

Discovering the Accelerating Universe

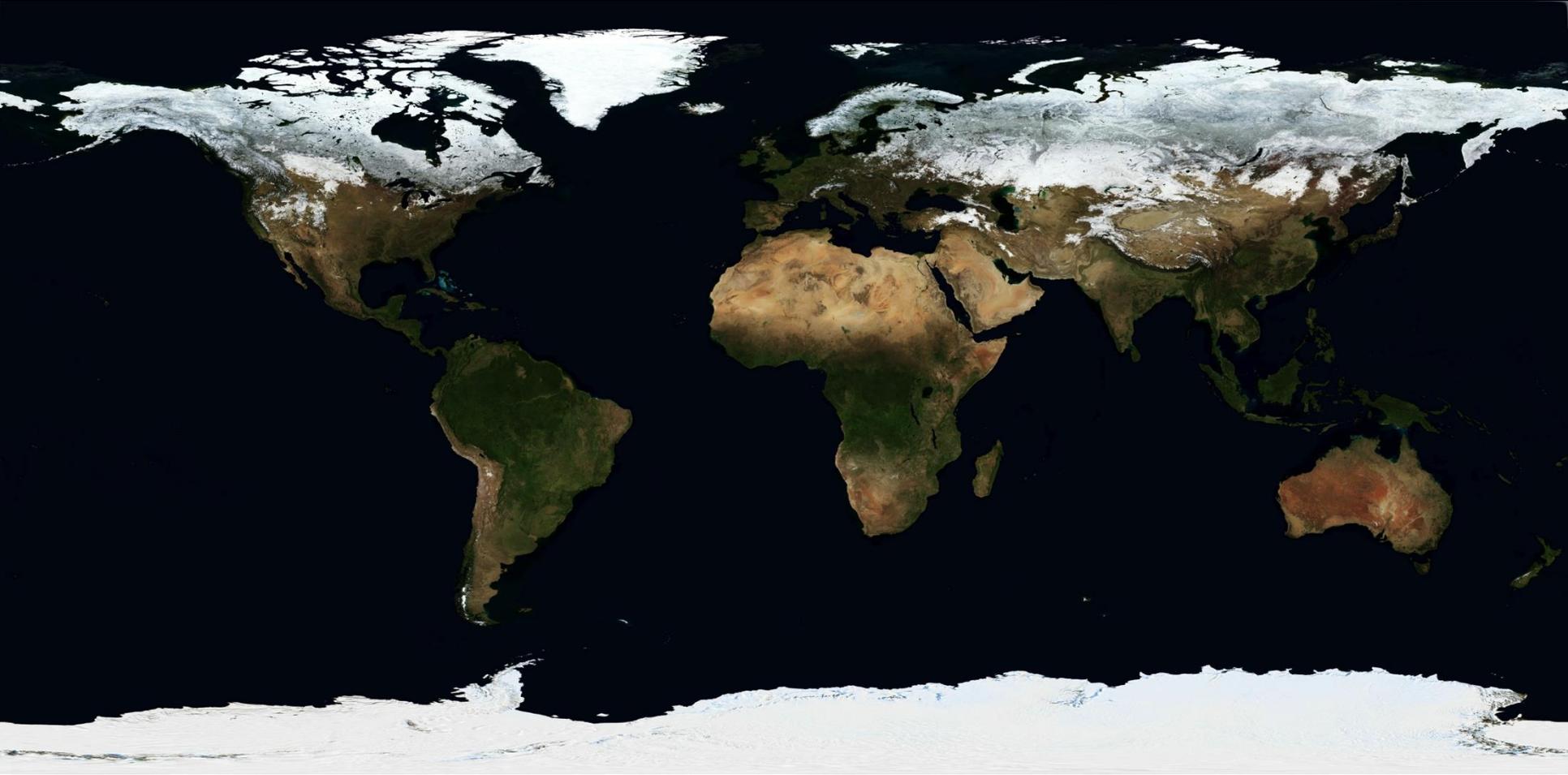


Bruno Leibundgut
European Southern Observatory (ESO)

How do we see our world?



