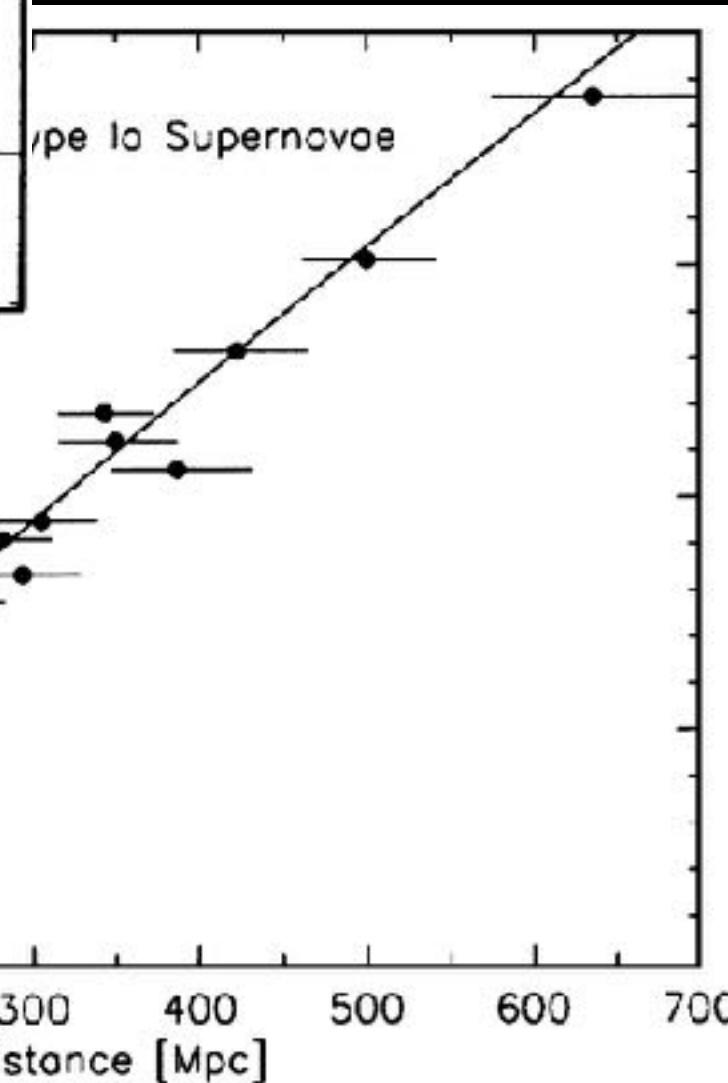
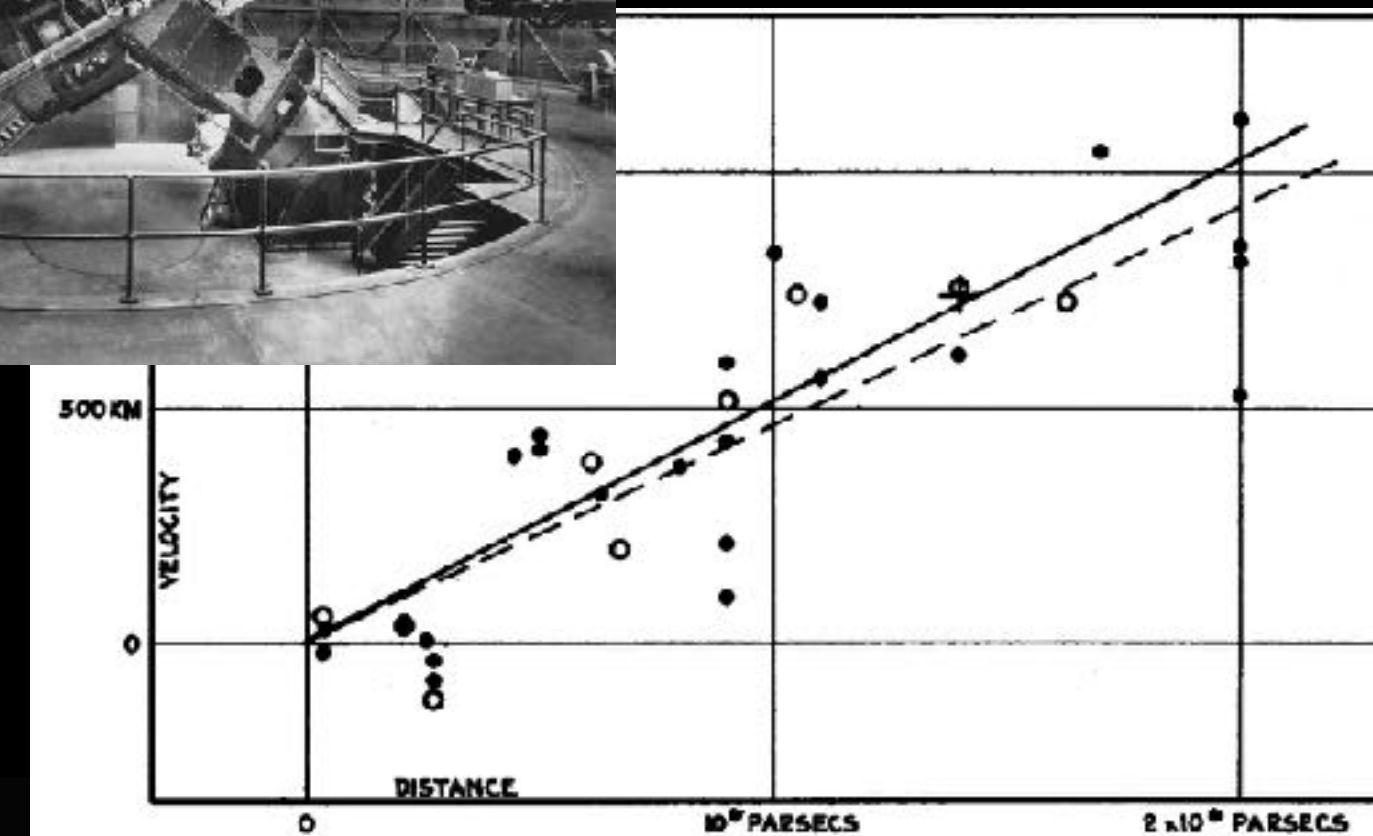
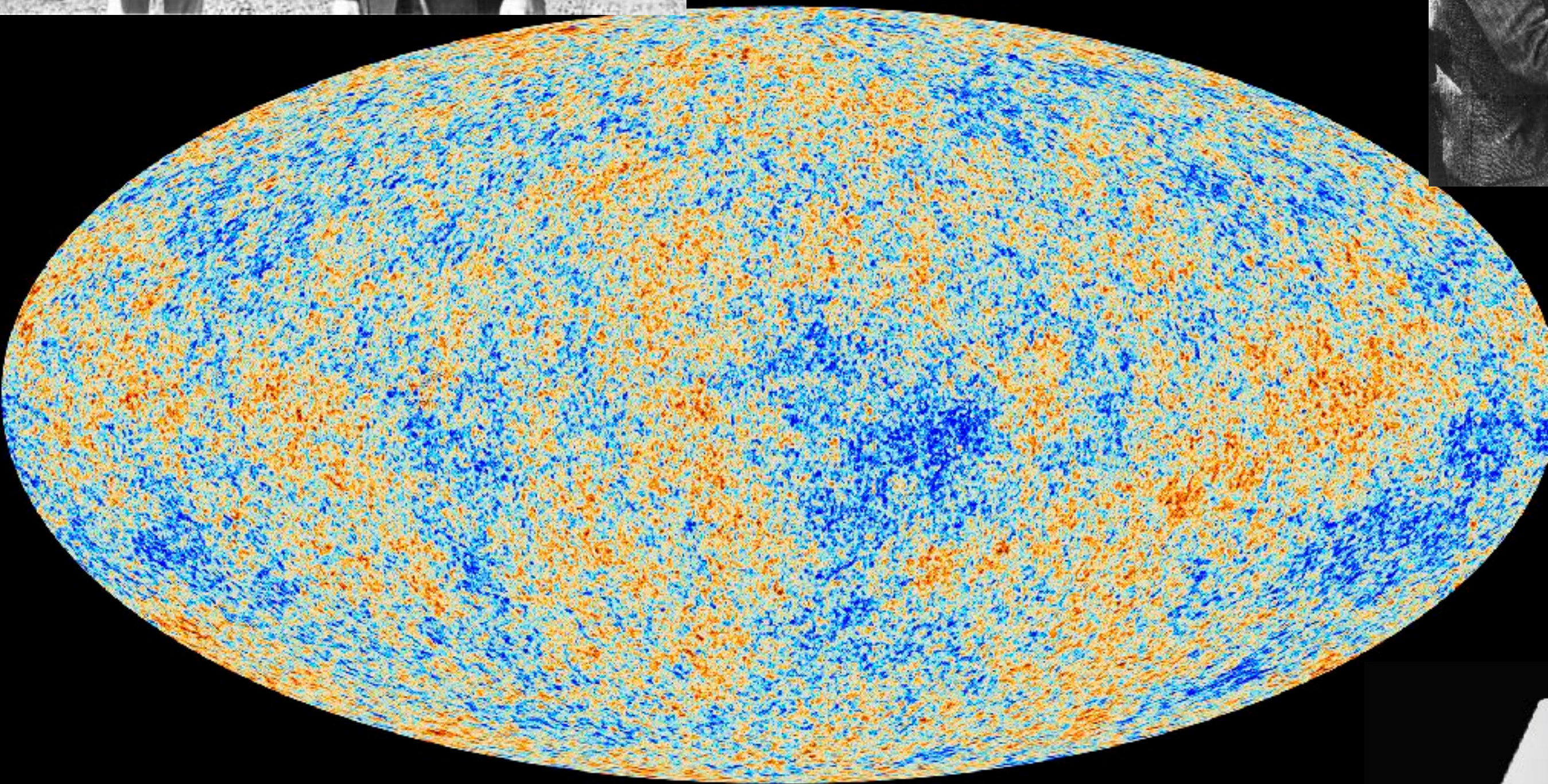
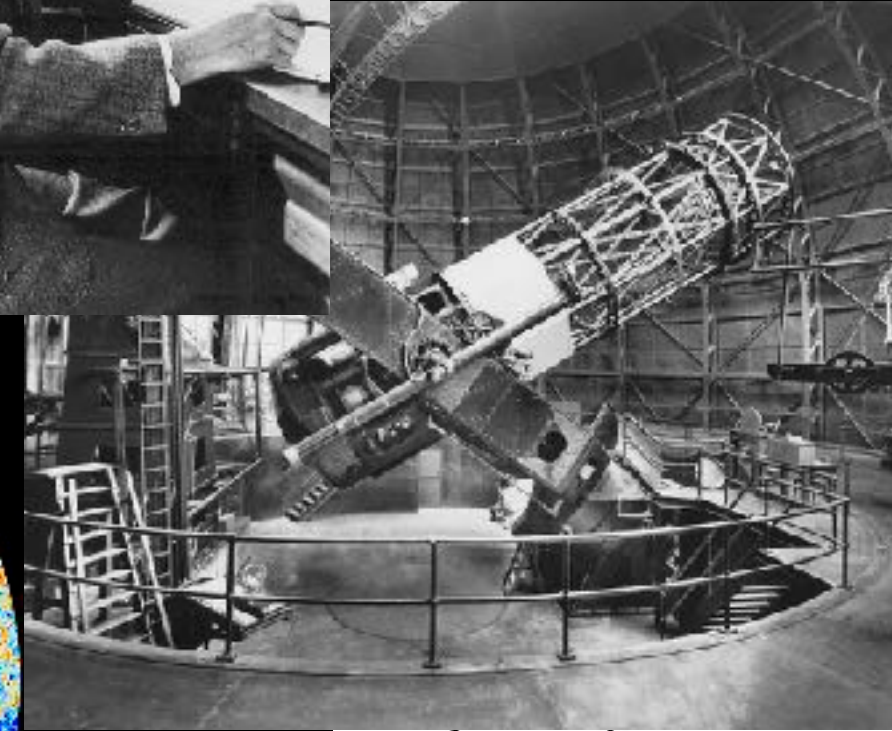
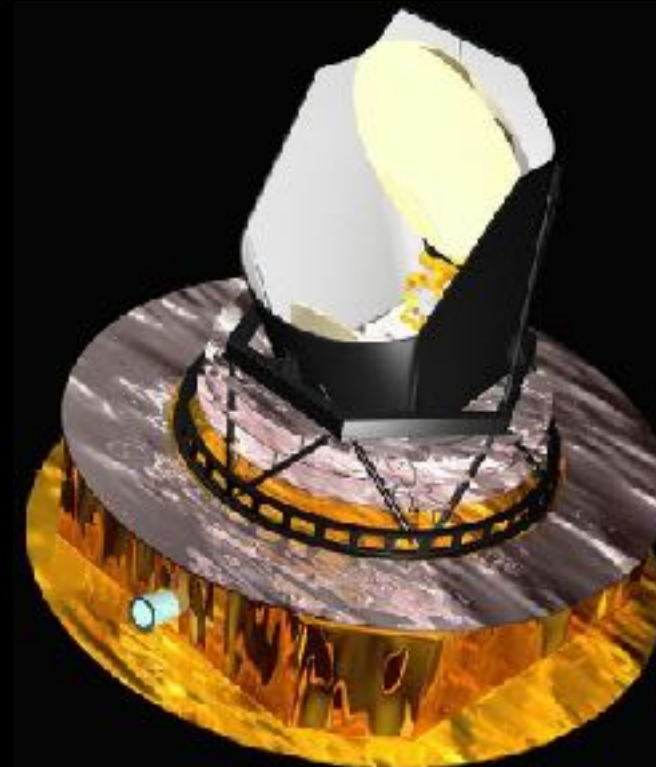


