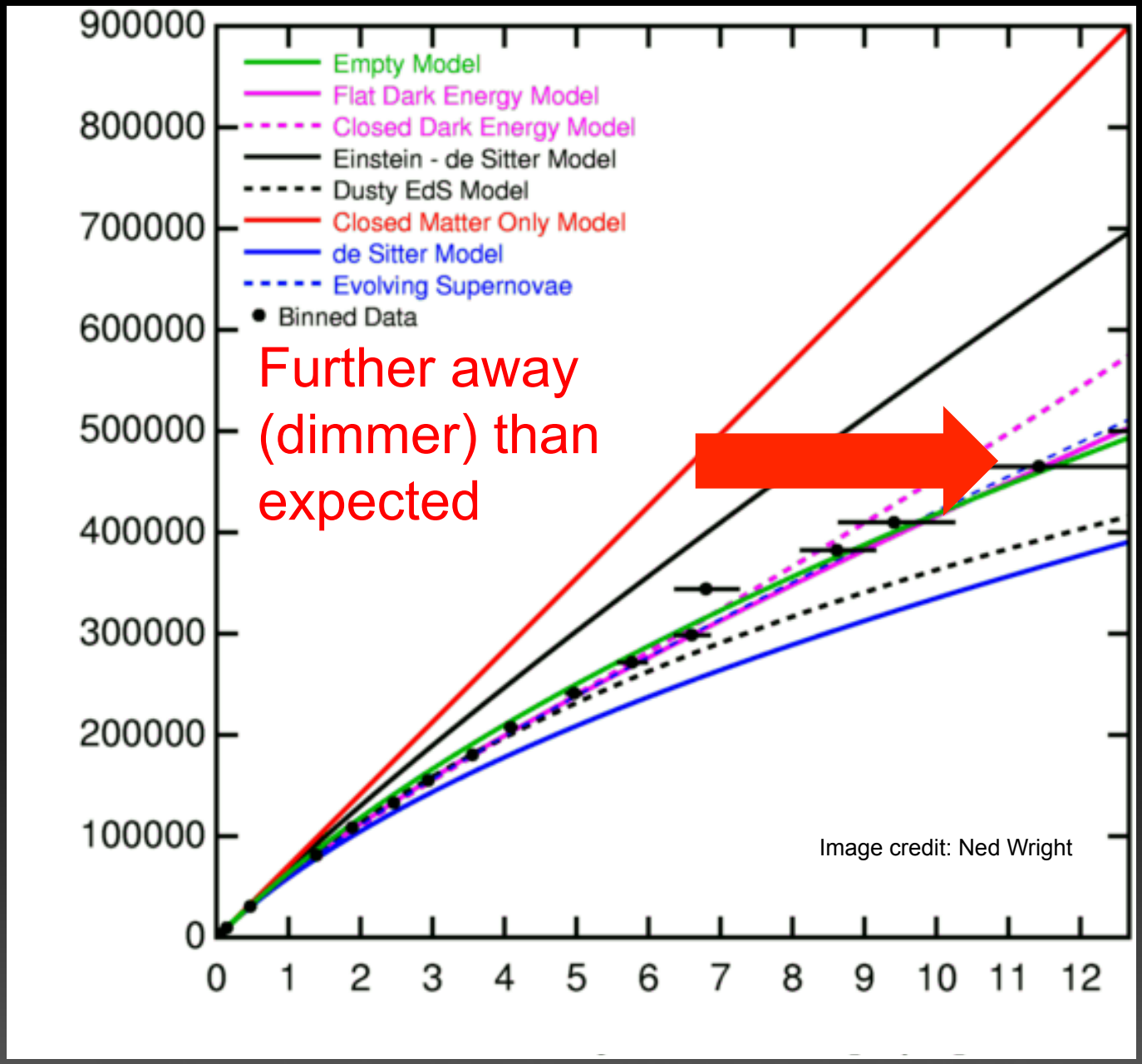

v (km/s)
100
50
observed
expected
from
luminous disk
5
10
R (kpc)
Image credit: Icecube