A changing world



The Earth at night

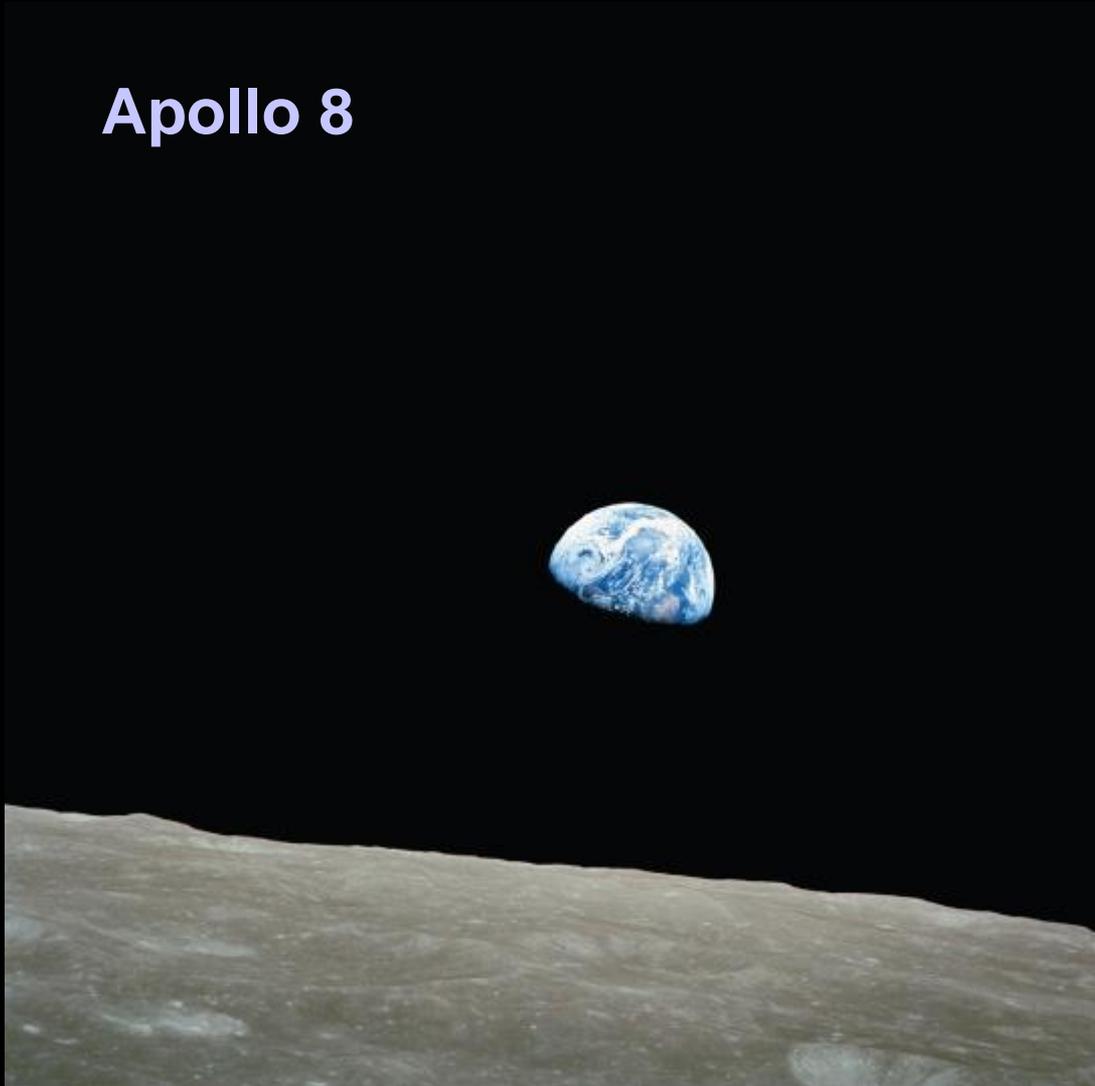


Our place in the universe



Our Home