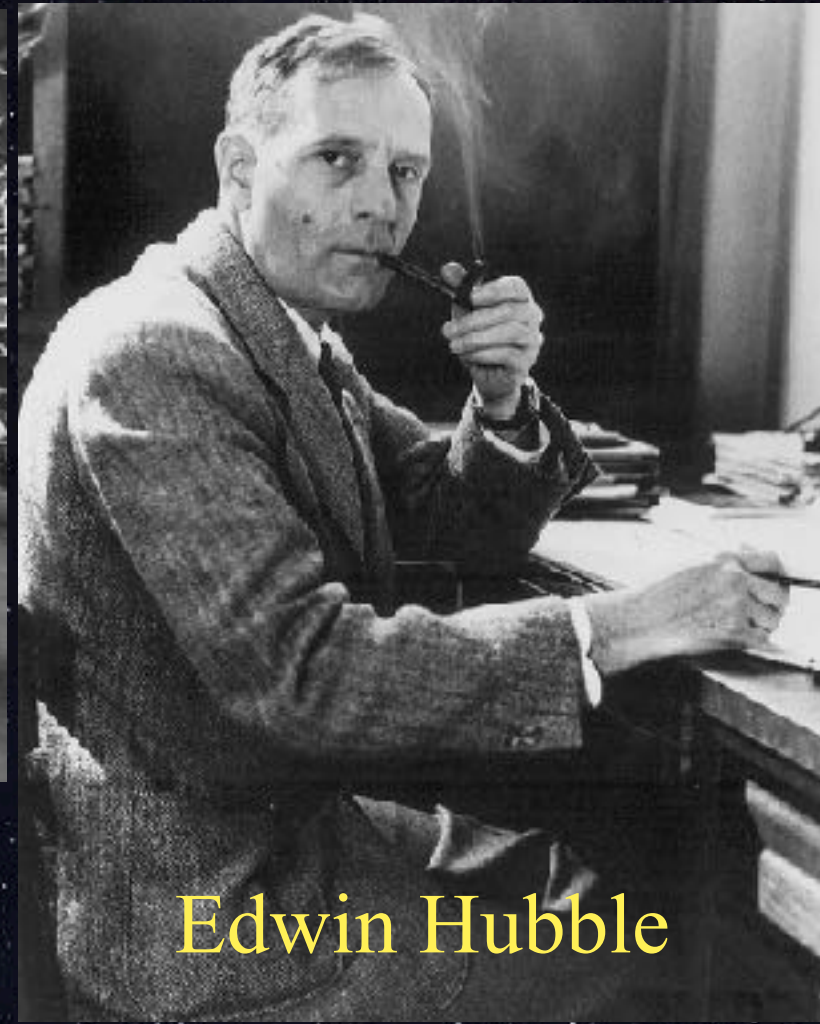
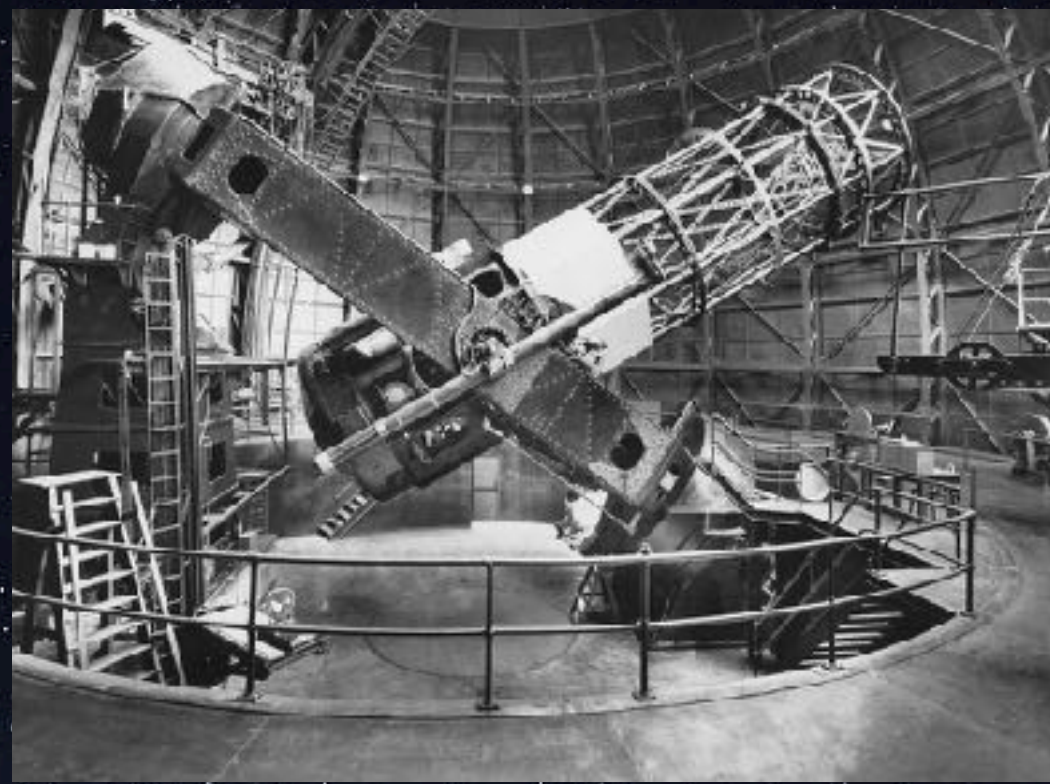
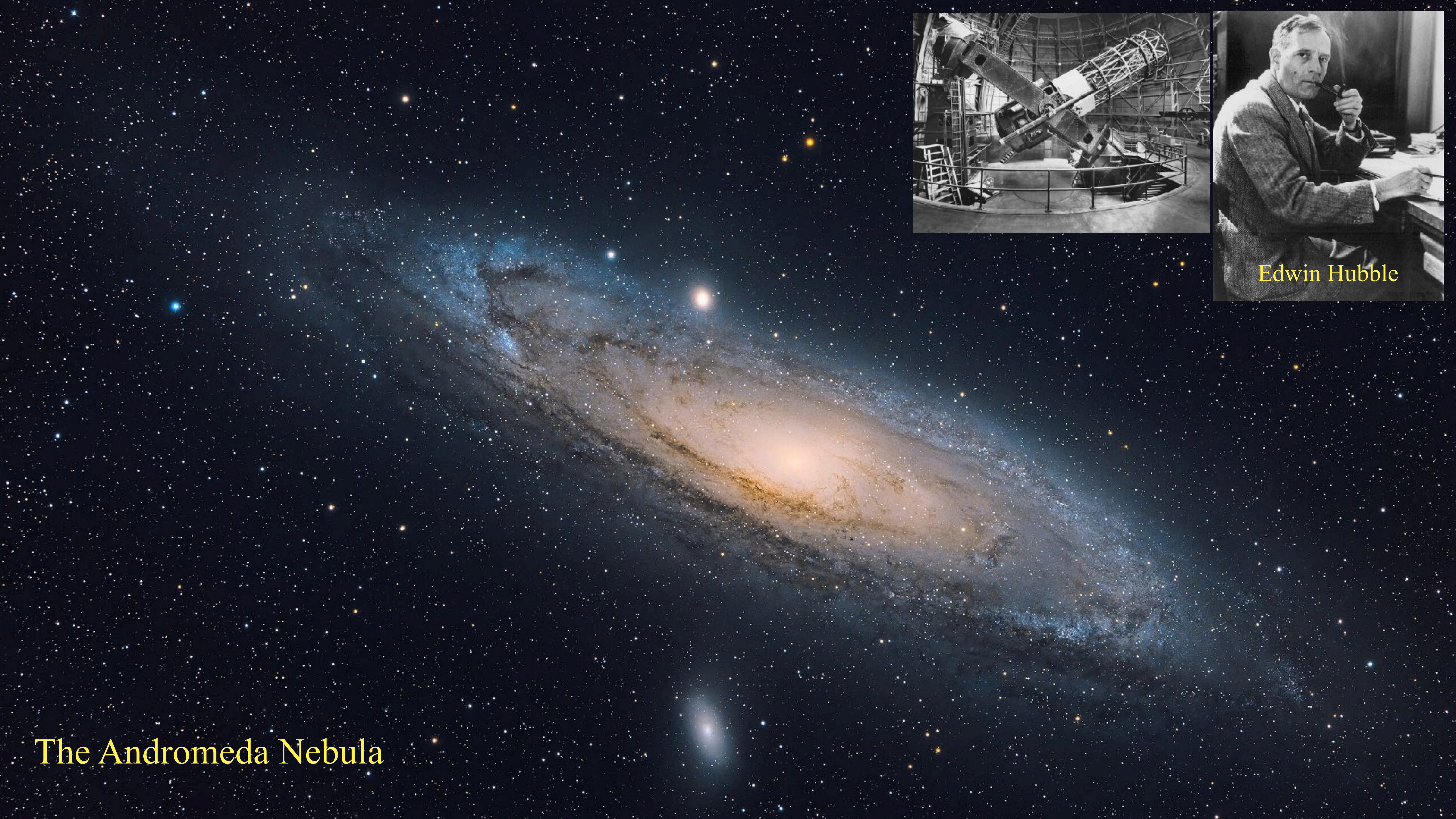
The Power of Science: Decoding the Universe's greatest mysteries

Shaw Laureate Forum 2025
HongKong



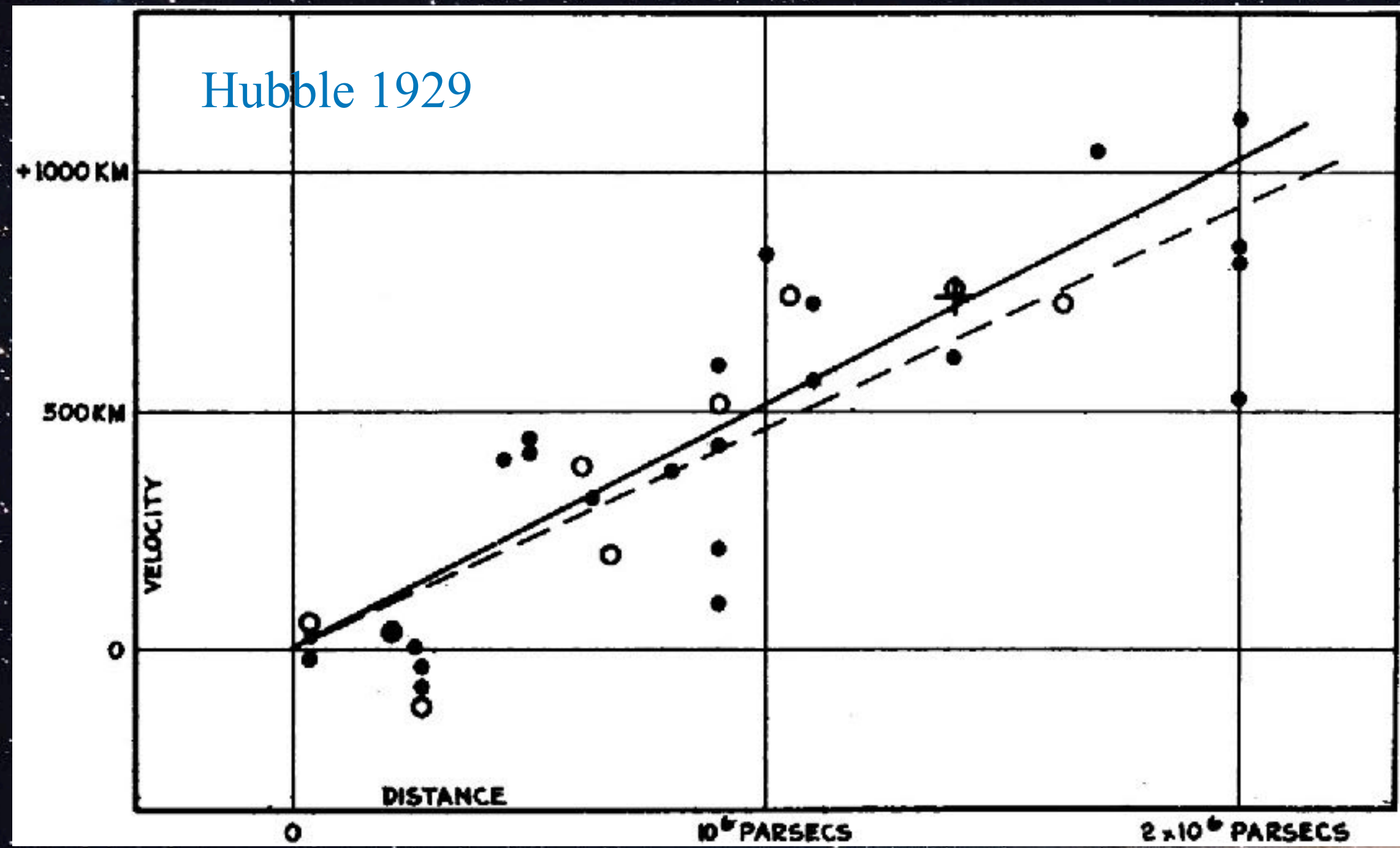
Simon White
Max Planck Institute for Astrophysics



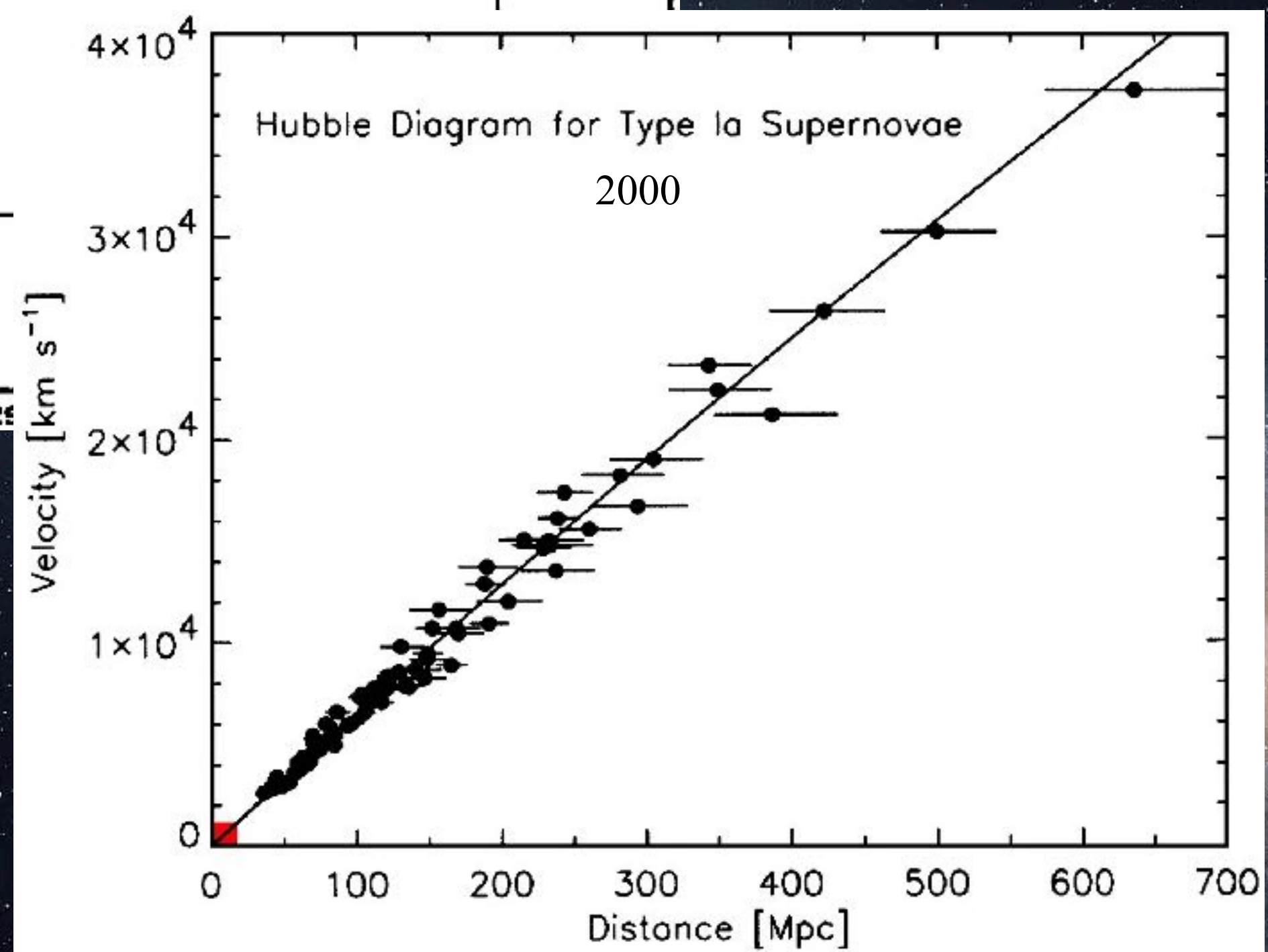
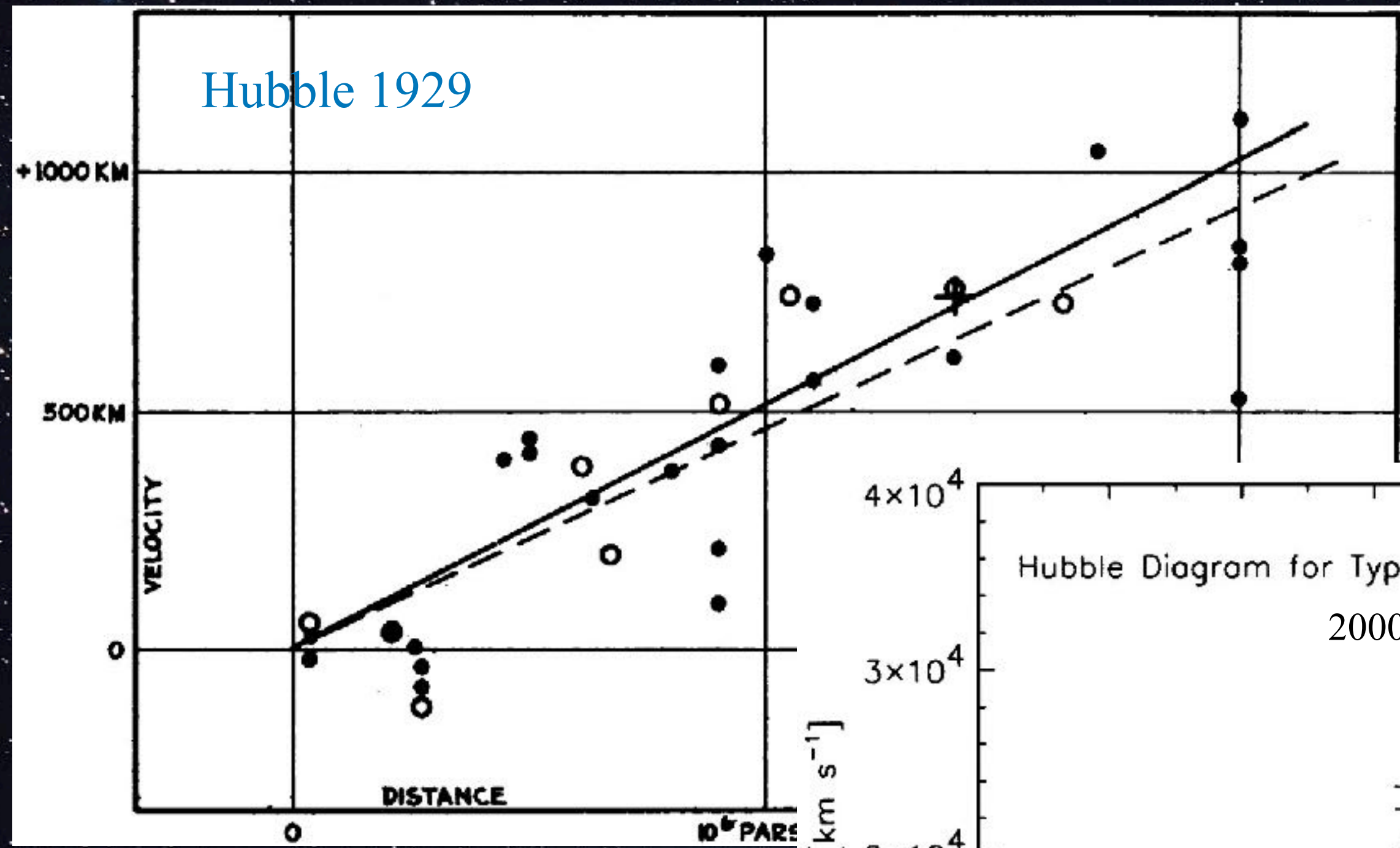