DARK MATTER

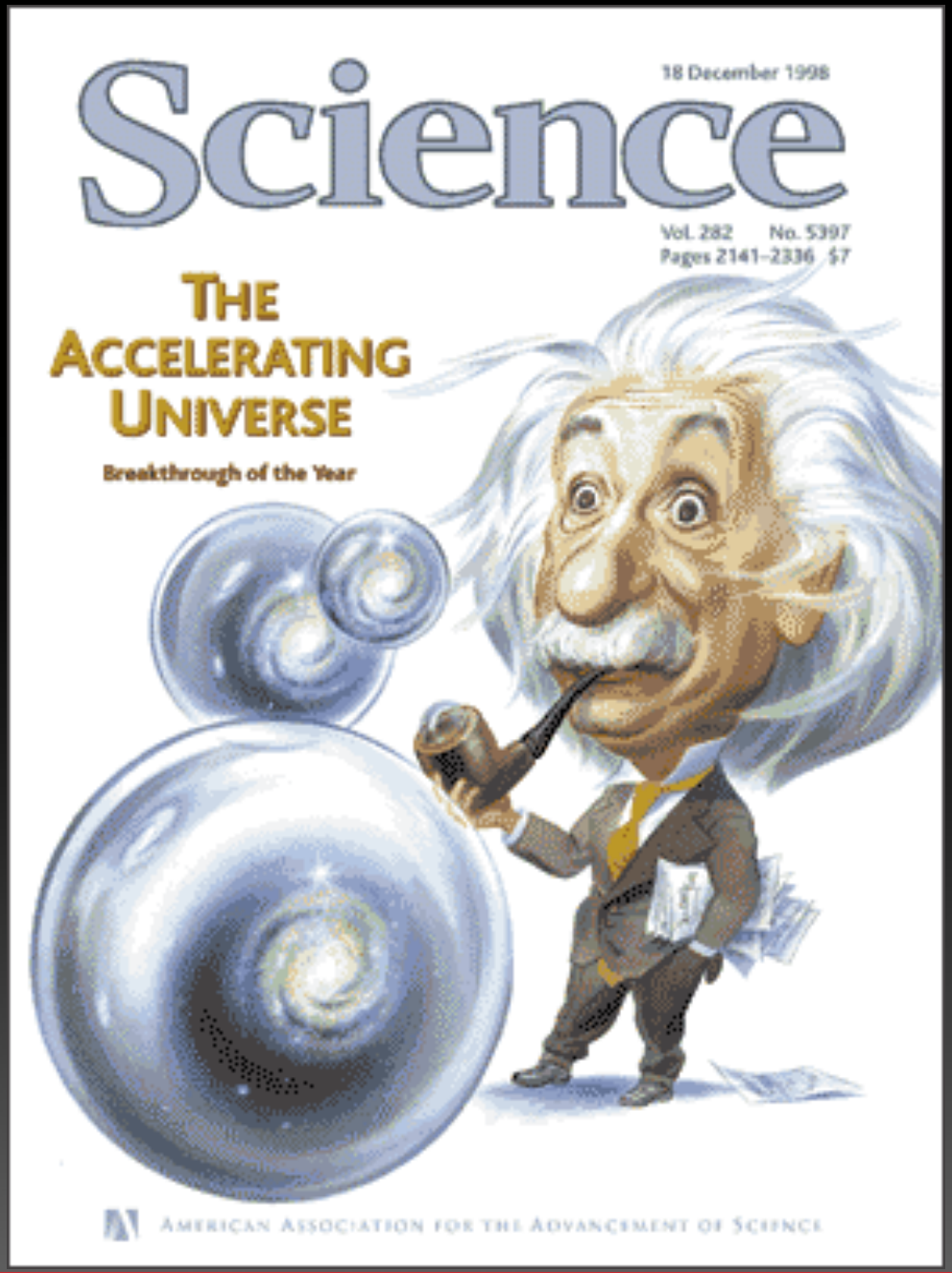

Image credit: NASA/ HST


DARK ENERGY
Image credit: NASA/ HST

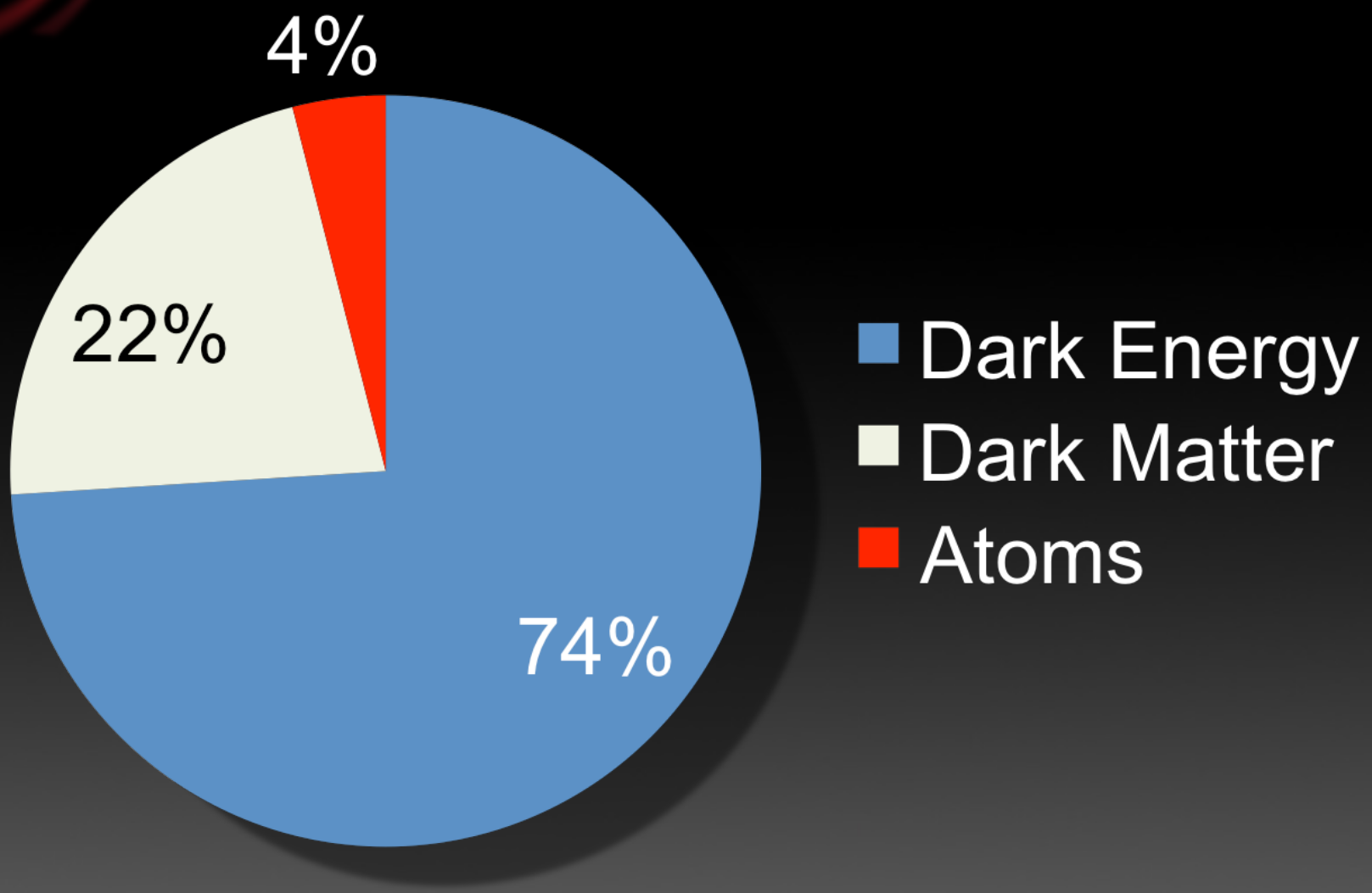

Velocity [km/s]
900000
800000
700000
600000
500000
400000
300000
200000
100000
0
Empty Model
Flat Dark Energy Model
Closed Dark Energy Model
Einstein - de Sitter Model
Dusty EdS Model
Closed Matter Only Model
de Sitter Model
Evolving Supernovae
Binned Data
Image credit: Ned Wright
0 1 2 3 4 5 6 7 8 9 10 11 12
Distance [Gpc]


Velocity [km/s]
900000
800000
700000
600000
500000
400000
300000
200000
100000
0
Empty Model
Flat Dark Energy Model
Closed Dark Energy Model
Einstein - de Sitter Model
Dusty EdS Model
Closed Matter Only Model
de Sitter Model
Evolving Supernovae
Binned Data
Further away
(dimmer) than
expected
Image credit: Ned Wright
0 1 2 3 4 5 6 7 8 9 10 11 12
Distance [Gpc]

Cosmological Constant Λ



Current contents of the Universe



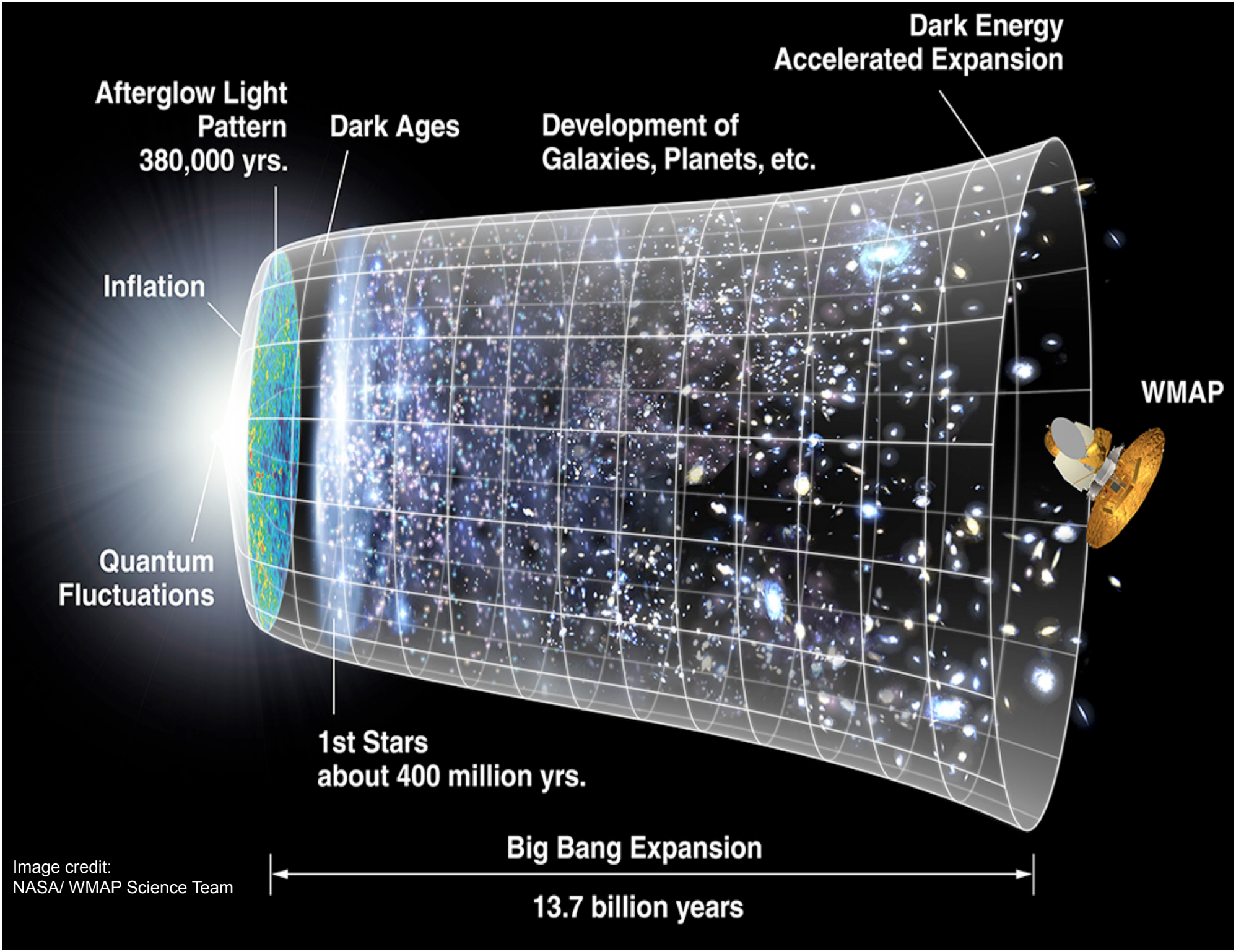


Image credit:
NASA/ WMAP Science Team

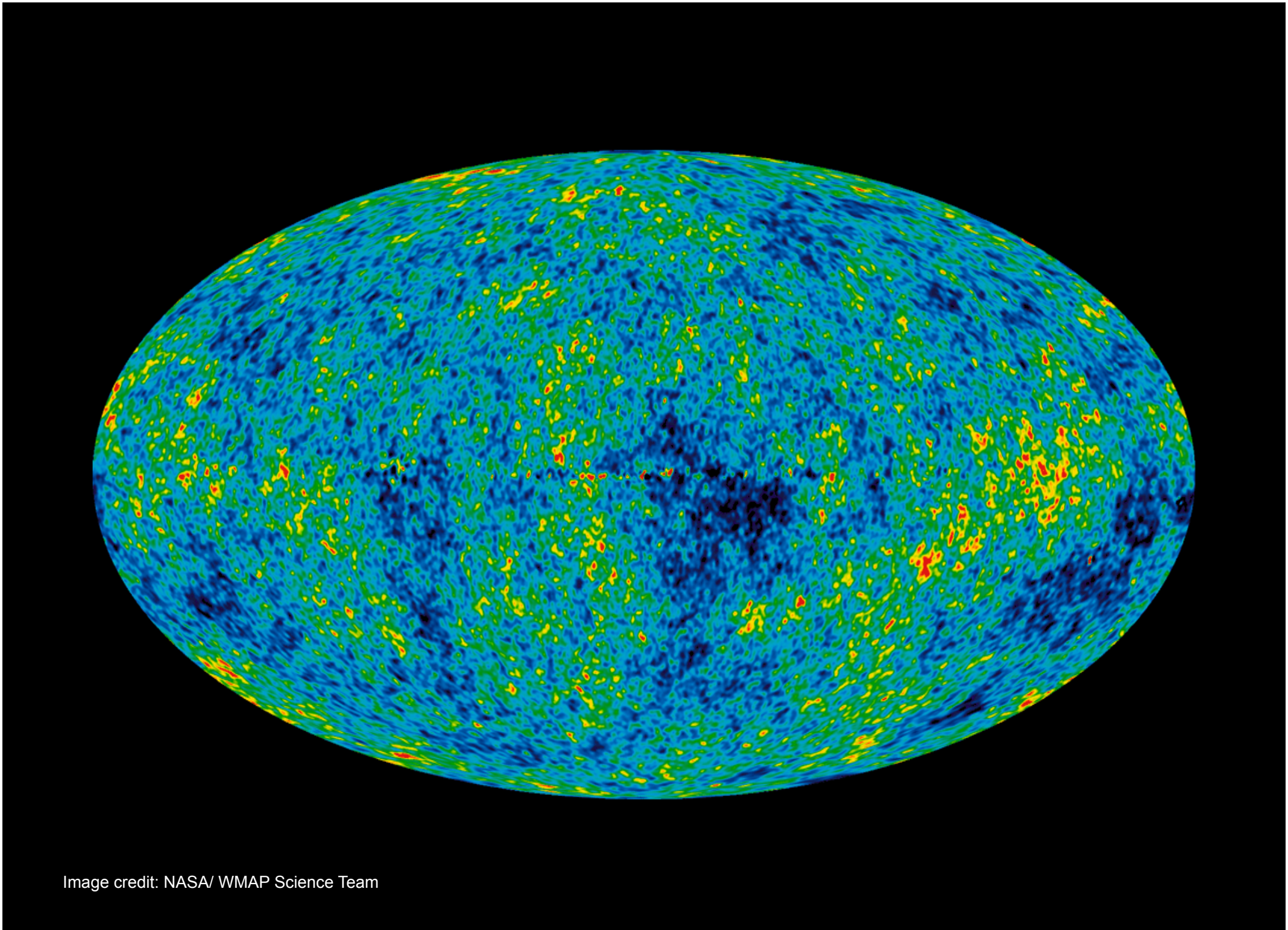


Image credit: NASA/ WMAP Science Team

During inflation, the Universe expands exponentially, enlarging quantum fluctuations to size of the Universe. Afterwards, scales re-enter as the Universe expands…