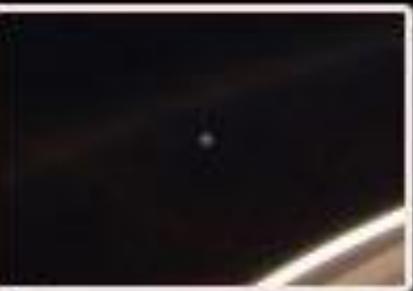
Apollo 8



Our Home

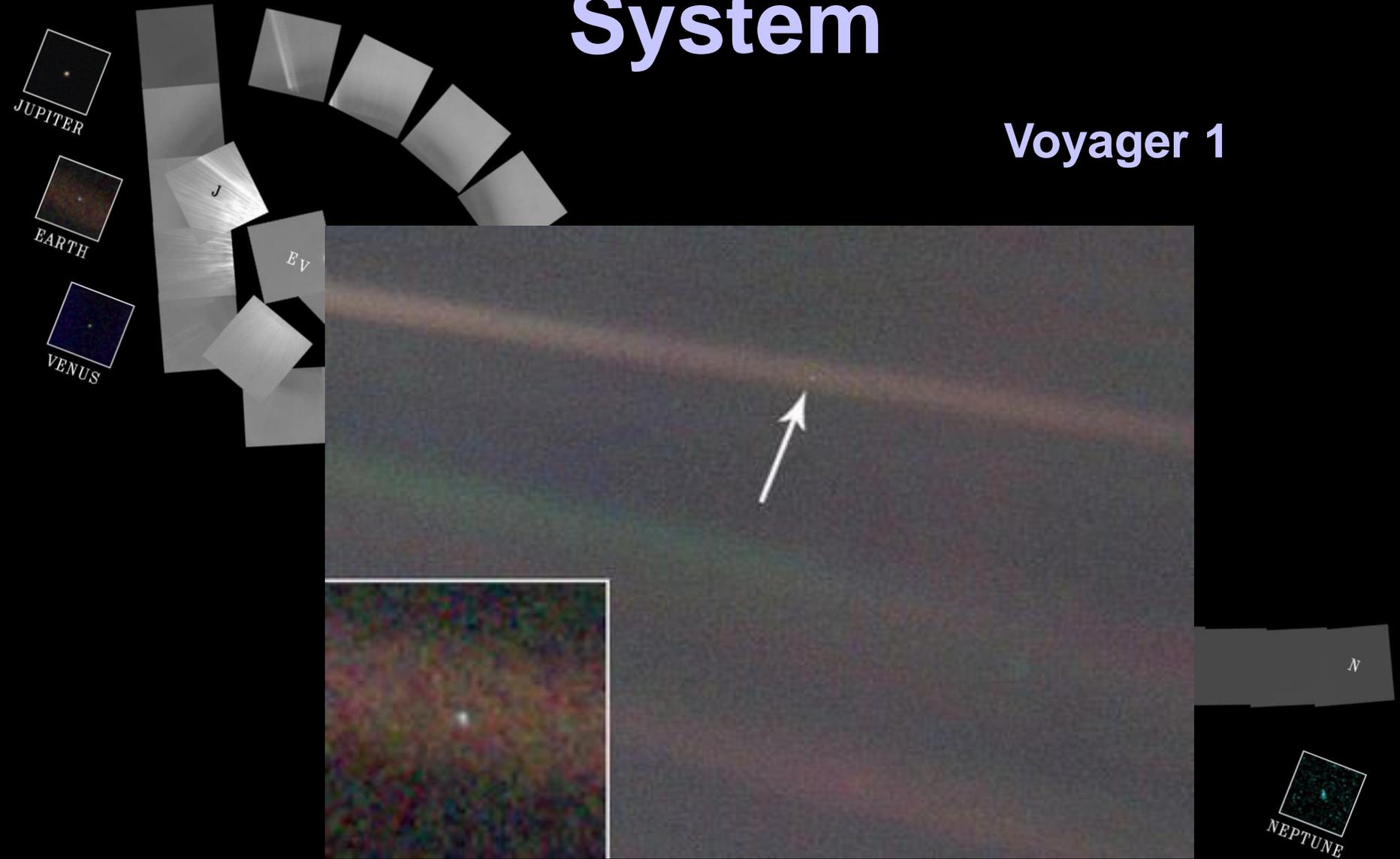


MESSENGER (© NASA)