Edwin Hubble

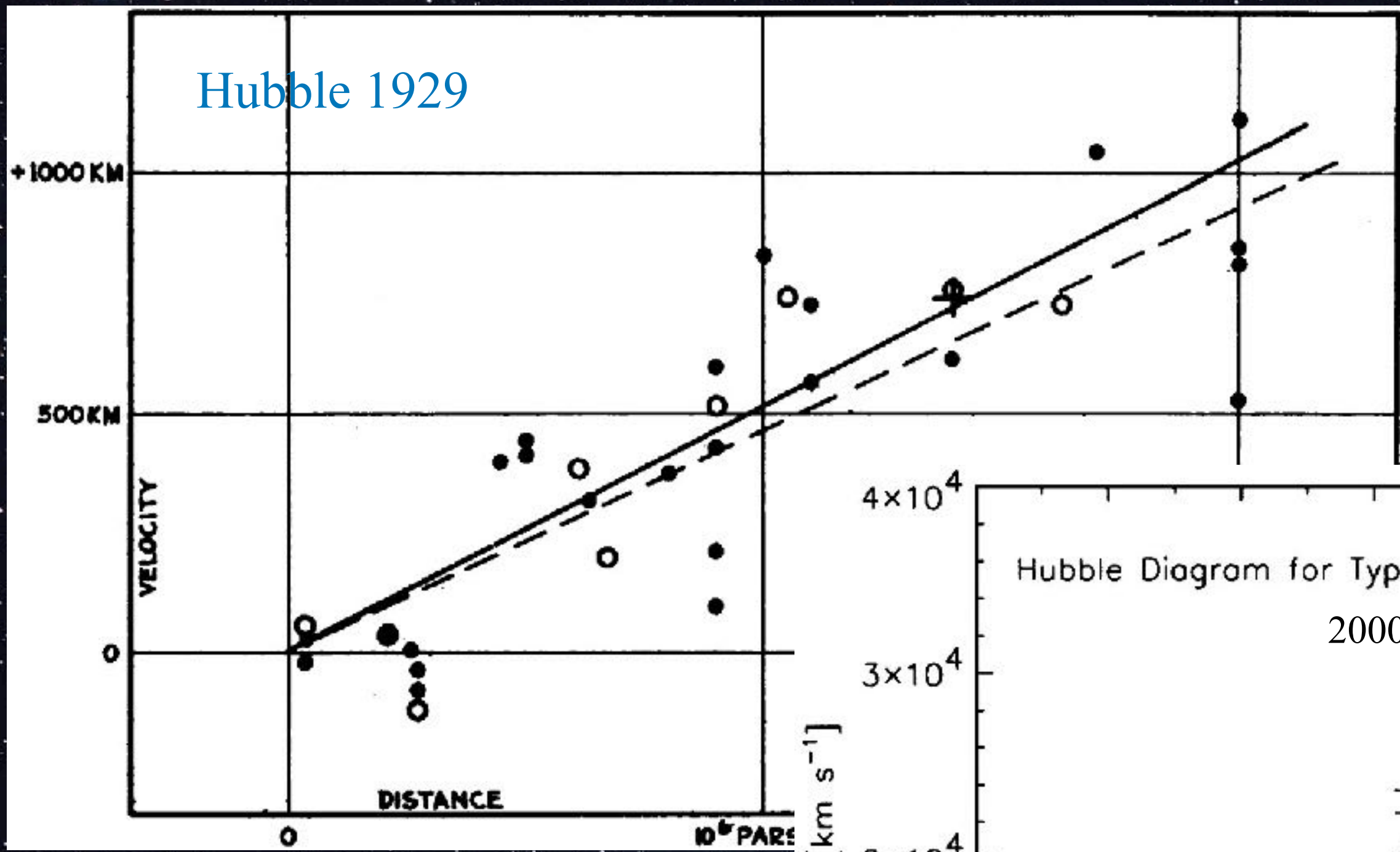
The Andromeda Nebula



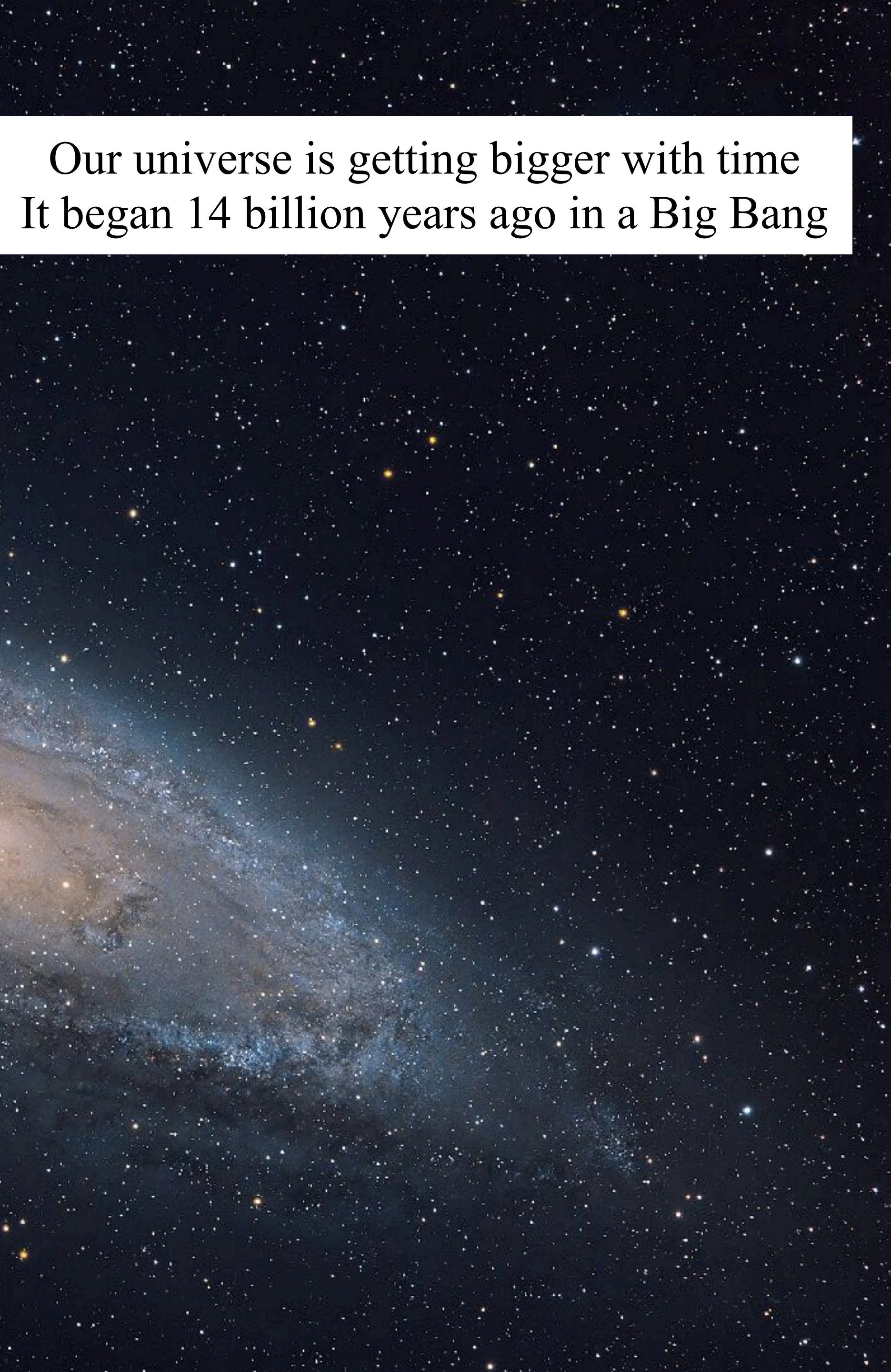
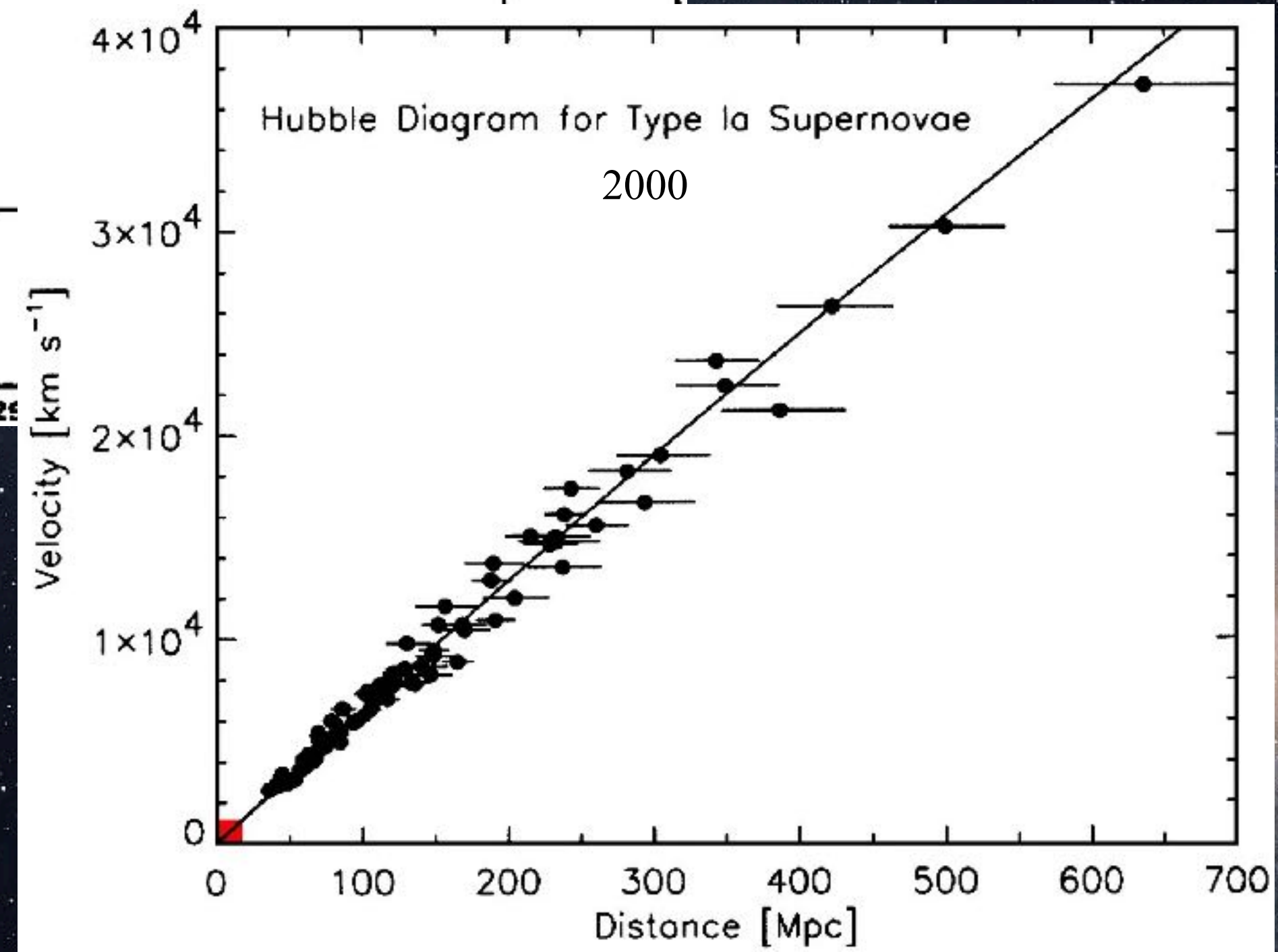
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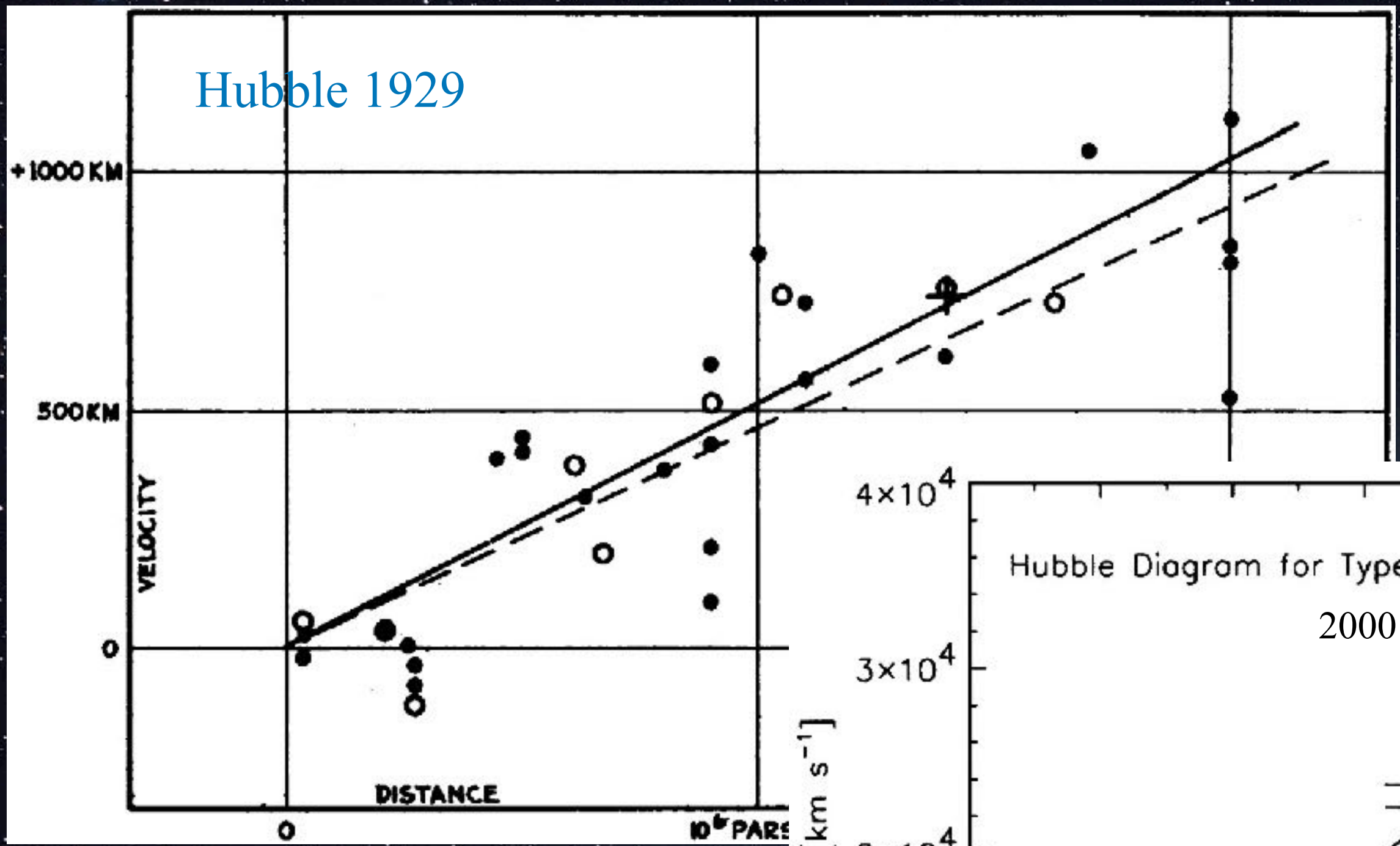
The Andromeda Nebula