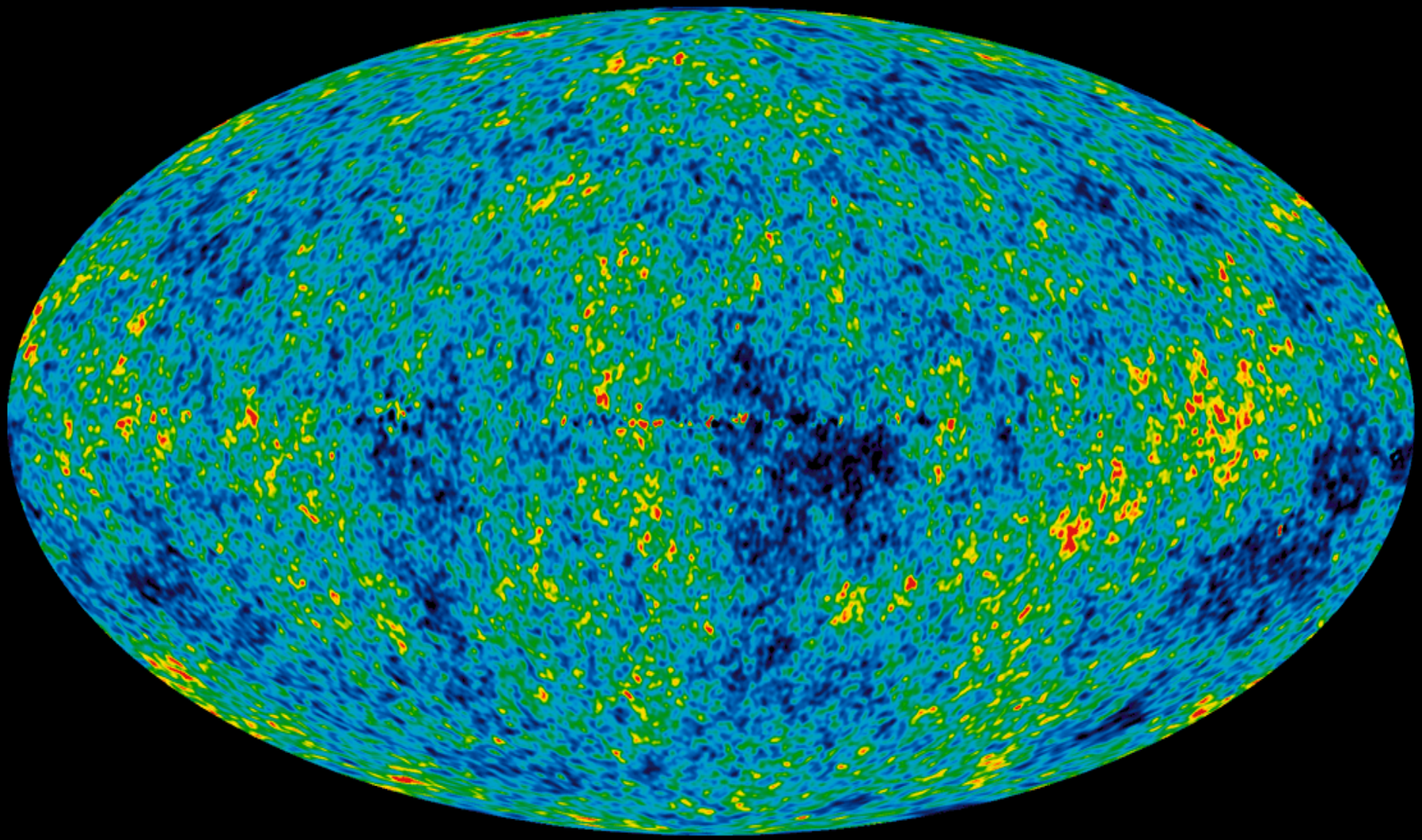
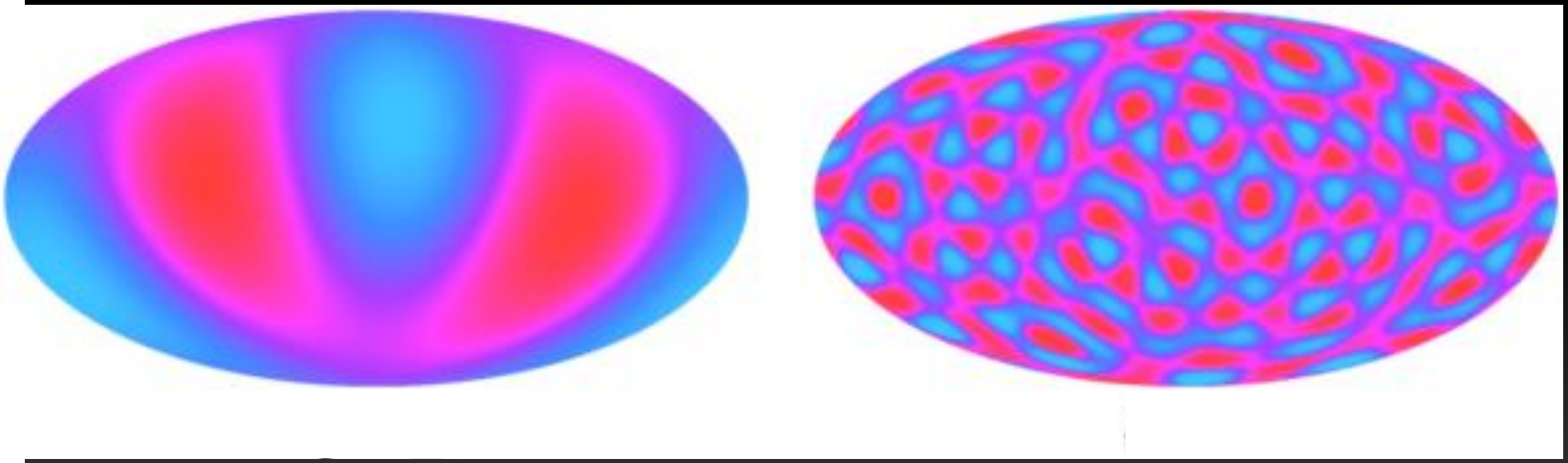