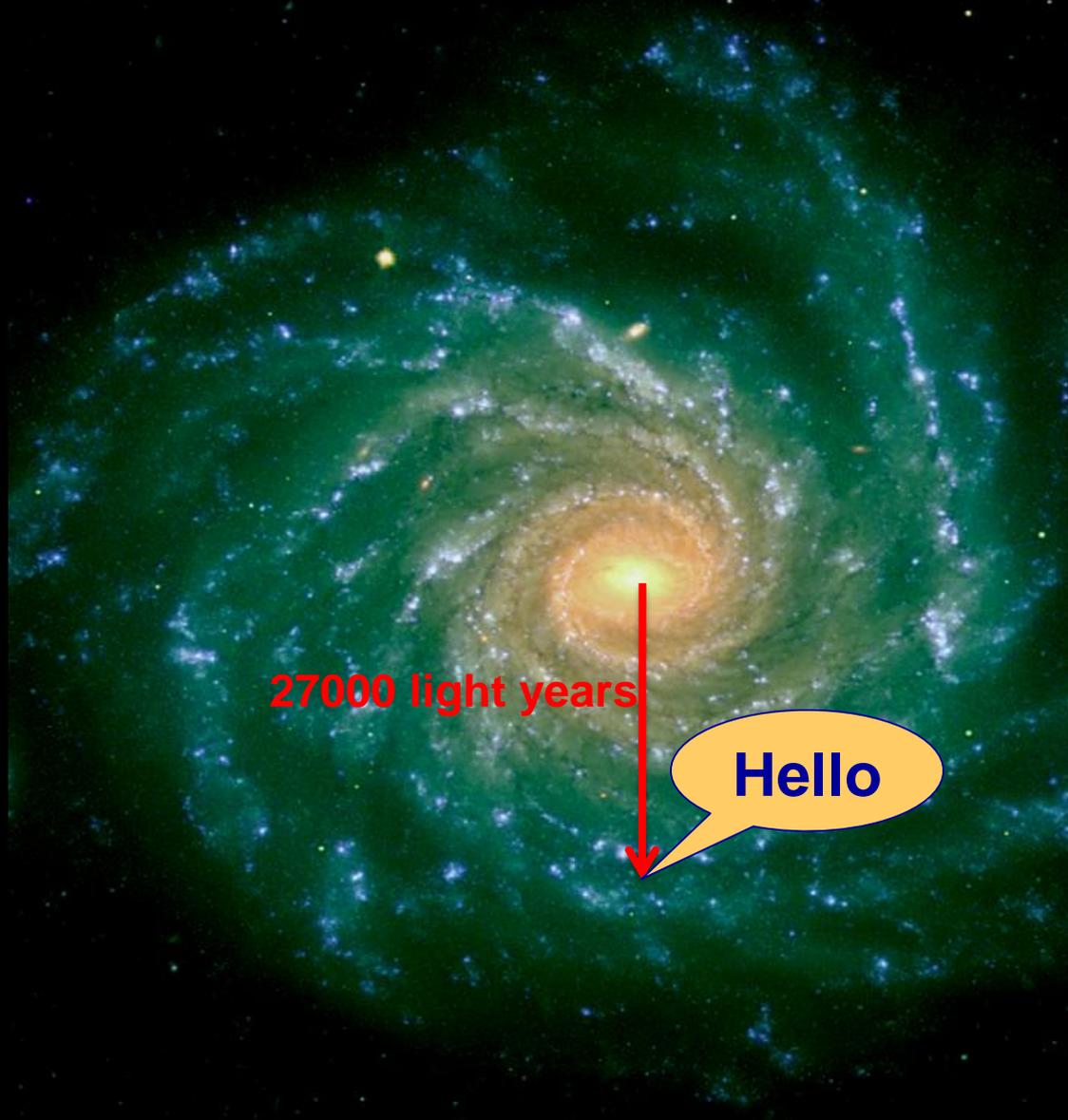


Family Portrait of the Solar System

Voyager 1



Our place in the Milky Way



27000 light years

Hello

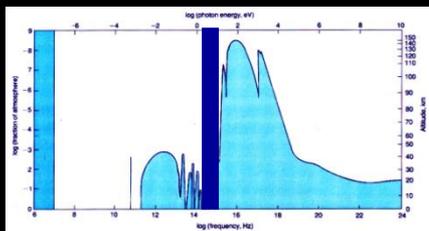
Place three grains of sand inside a vast cathedral, and the cathedral will be more closely packed with sand than space is with stars.