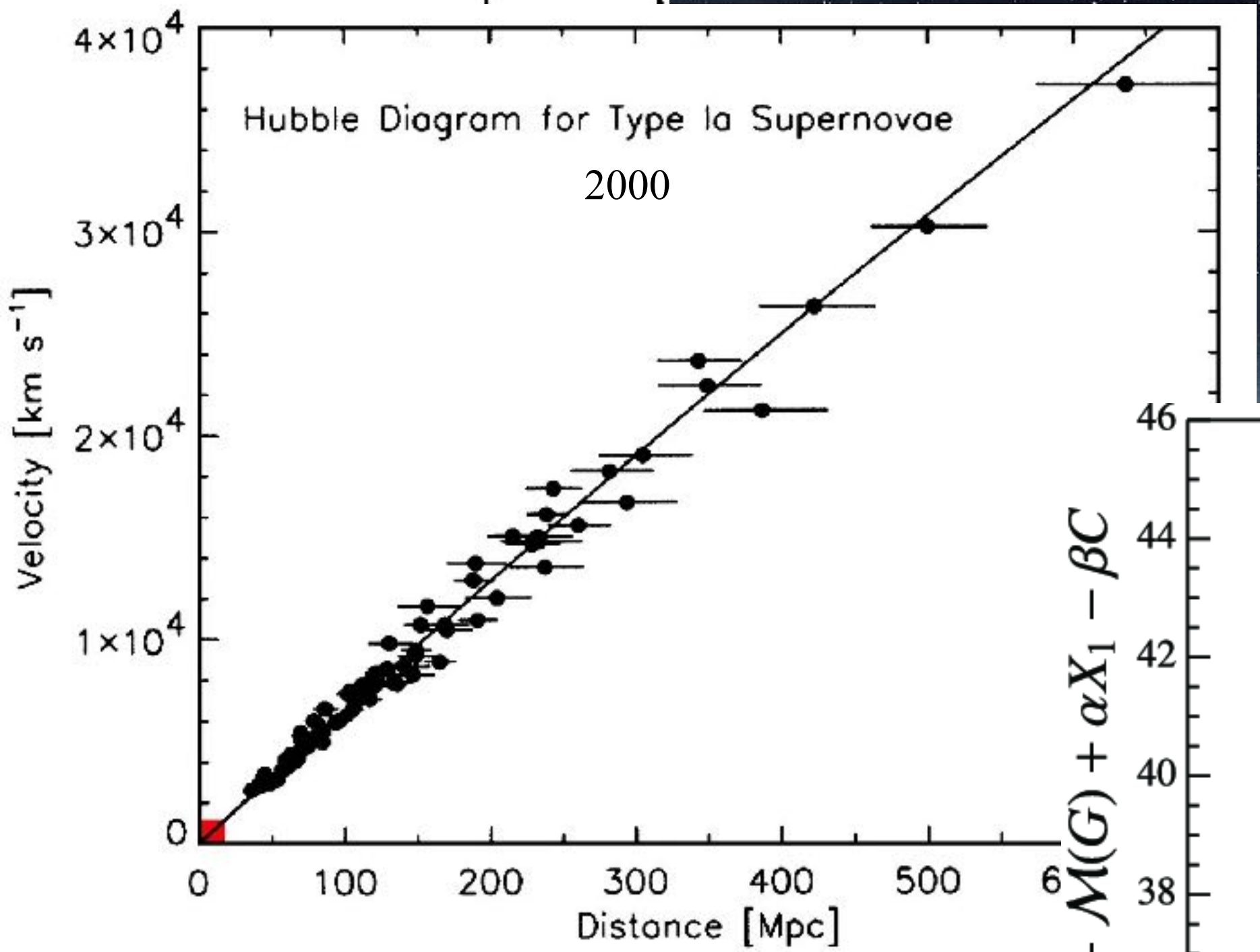
Our universe is getting bigger with time
It began 14 billion years ago in a Big Bang



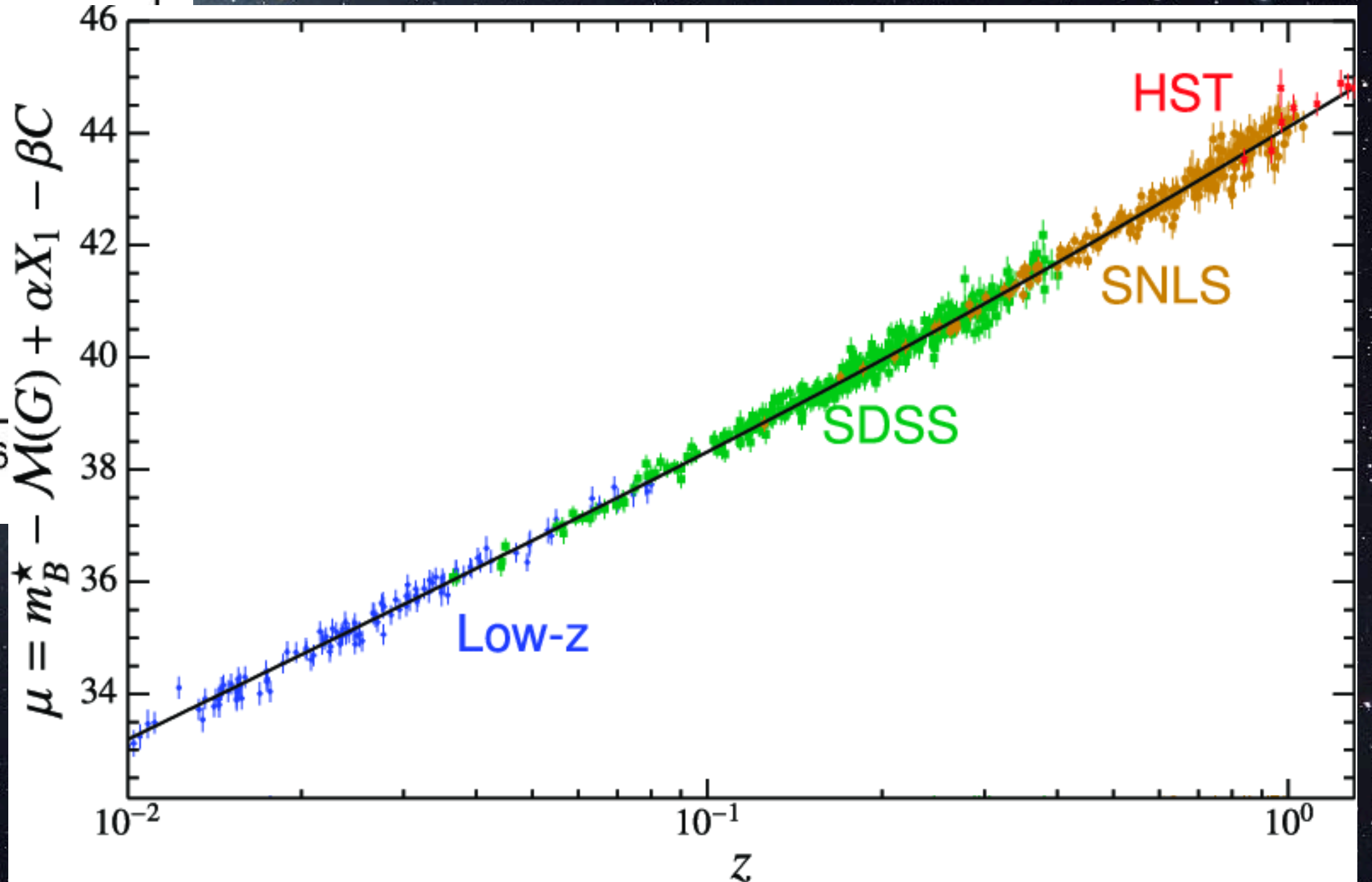
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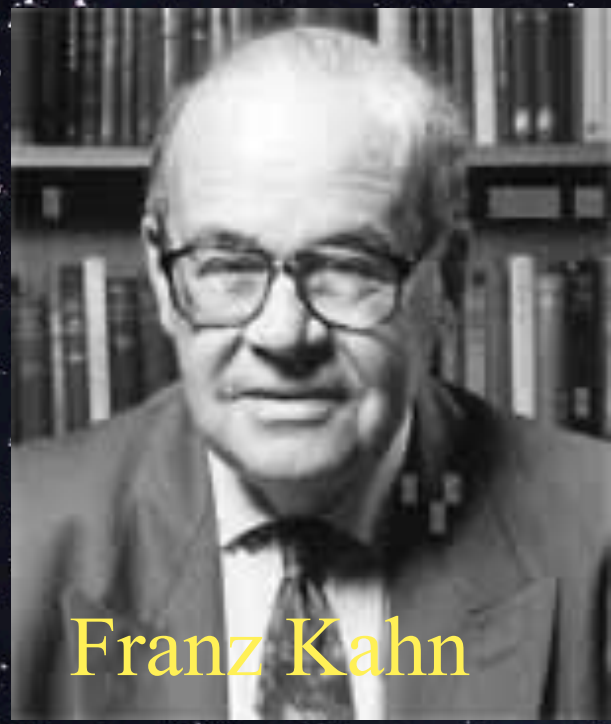
The recent expansion is accelerating
→ Dark Energy!