Image credit: NASA/ WMAP Science Team

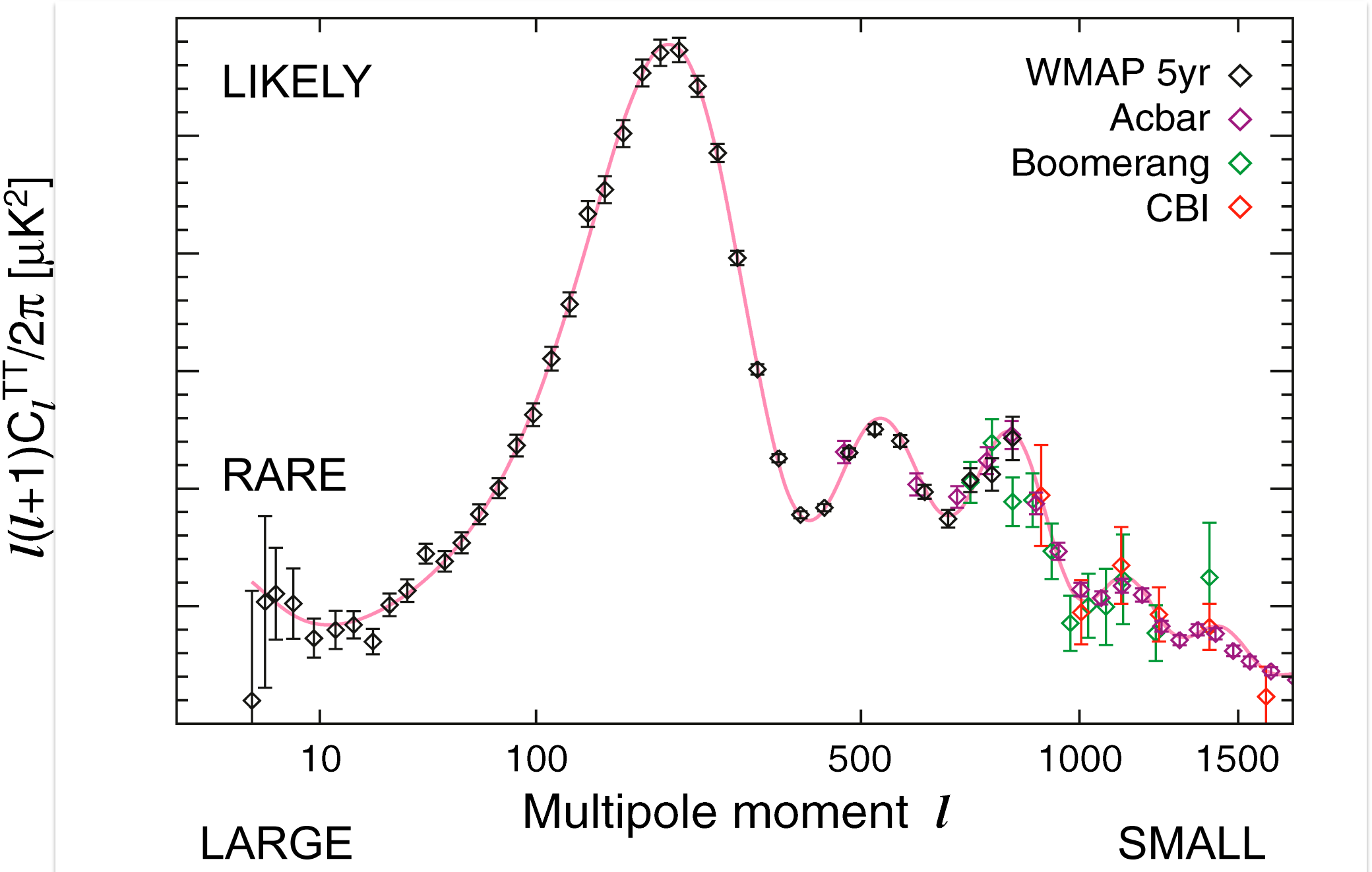
The fluctuations can be studied



l = 2

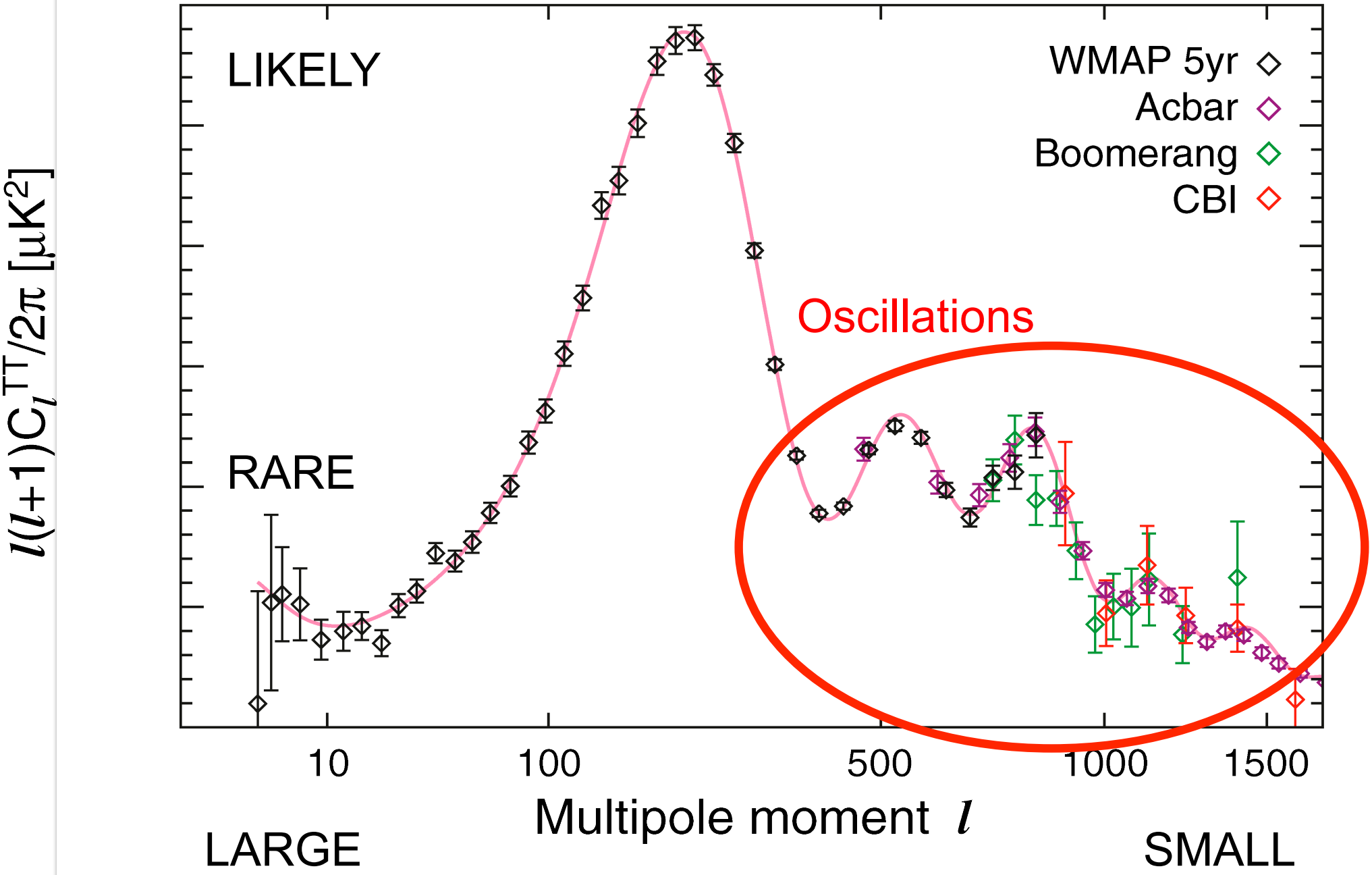
l = 16

Image credit: NASA/ WMAP Science Team



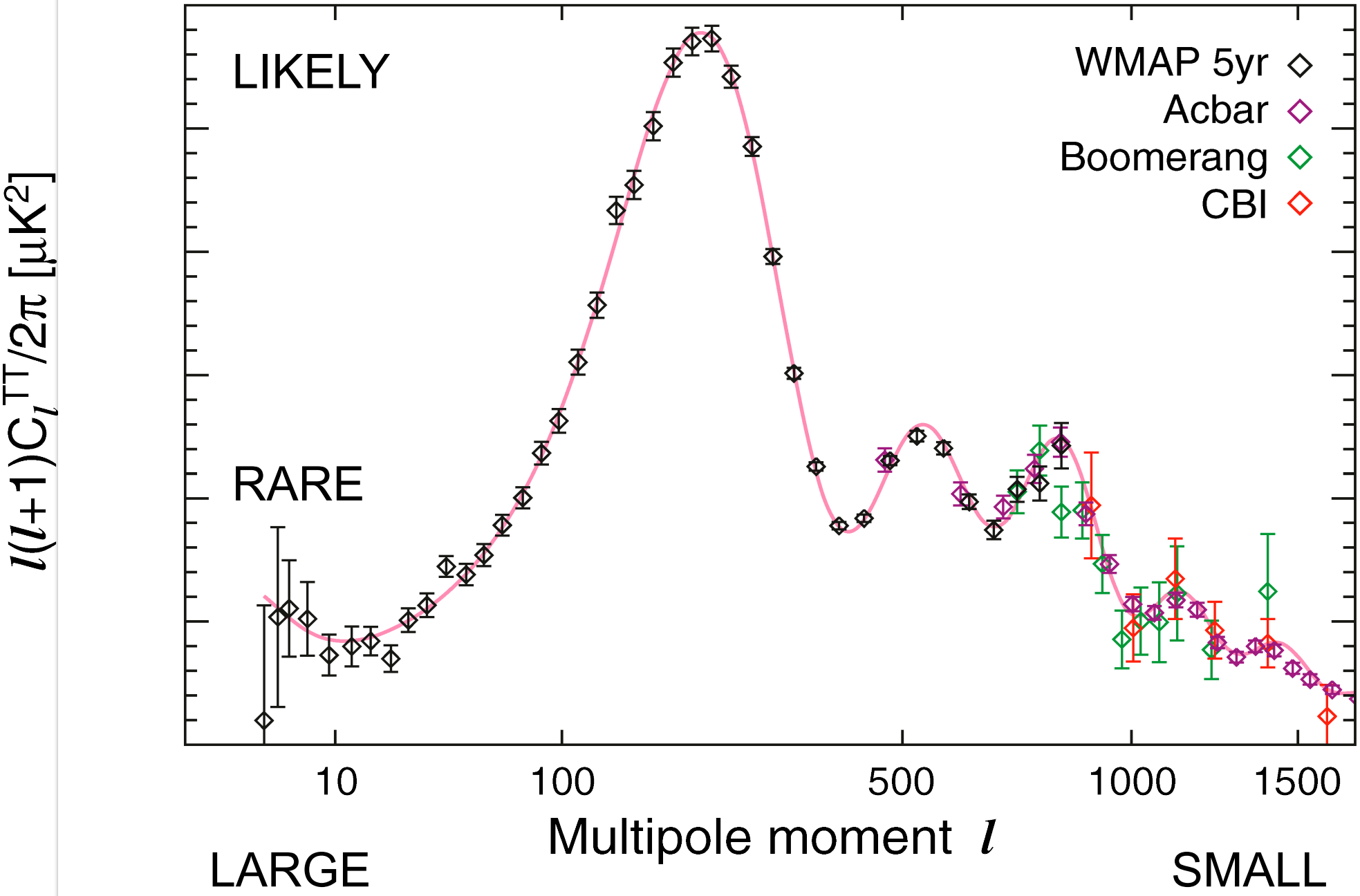
Power spectrum signal as a function of scale; l = 180° / θ_{obs}