James Jeans
quoted in
Big Bang by Simon Singh (2004)

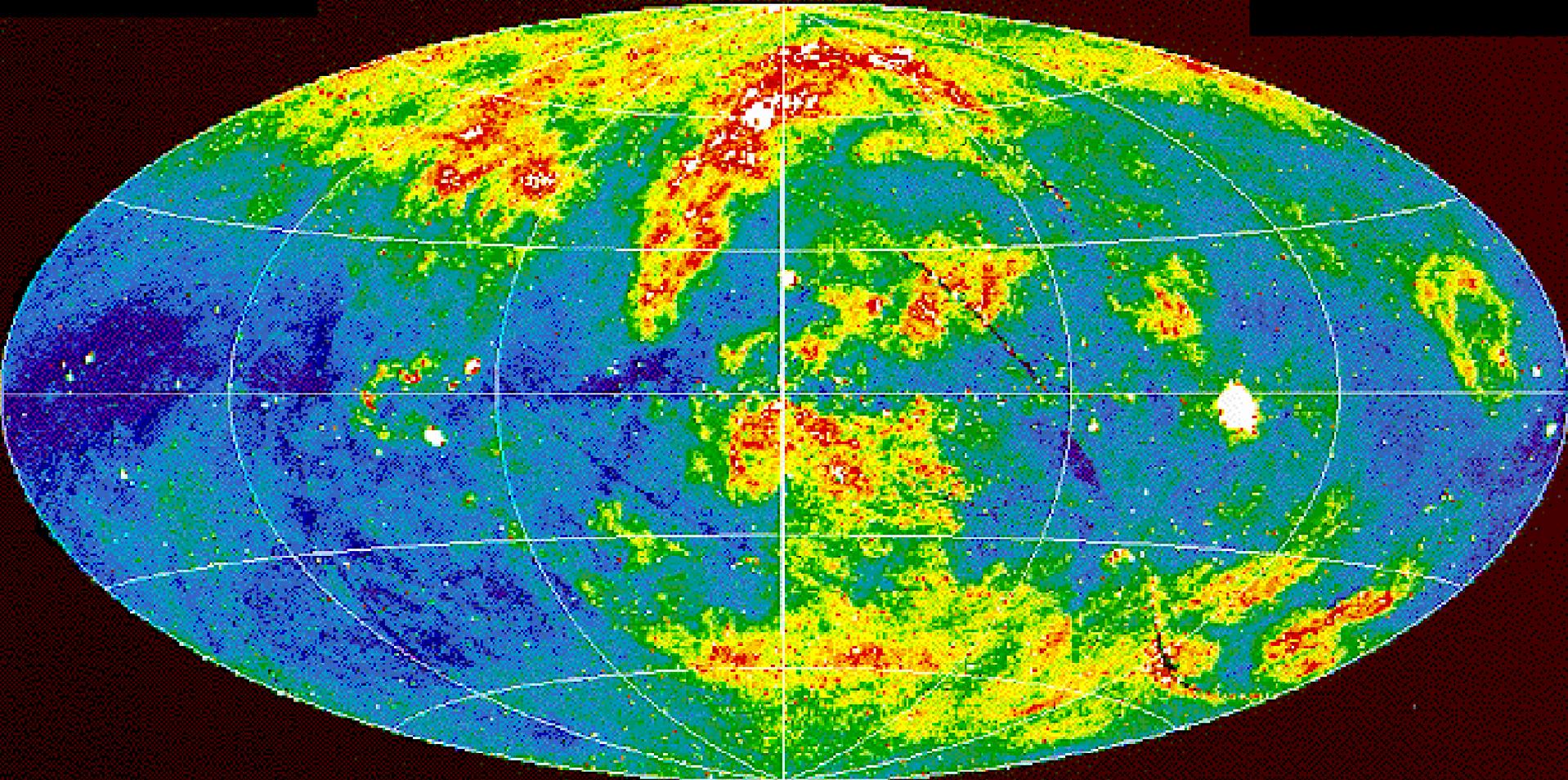
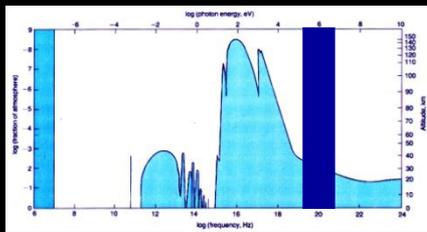
Earth's atmosphere Shield and Window to the Universe