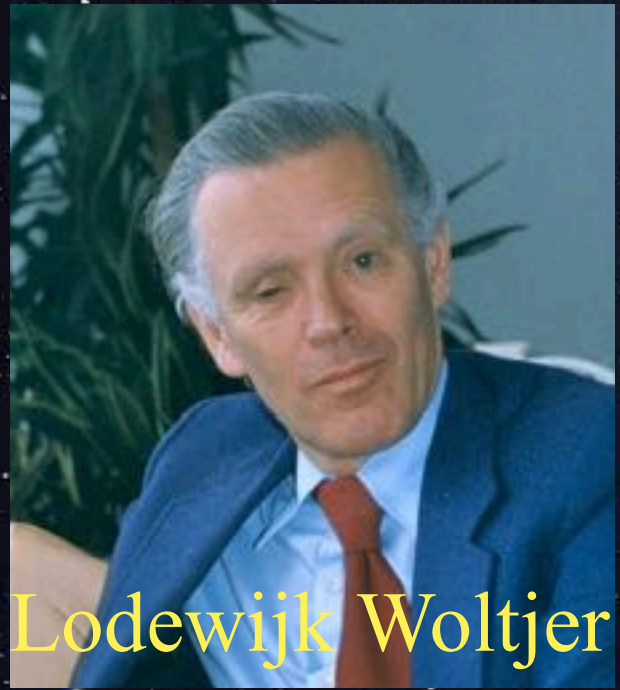
The Andromeda Nebula



The Andromeda Nebula



Franz Kahn



Lodewijk Woltjer

Kahn & Woltjer 1959

Distance to Andromeda: 1.8 million light years

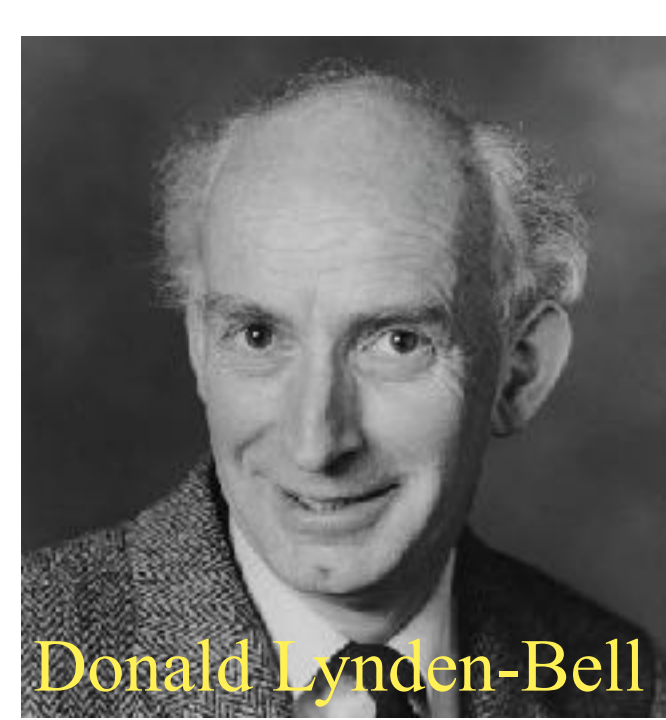
Approach speed: 125 km/sec

Time since the Big Bang: 10 billion years

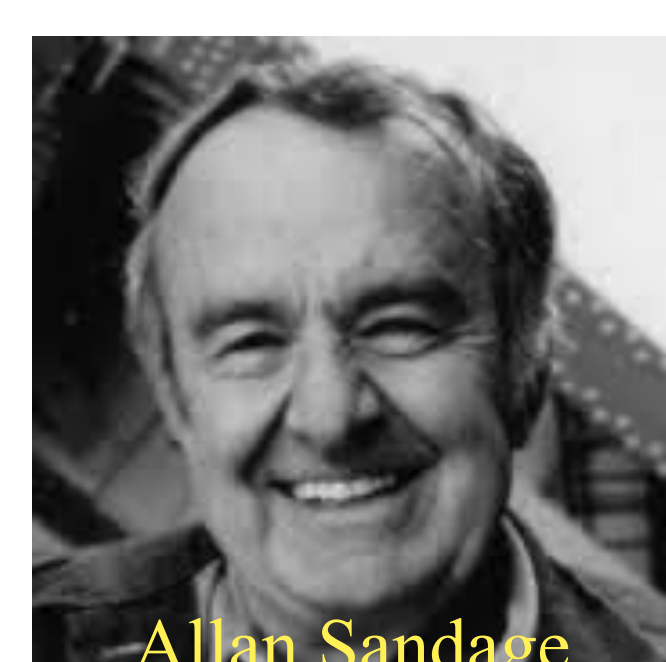
→ Total mass: 2000 billion Suns

The two galaxies have 500 billion stars, so most of the mass in the system is **Dark Matter**

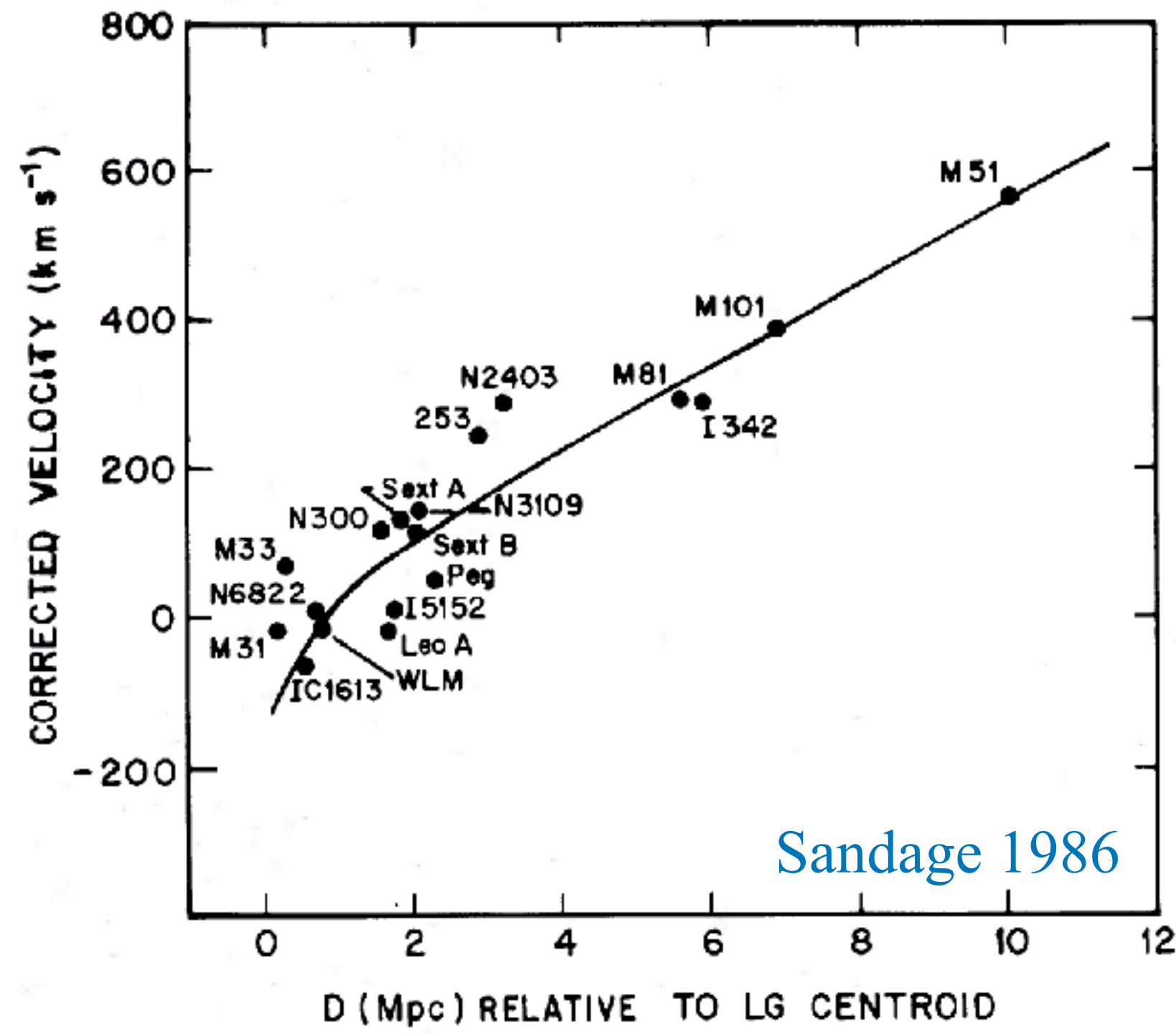
The Andromeda Nebula



Donald Lynden-Bell



Allan Sandage



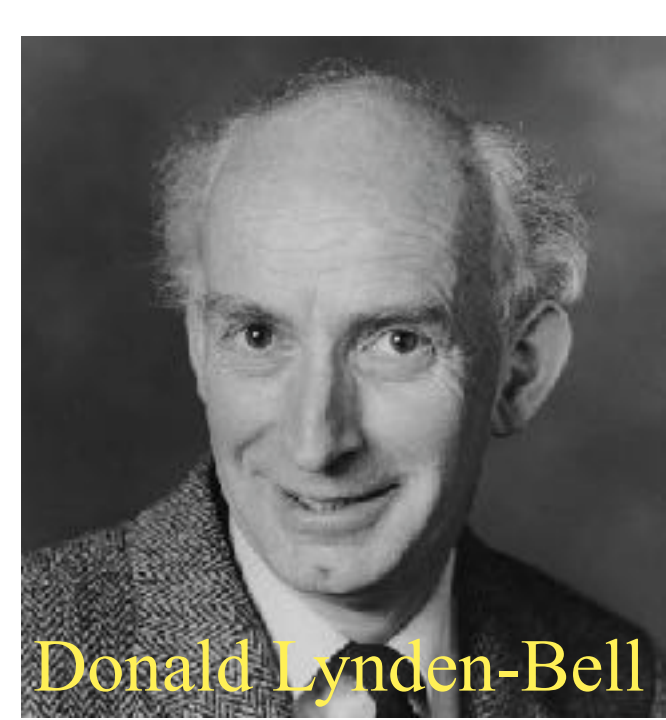
Sandage 1986

Nearby galaxies beyond Andromeda are all receding with the cosmic expansion.

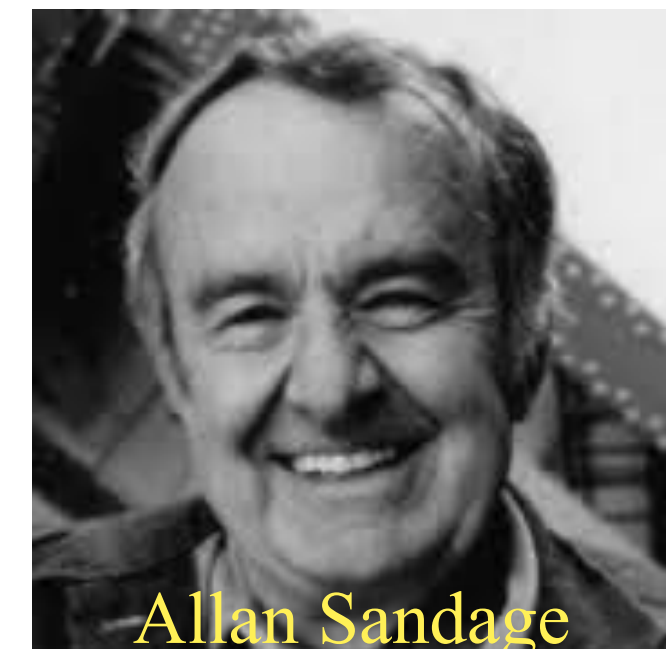
The *only* significant mass in the nearby region seems to be that of the Milky Way+Andromeda

Sandage estimated this mass to be just 3000 billion Suns - similar to Kahn & Woltjer 1959

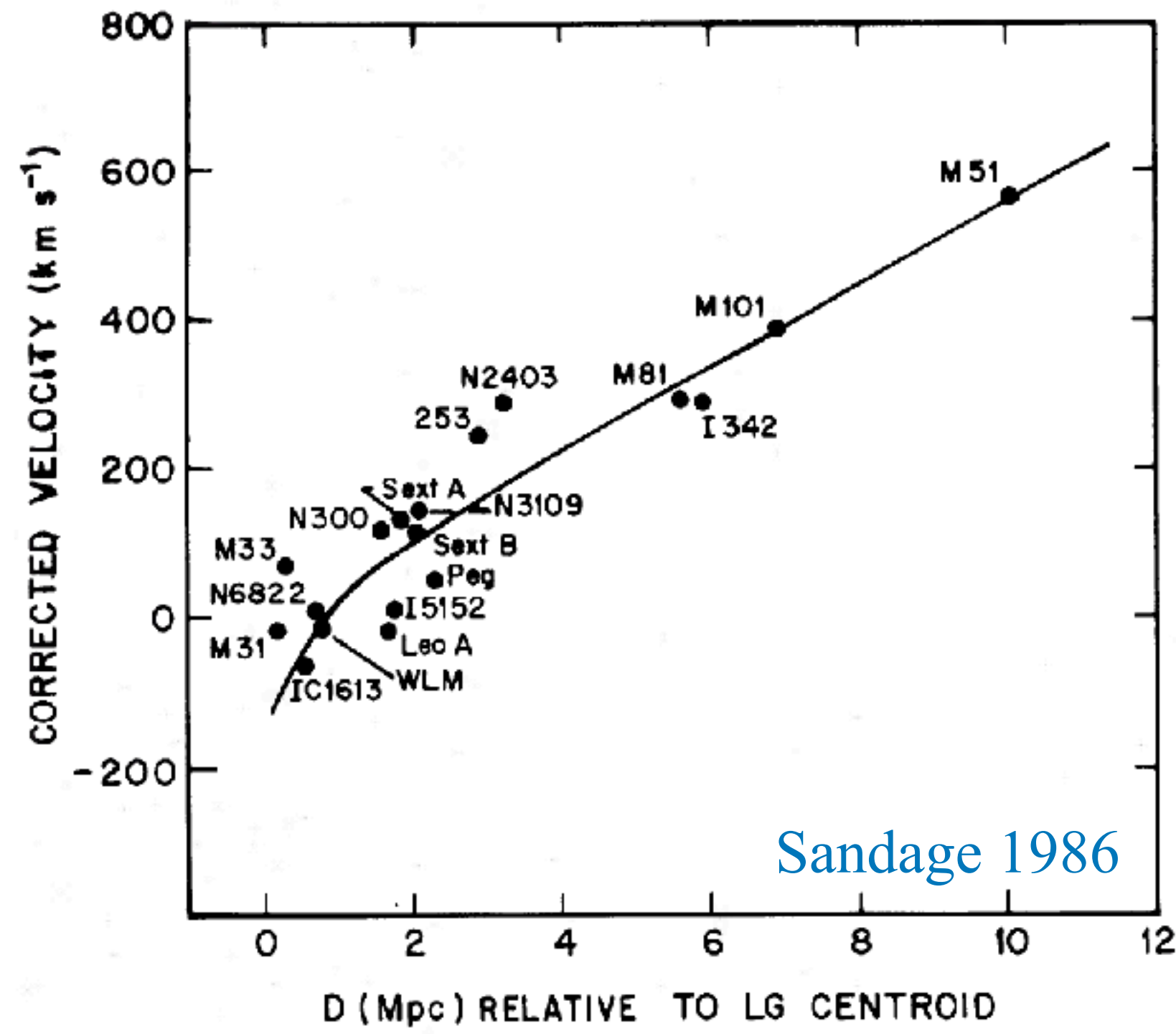
What about the mass of all the other galaxies?



Donald Lynden-Bell



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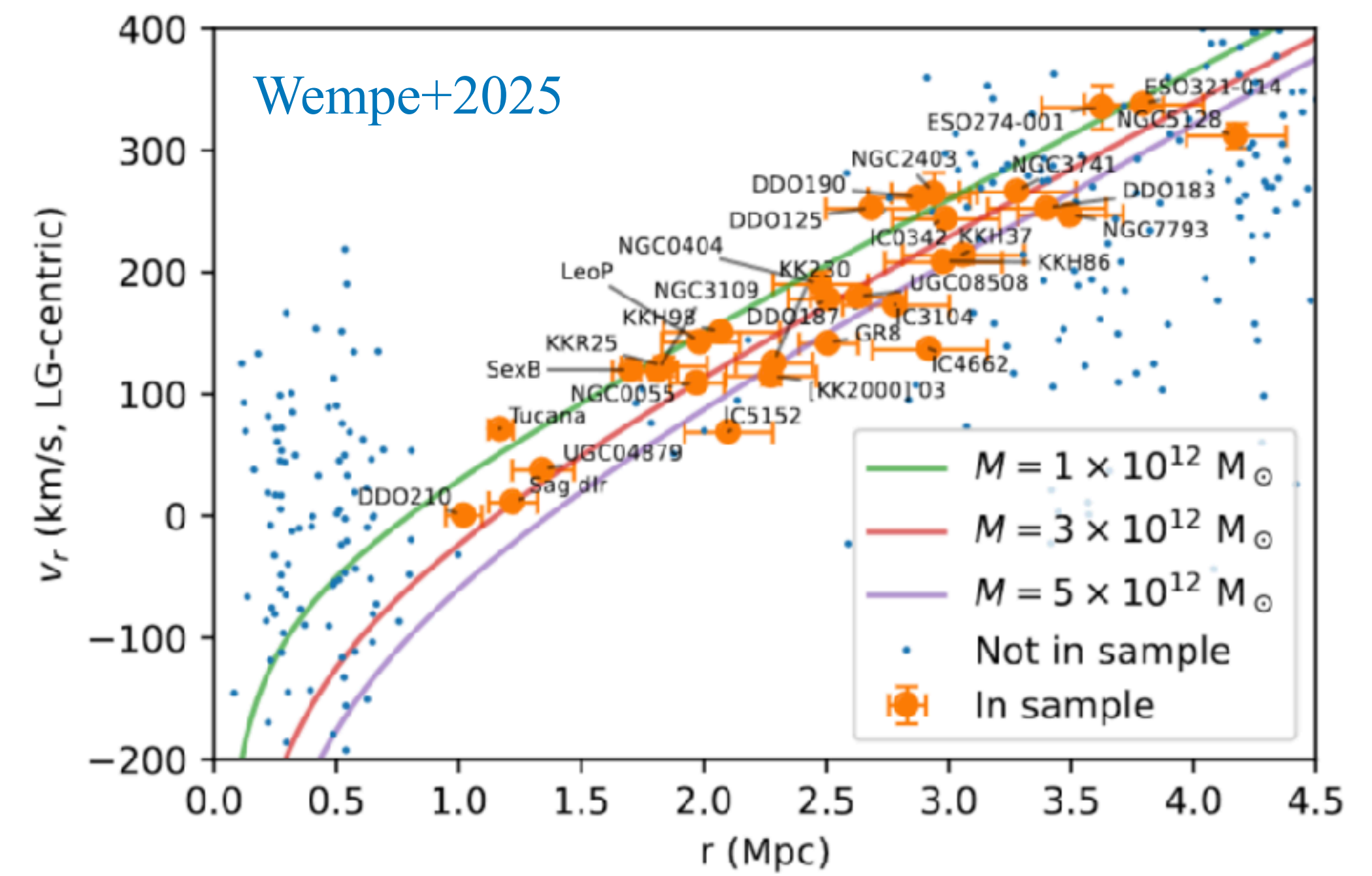
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What about the mass of all the other galaxies?