Image credit: Nolta et al 2009



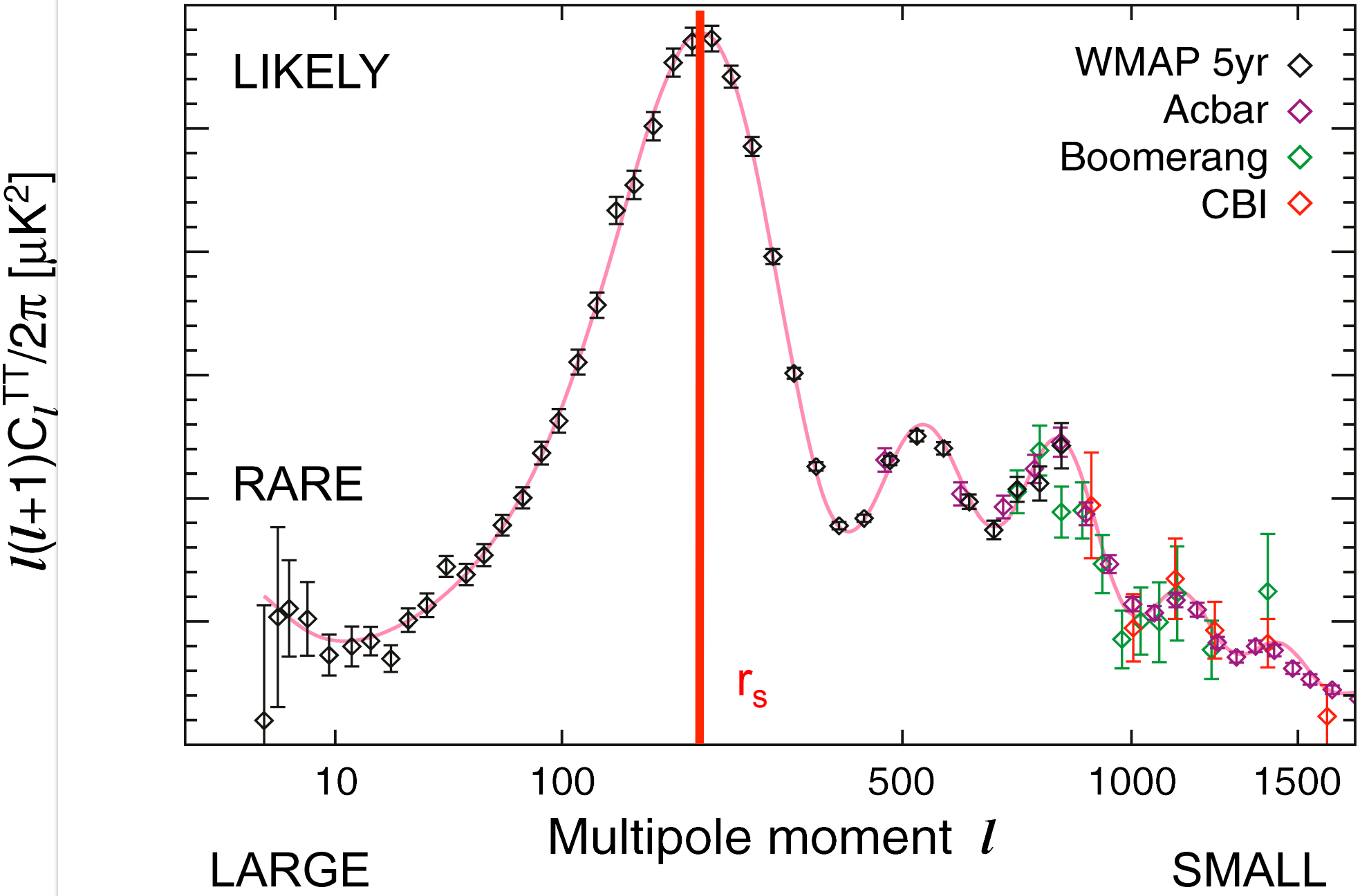
Hot plasma supports soundwaves

Image credit: Nolta et al 2009



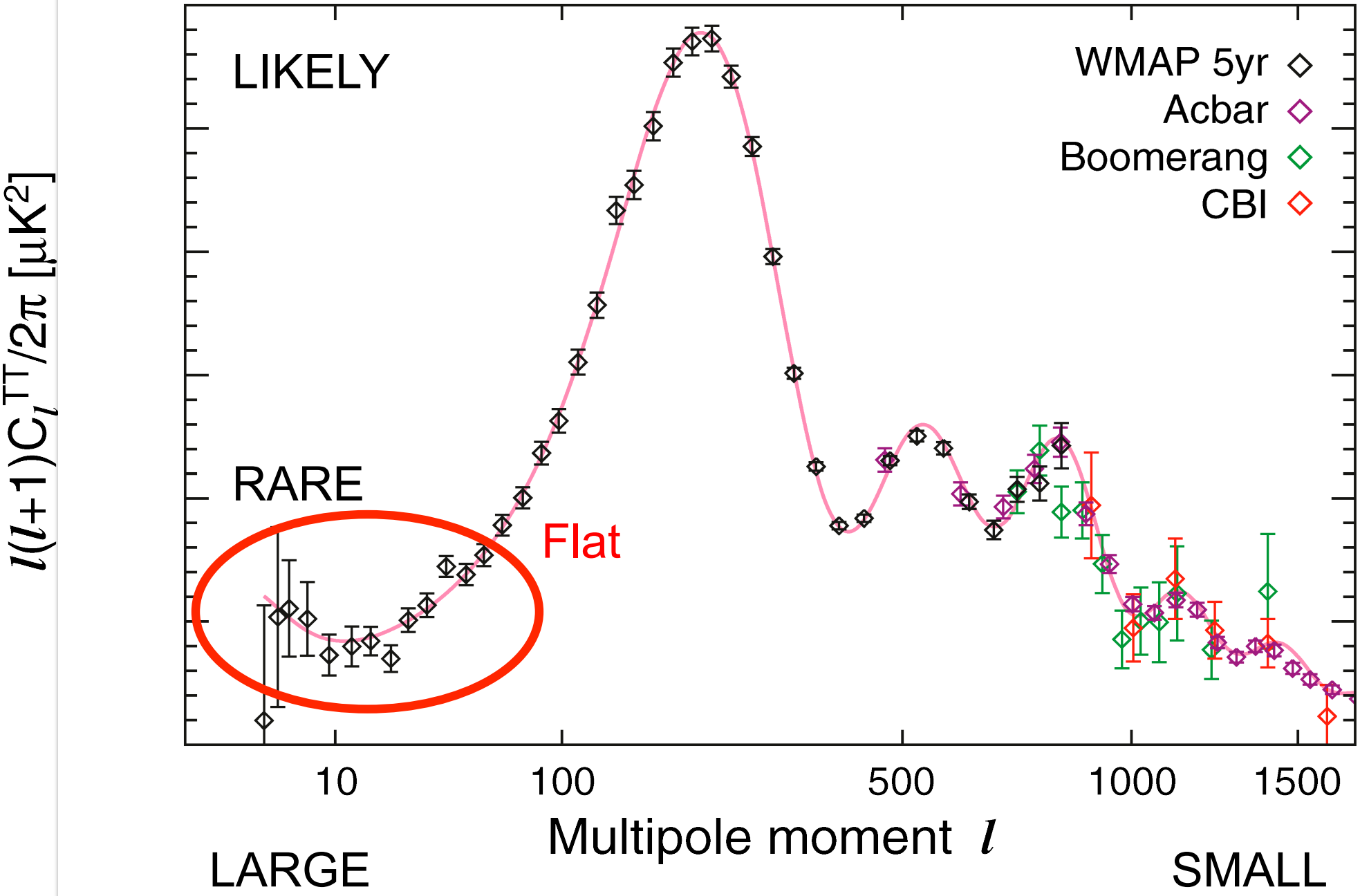
So how do we know what size the blobs are meant to be?