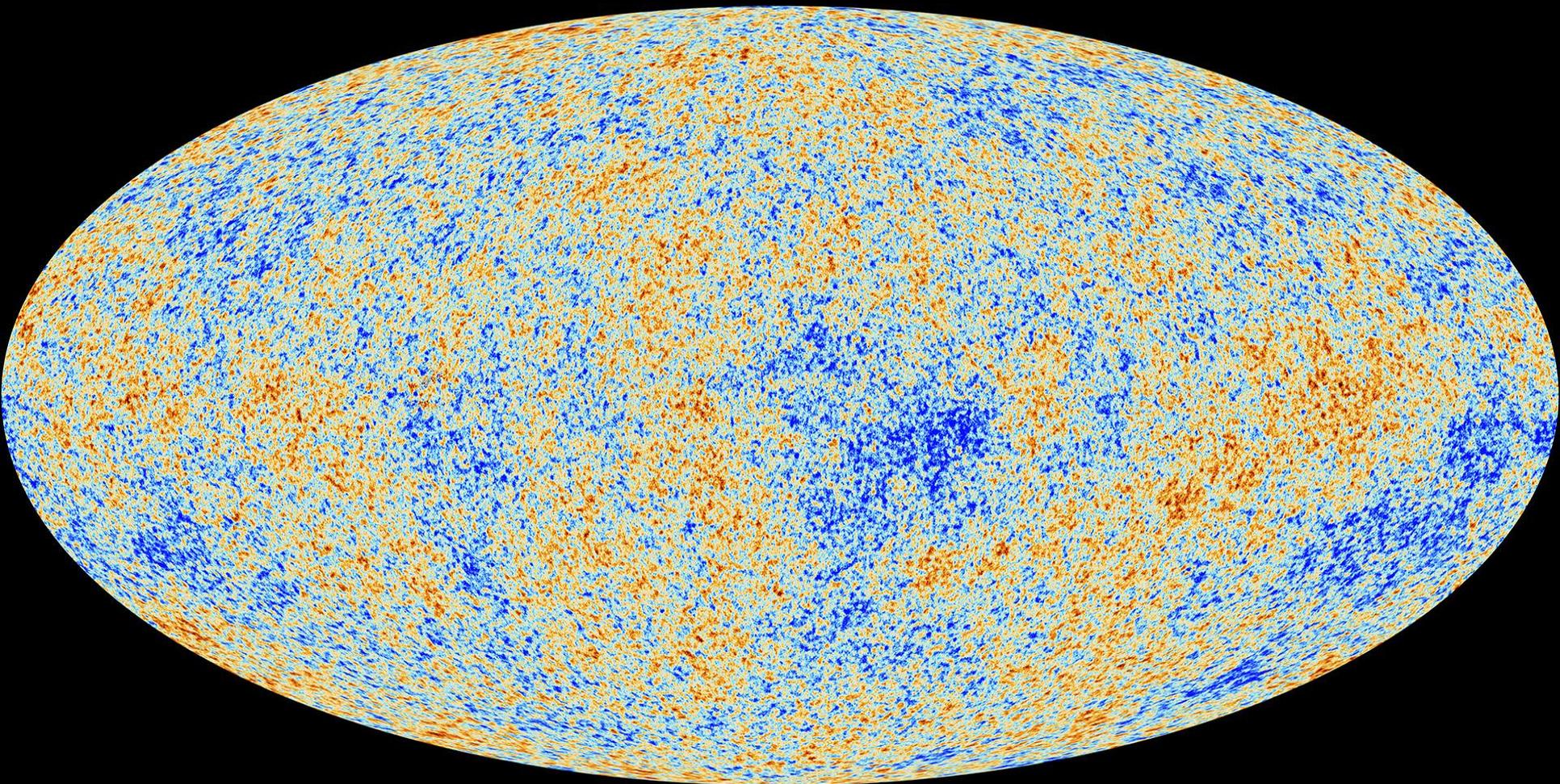
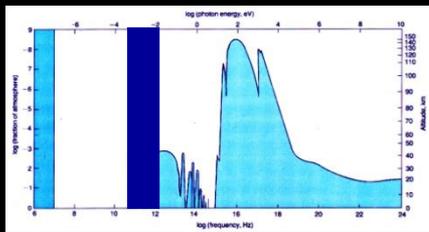
„visible“



„invisible“



„invisible“





The dark side of the universe

What is the universe made of?