40 years later the problem is the same.
 From 3 to 12 million light-years all galaxies are receding:
 → total mass no bigger than the Milky Way+Andromeda

A PUZZLE

Why do we fail to see any mass beyond Andromeda?



Wempe+2025

The Cosmic Microwave Background



Penzias & Wilson 1964

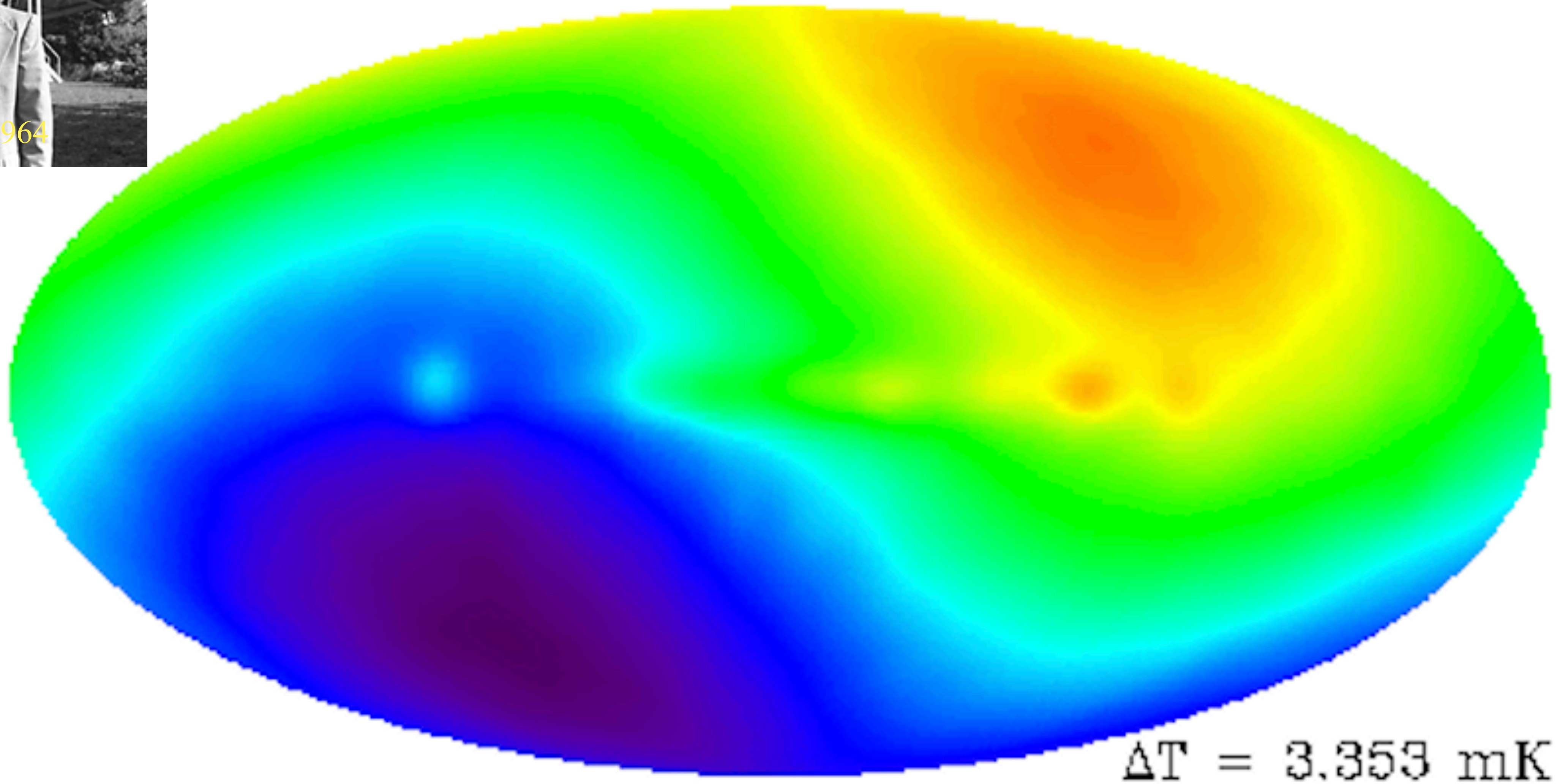


COBE 1992

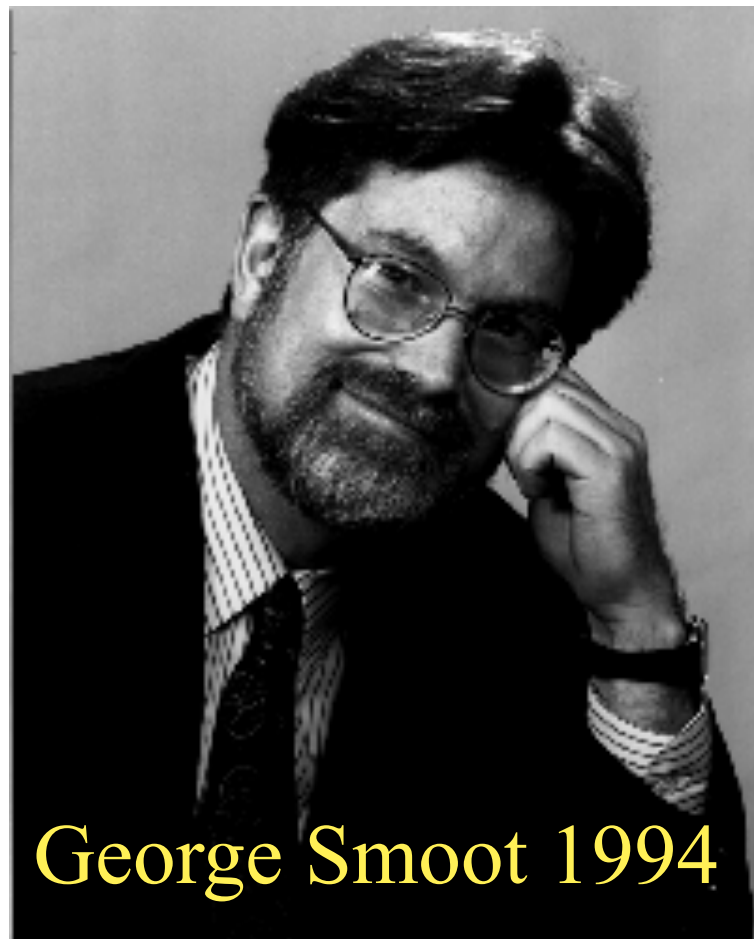
$$T = 2.728 \text{ K}$$

Left-over heat from the Hot Big Bang

The Cosmic Microwave Background

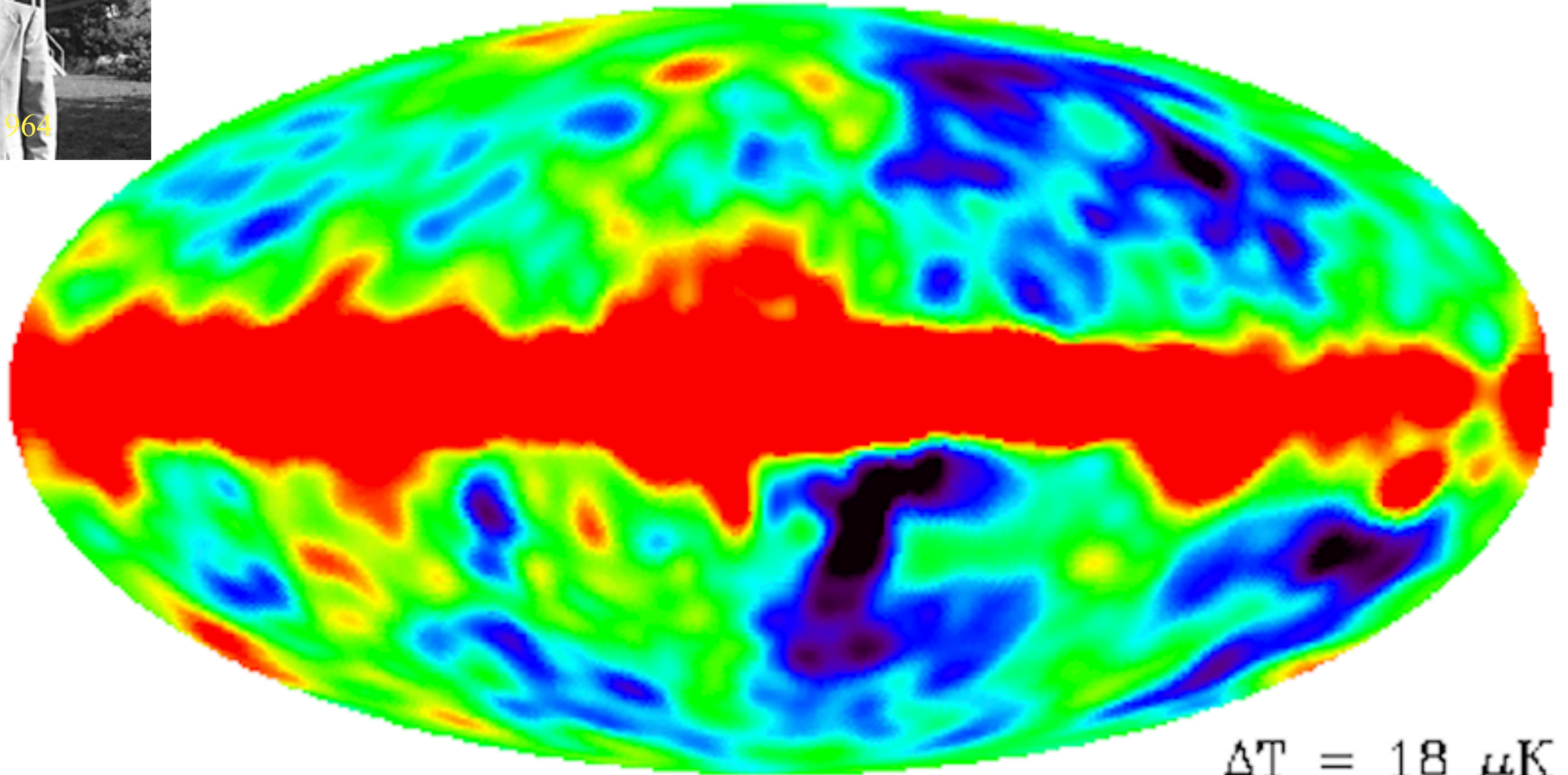


COBE 1992

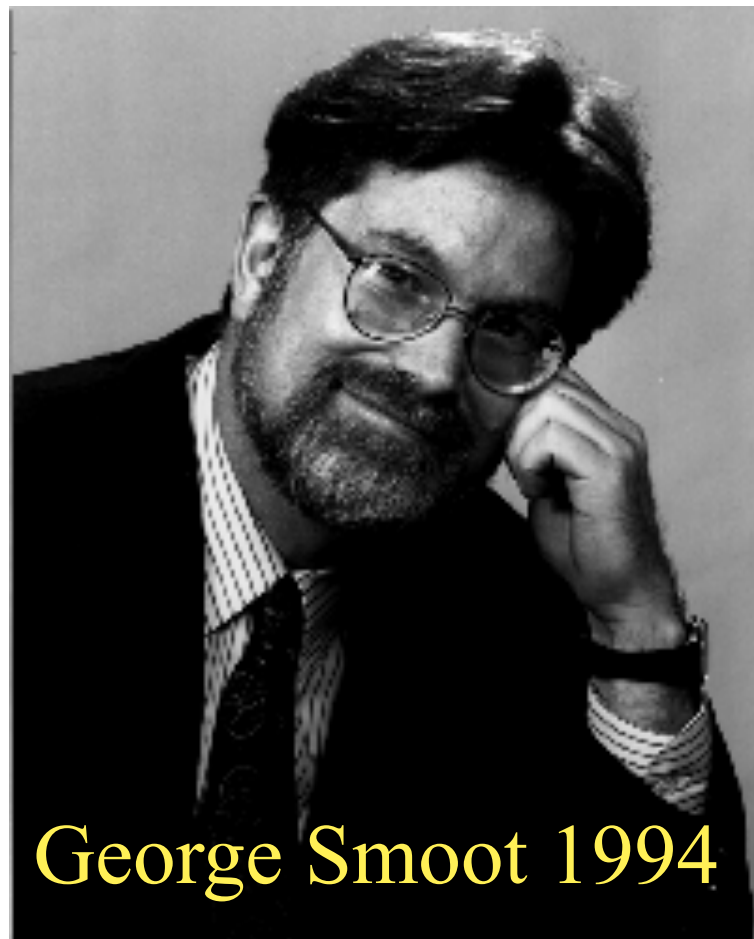


The Sun's motion through the Universe as a whole

The Cosmic Microwave Background

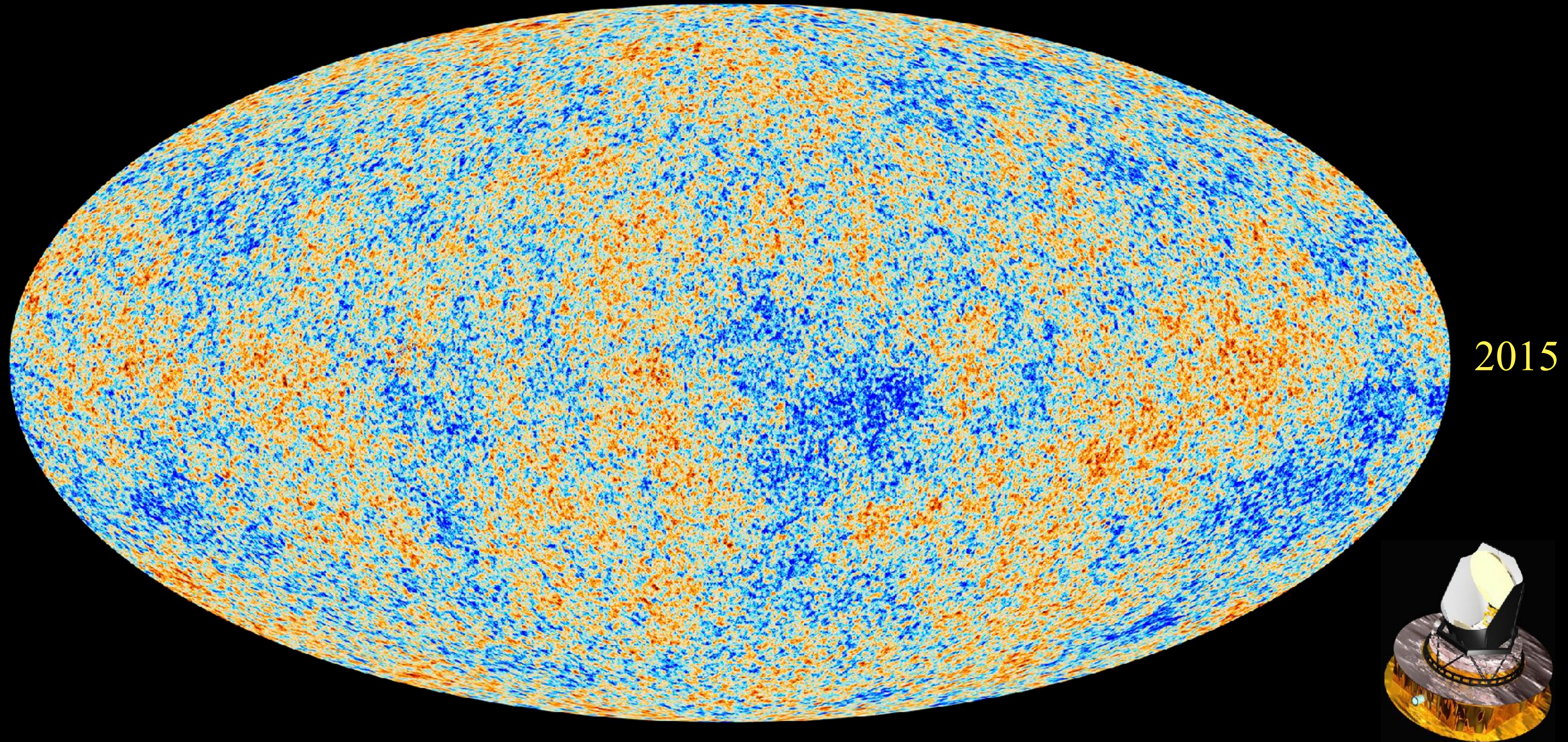


COBE 1992



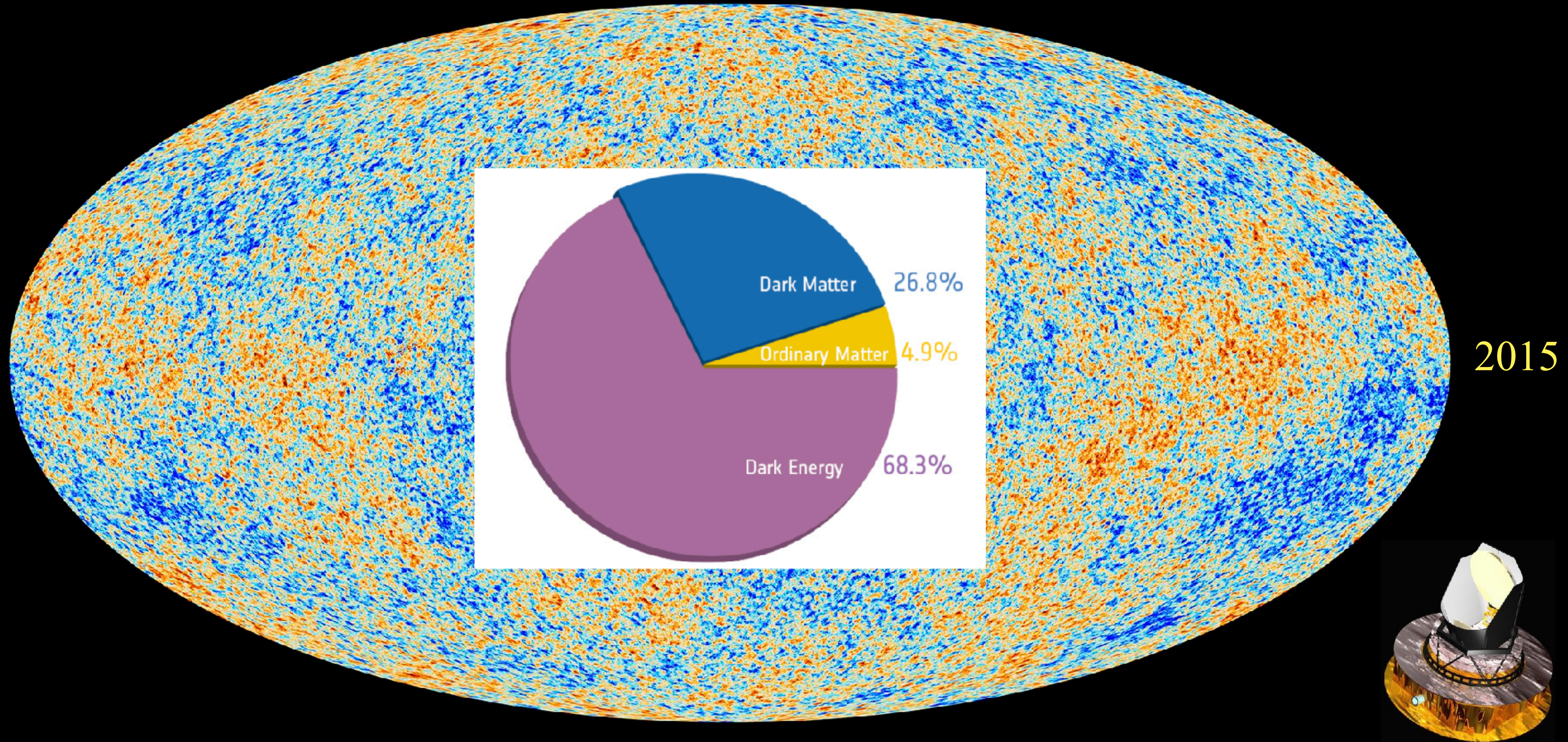
Milky Way emission and primordial structure

The Planck Map of the Cosmic Microwave Background