Image credit: Nolta et al 2009



The first peak is a wave that just fits within the horizon…

Image credit: Nolta et al 2009



For scales larger than the Universe nothing can collapse so flat

Image credit: Nolta et al 2009

The Shape of the Universe

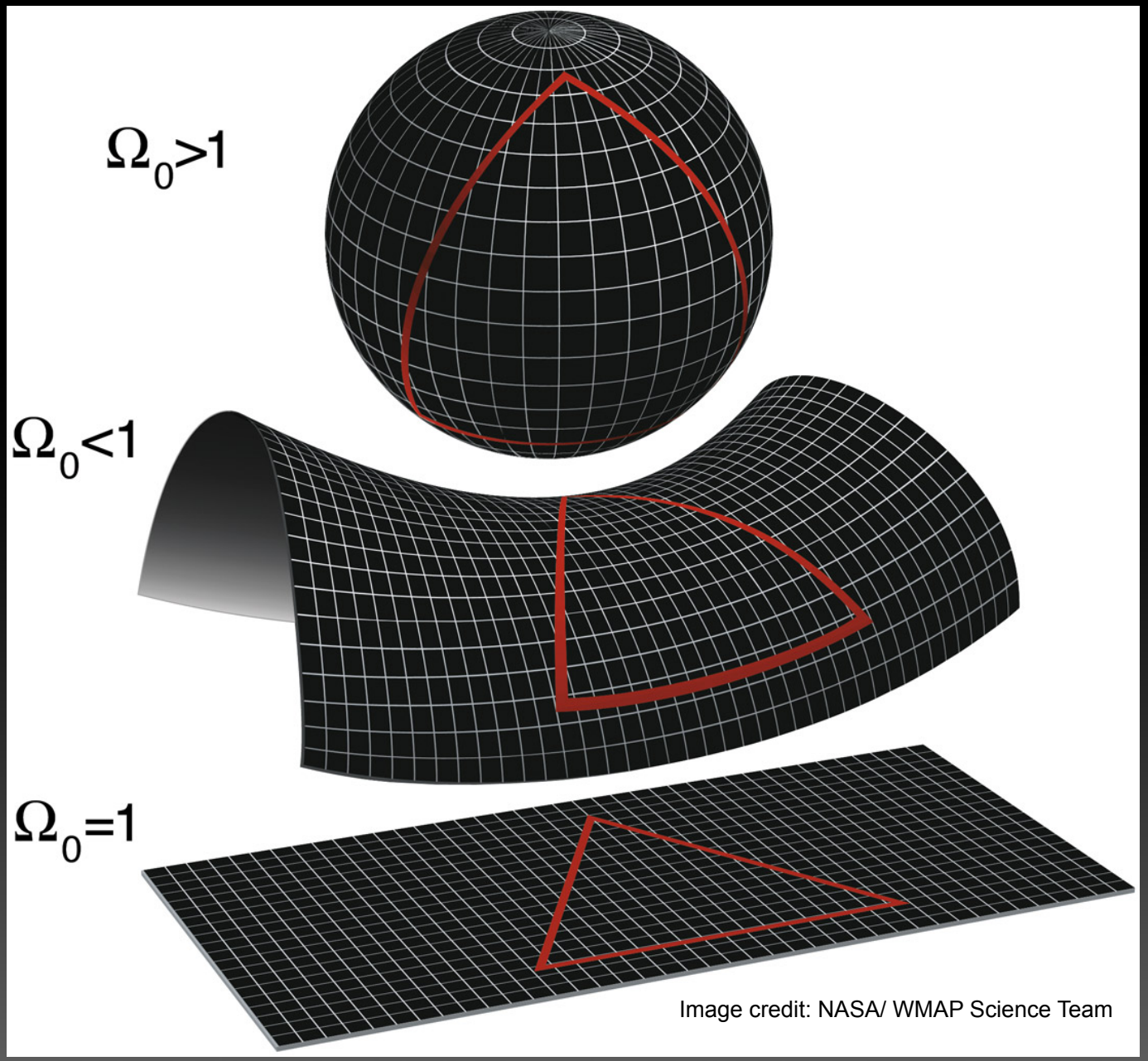


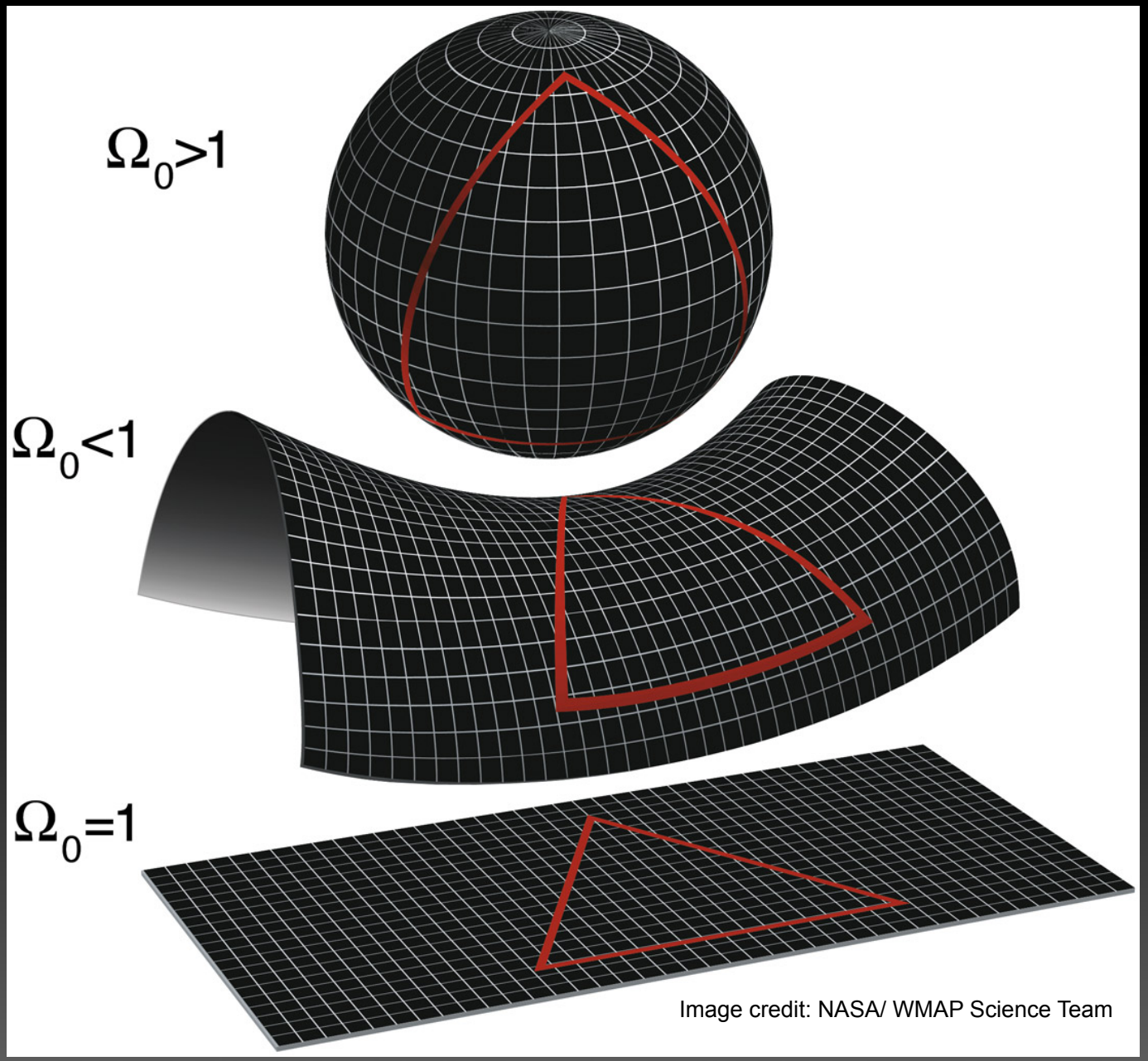
Image credit: NASA/ WMAP Science Team

The Shape of the Universe

Closed

Open

Flat



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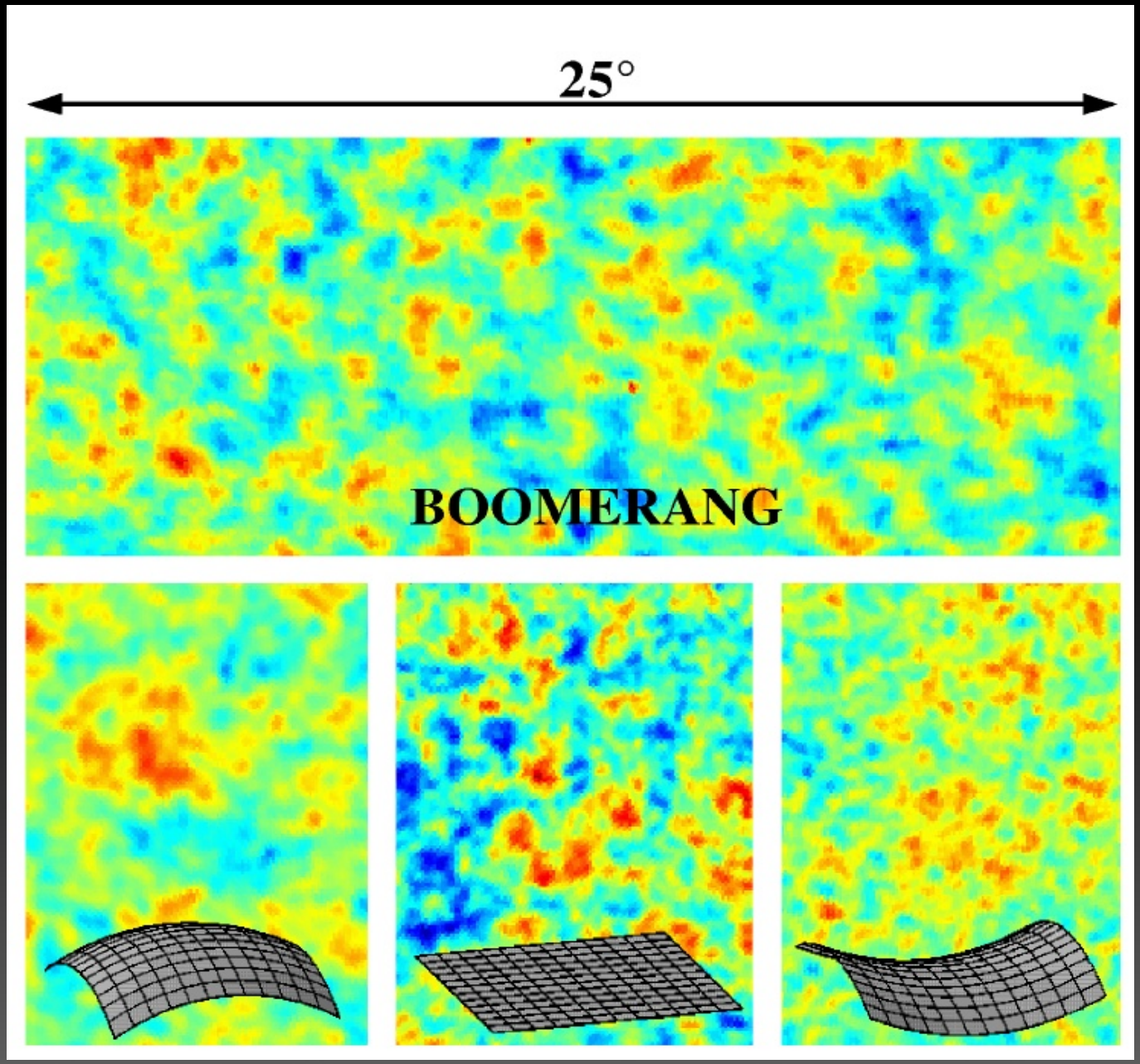