How do we understand the universe?

What are Dark Matter and Dark Energy?

The „invisible” Universe

- Large parts of the Universe are dark
- „Dark“ (non-luminous matter) is everywhere
 - e.g. planets, molecules, dust, cool gas
- Measurements through indirect methods
 - ➡ Gravitation!
 - ➡ Model for the evolution of the Universe
 - ➡ Einstein’s Theory of Relativity

Basics of Cosmology

(our world view)

Theory of Gravity

Einstein's Theory of General Relativity

Isotropy

There are no preferred directions in the Universe

Homogeneity

**No special region in the Universe
(e.g. no centre)**

Anthropic Principle

The Universe created us

Gravitation!

Of the four fundamental forces (Gravitation, Electromagnetism, Weak and Strong Forces) **only gravitation determines the evolution of the universe.**





WALL TO WALL
ALL BENEFIT
FOR WORLD
CUP
LHO MAM 2003

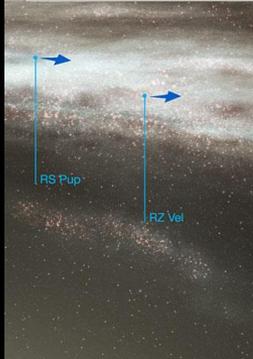
$R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R = -\frac{8\pi G}{c^4} T_{\mu\nu}$
A. EINSTEIN

AMSTERDAM
VOLK

E. RAY S. ALBA

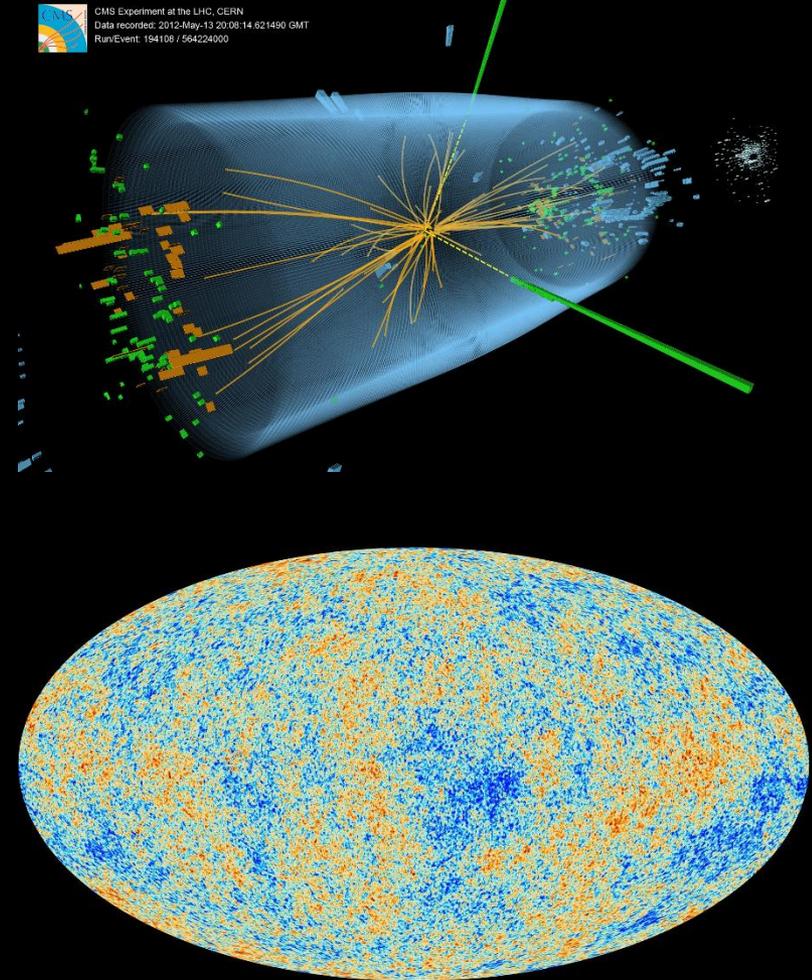
What is in the Universe?