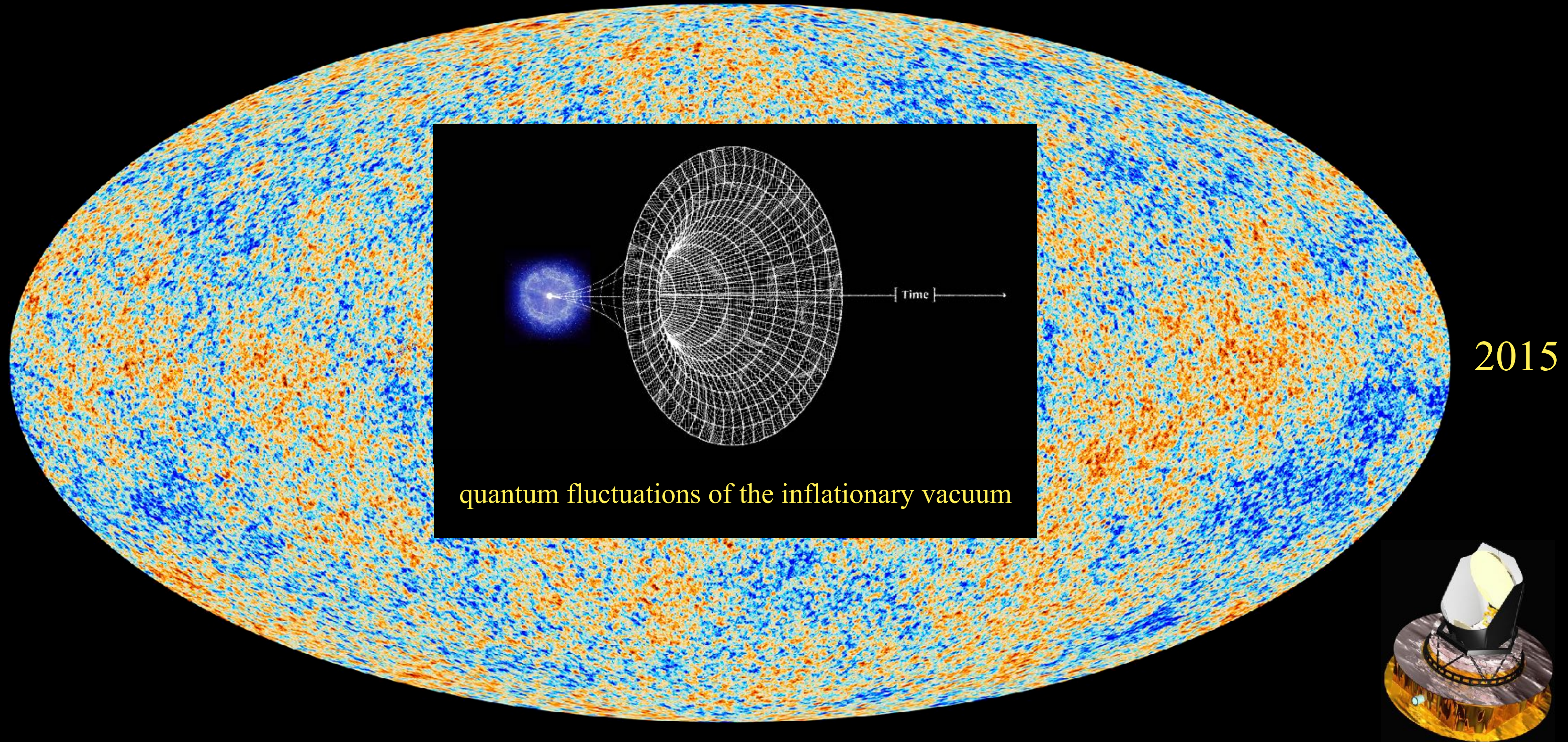
The Universe at age 380,000 years: the initial conditions for *all* structure formation

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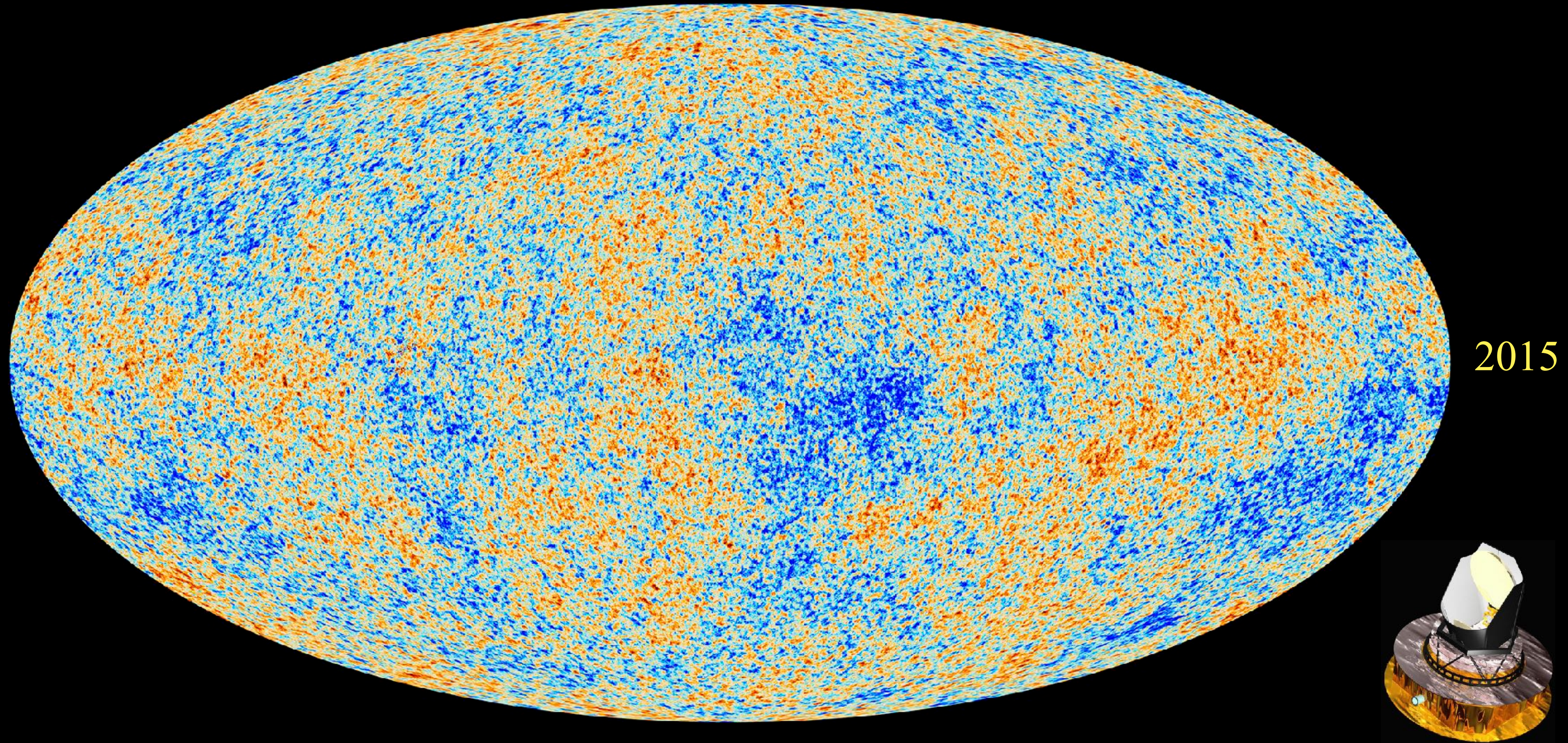
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The Universe at age 380,000 years: the initial conditions for *all* structure formation

a=0.016
z=63.000
t=0.033 Gyr

Supercomputer simulation of a Milky Way+Andromeda analogue

Initial time: 33 million years after Big Bang

Initial state: As in the Planck CMB map

Final time: Today

Final state: Match the position, velocity and mass of Milky Way+Andromeda *and* the nearby Hubble flow

The computer can solve the puzzle!

a=0.016
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Another
**Supercomputer simulation of a
Milky Way+Andromeda analogue**