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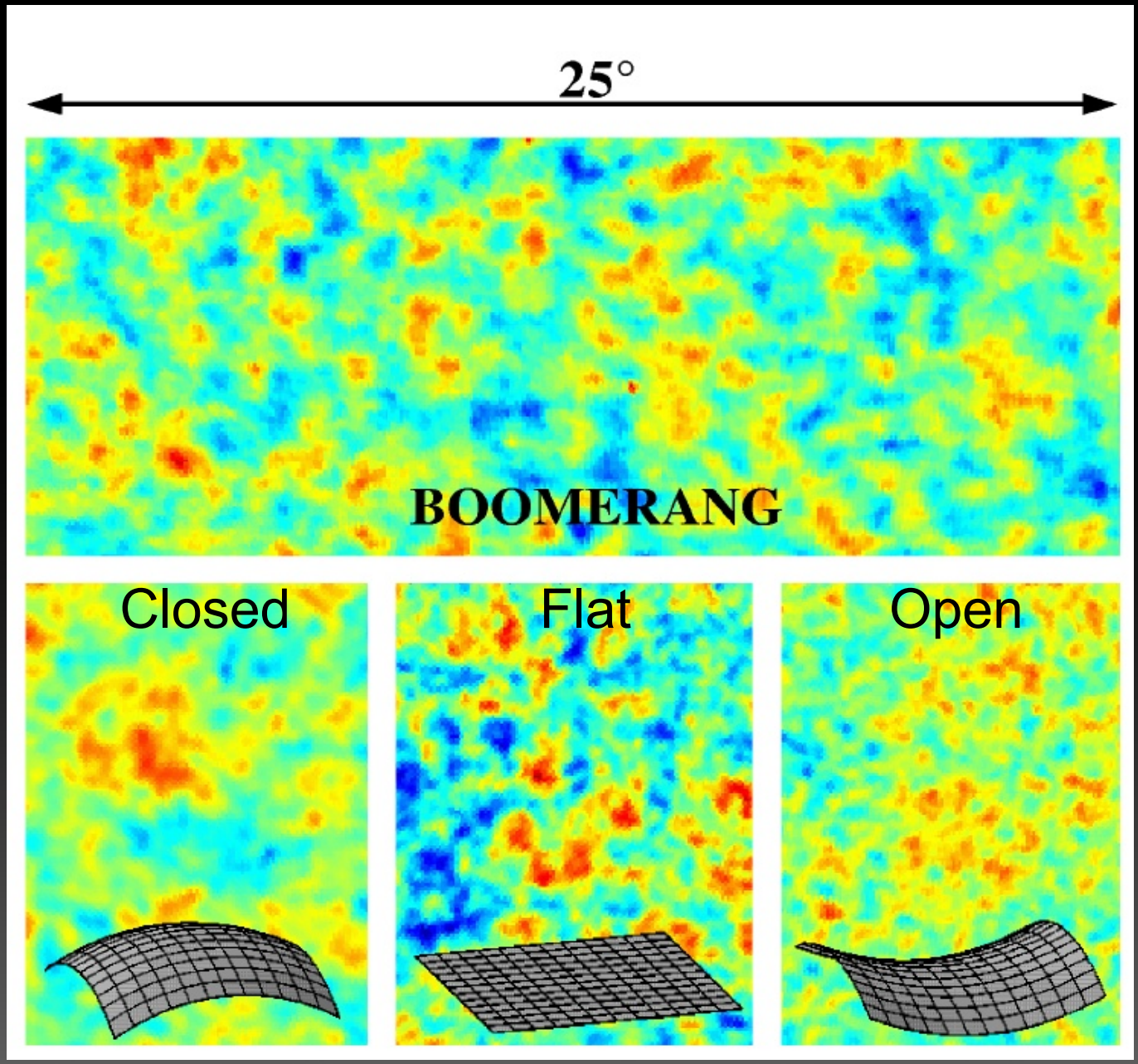
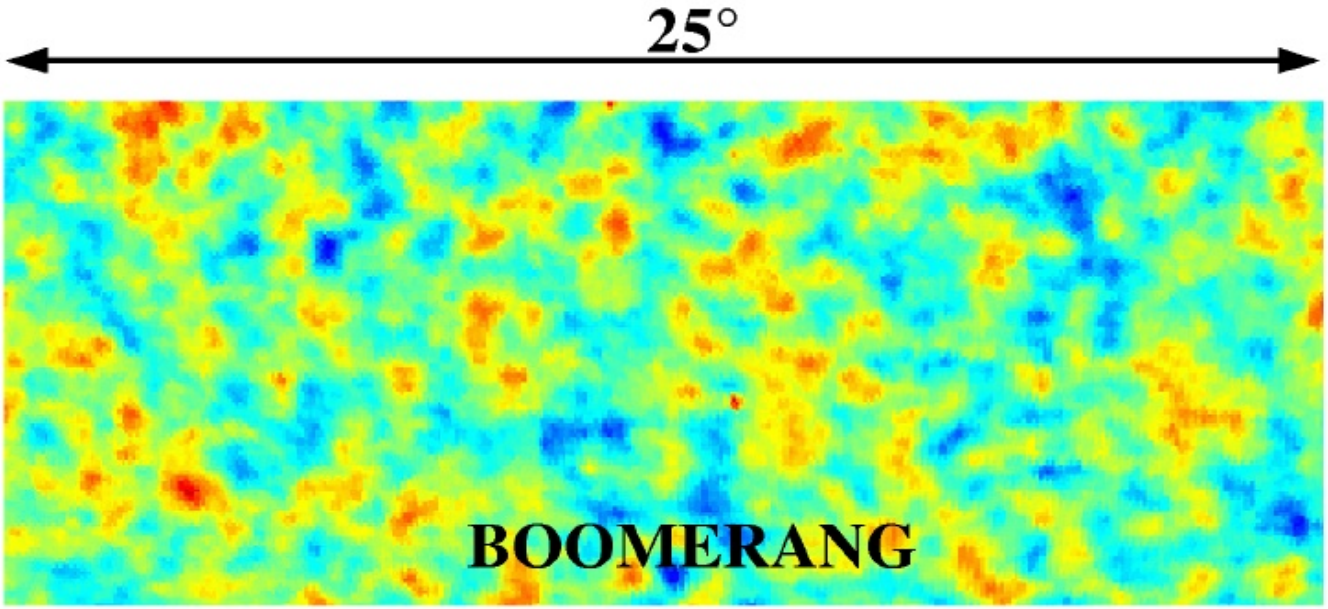
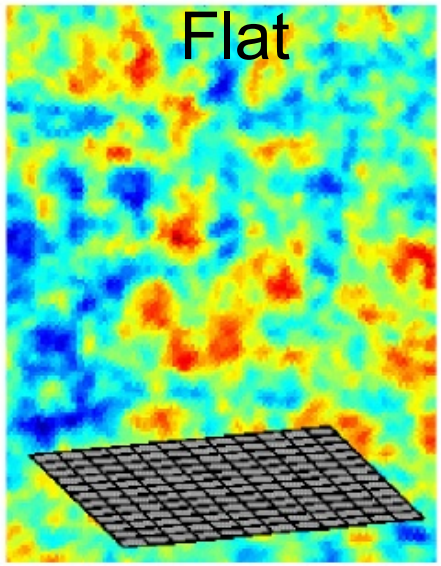
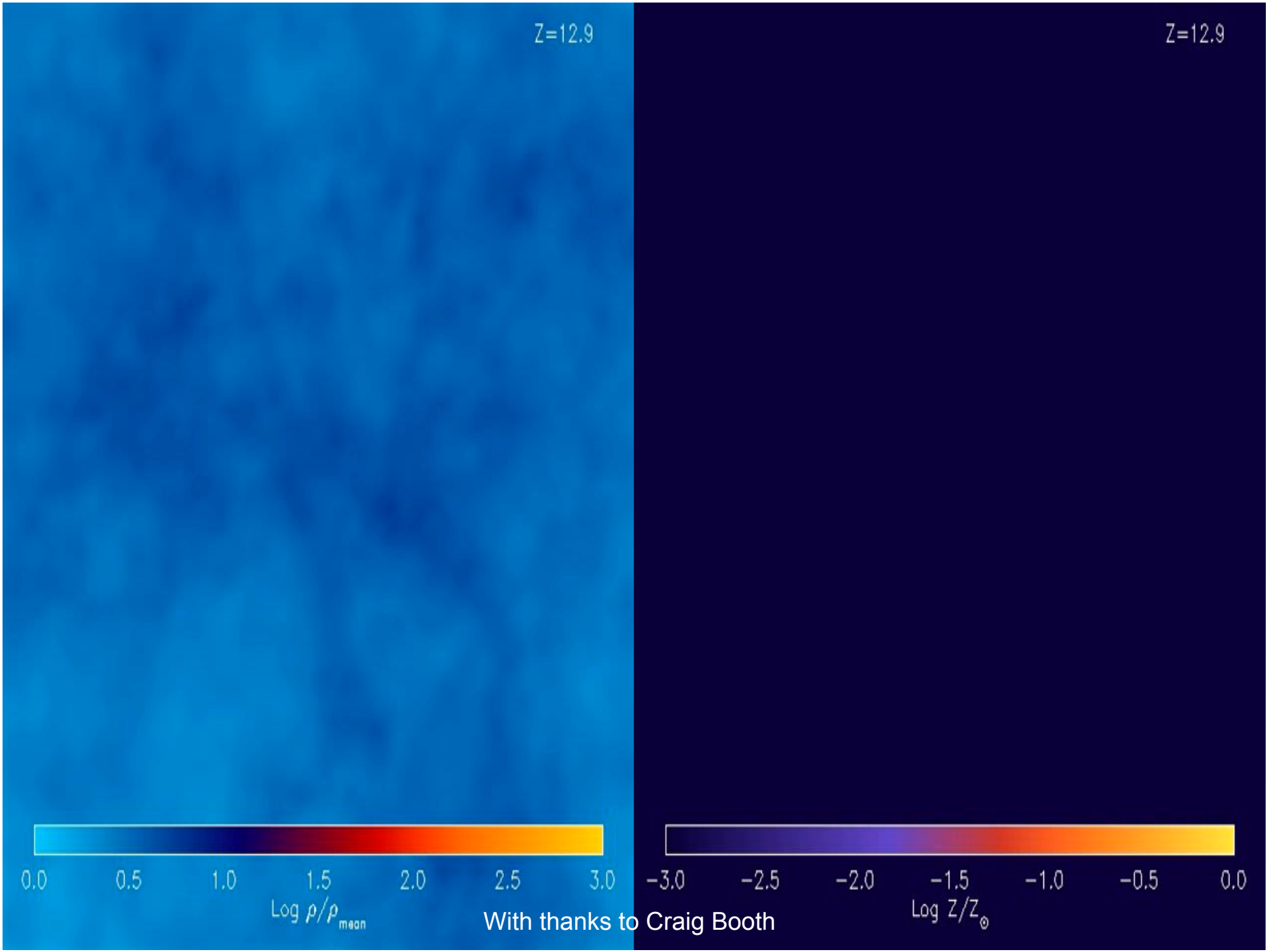


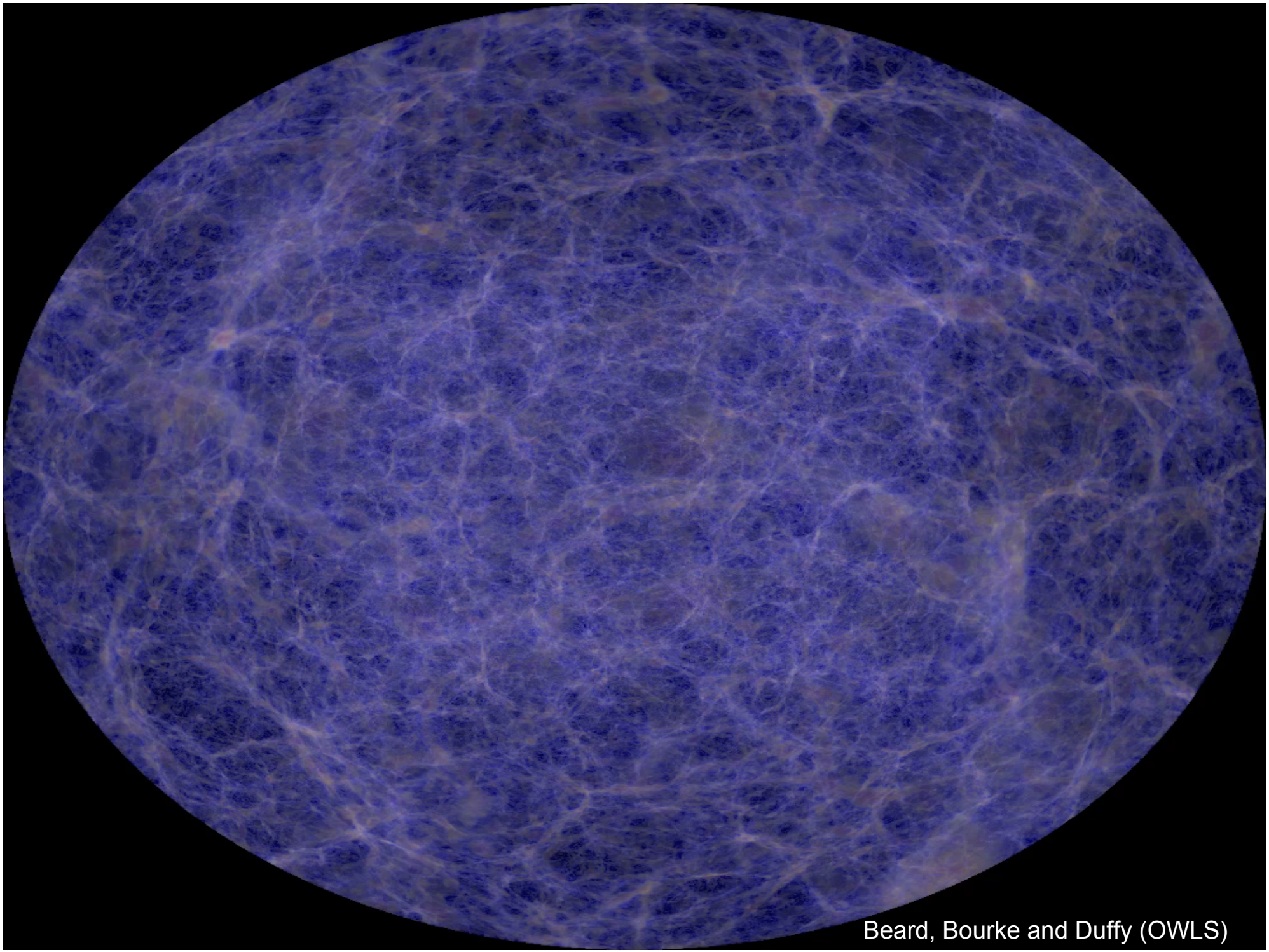
The Shape of the Universe

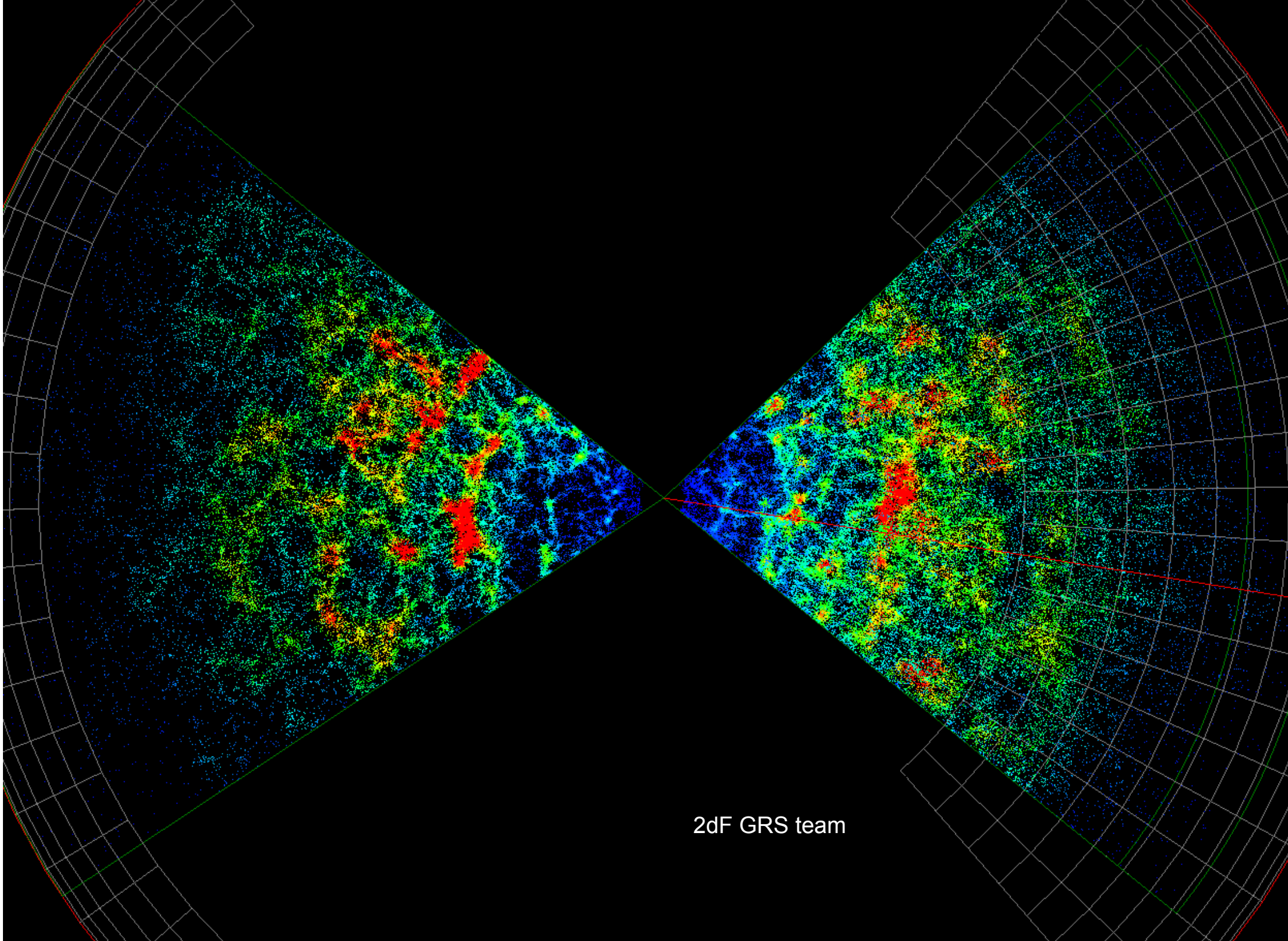






With thanks to Craig Booth


Beard, Bourke and Duffy (OWLS)


2dF GRS team

Λ-CDM Cosmology

What's the age..?

2 or 14 billion years old

Λ-CDM Cosmology

What's the age..?

13.8 billion years old

Λ-CDM Cosmology

What's the age..? 13.8 billion years old

Shape of the Universe..? Open, Closed or Flat

Λ-CDM Cosmology

What's the age..? 13.8 billion years old

Shape of the Universe..? Flat

Λ-CDM Cosmology

What's the age..?	13.8 billion years old
Shape of the Universe..?	Flat
Dominant component..?	Atoms, Dark Matter, Dark Energy

Λ-CDM Cosmology

What's the age..?	13.8 billion years old
Shape of the Universe..?	Flat
Dominant component..?	Dark Energy
then..?	Dark Matter or Atoms

Λ-CDM Cosmology

What's the age..?	13.8 billion years old
Shape of the Universe..?	Flat
Dominant component..?	Dark Energy Dark Matter Atoms

Λ-CDM Cosmology

Yet we've never known so little about our Universe

Λ-CDM Cosmology

Yet we've never known so little about our Universe

96% of the Universe is 'Dark', i.e. unknown.

Λ-CDM Cosmology

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What was inflation?

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Will the Universe continue expanding forever?
It depends if Einstein was right…

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Phantom Dark Energy

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Phantom Dark Energy

Quintessence

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Quintessence

Maybe even General Relativity is wrong…

Thanks – questions?