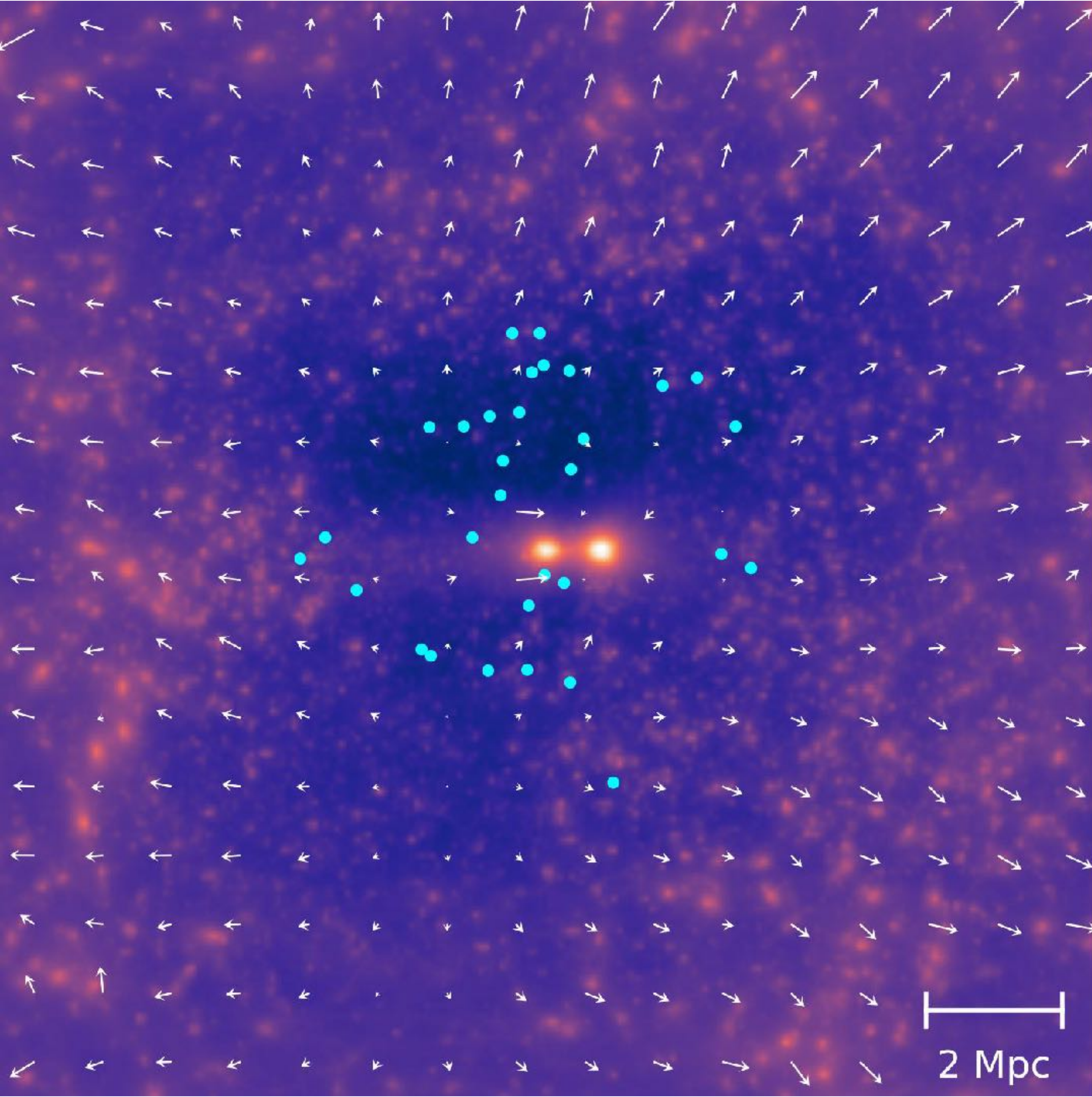
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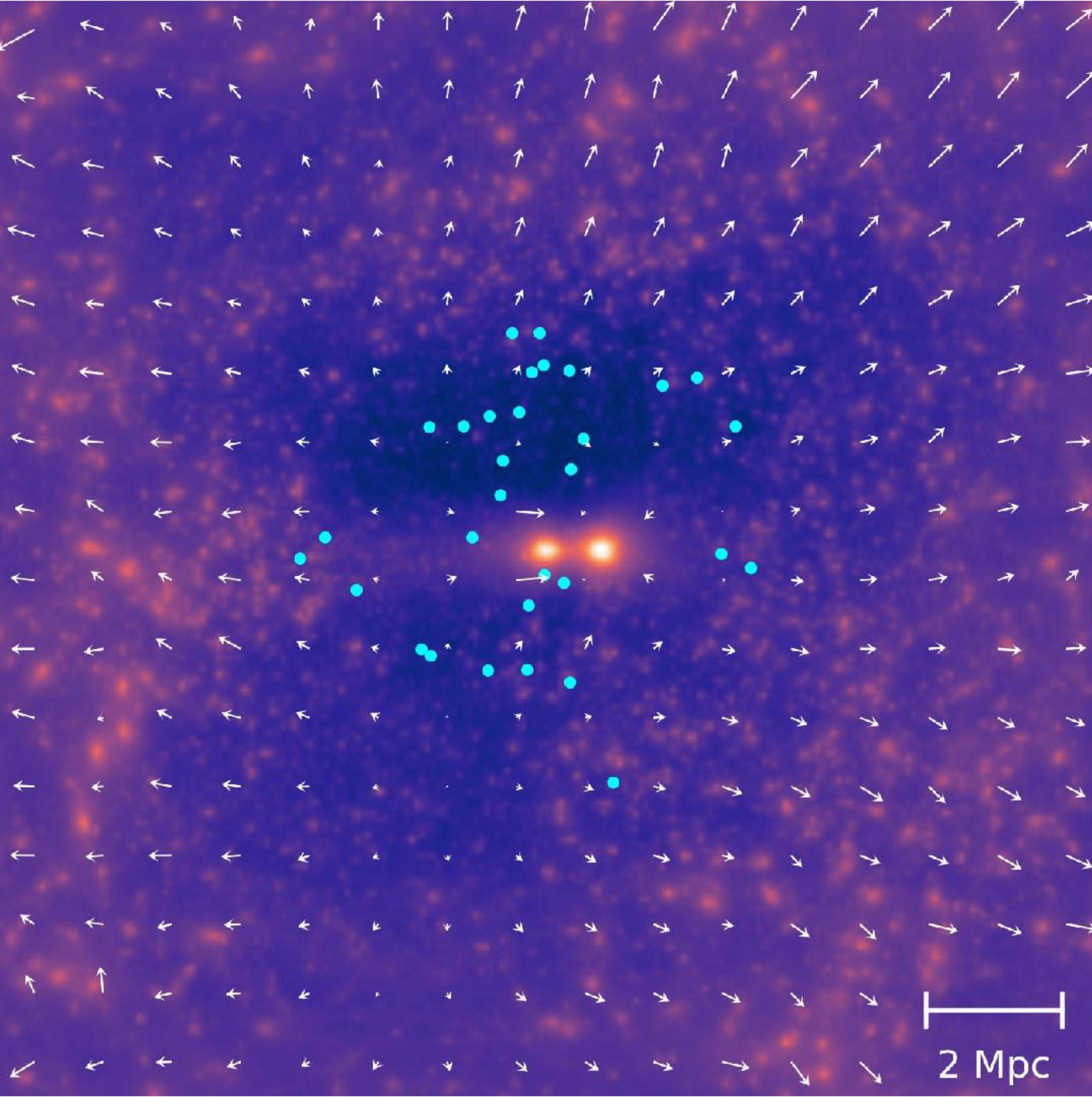
Average of 200 solutions of the Puzzle

The masses of the Milky Way and Andromeda are correct

The mass within 4 Mpc is 6 x (Milky Way+ Andromeda)

Nevertheless

the Hubble flow is unaffected at nearby galaxy positions!



Average of 200 solutions of the Puzzle

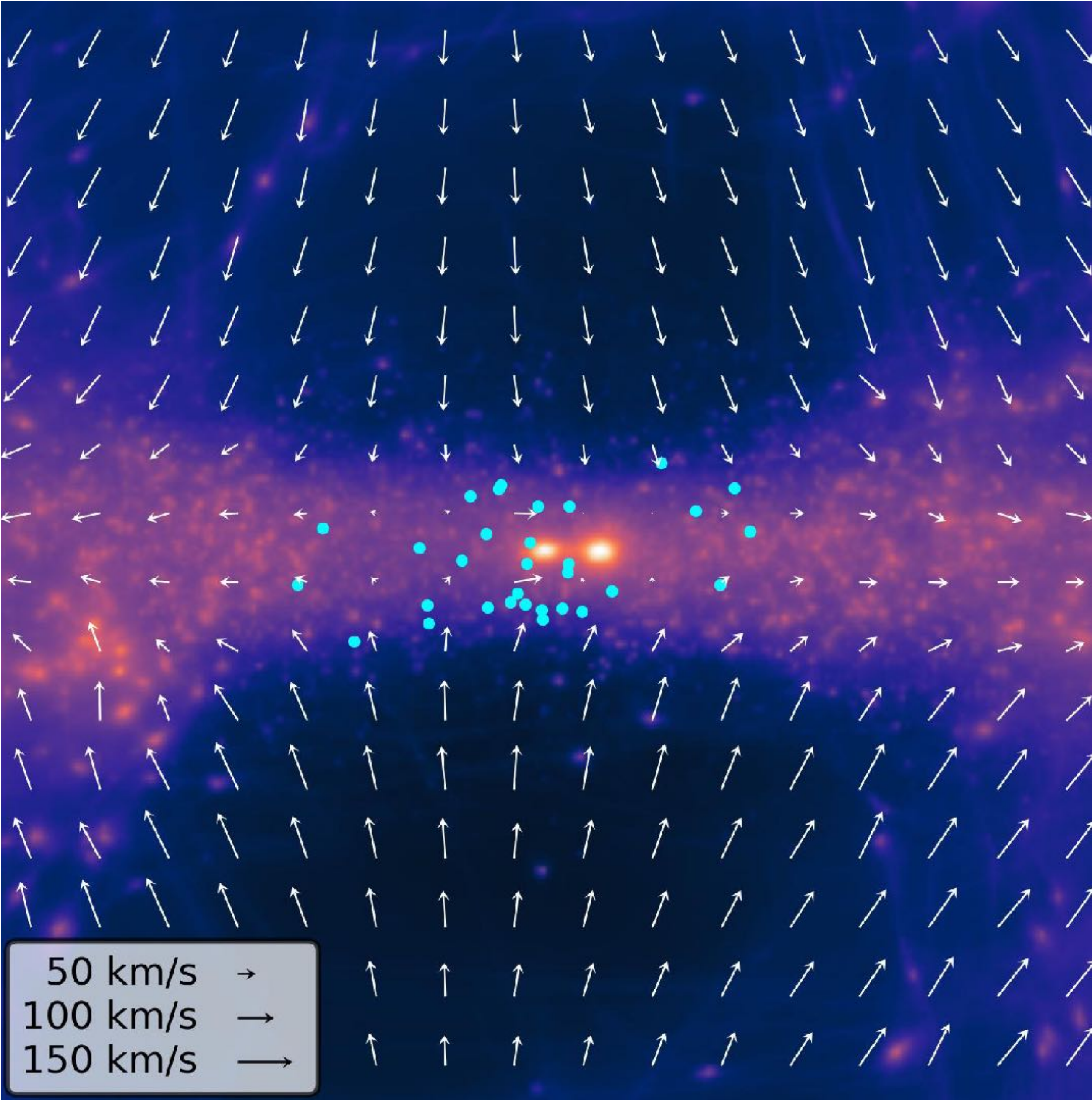
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How has the computer solved the problem?



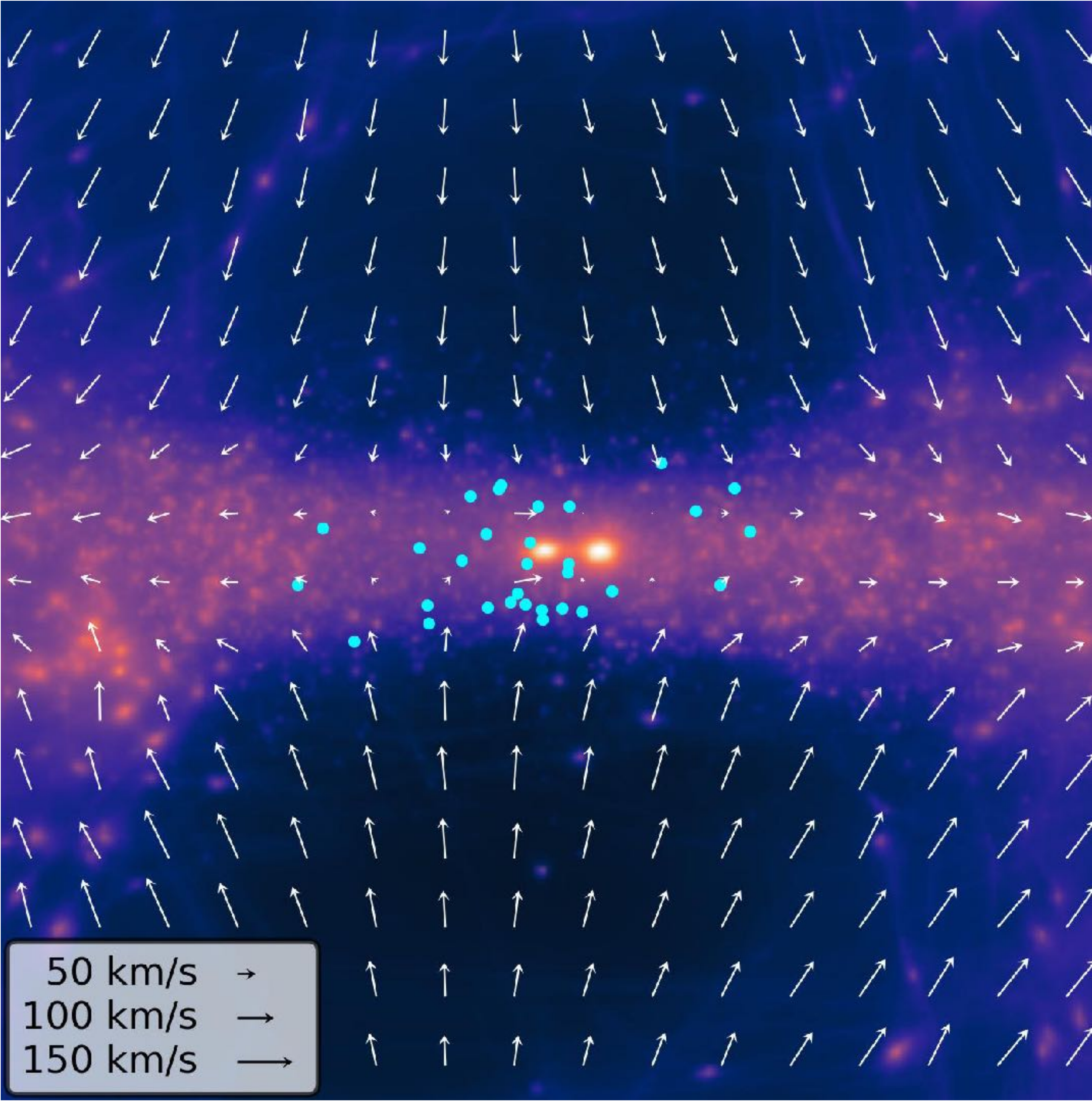
Average of 200 solutions of the Puzzle

Mass is strongly concentrated into a Local Sheet

Mass at larger distances is pulling nearby galaxies away and so compensates the inward pull of MW+Andromeda

The Hubble flow is still almost unperturbed at the positions of nearby galaxies

Strong inflow onto the Local Sheet is predicted, but there are no galaxies to observe in these regions



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The world beyond Andromeda is flat!!