- We are!

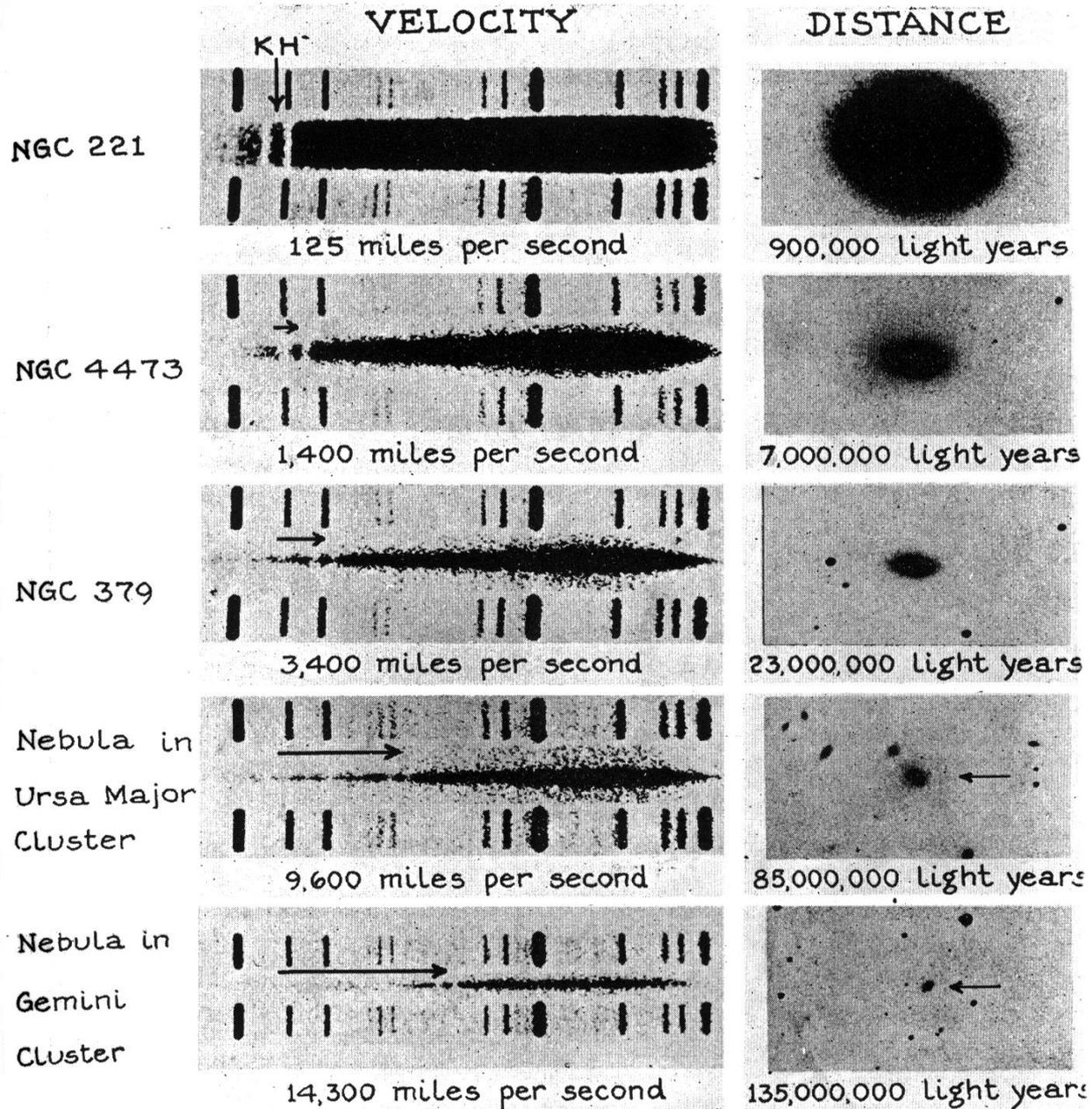


What is in the Universe?

- What else?
 - Elementary particles
 - Neutrinos
 - Higgs particle
 - yet unknown particles
 - Other forms of energy
 - radiation
 - ?????



THE VELOCITY-DISTANCE RELATION FOR EXTRA-GALACTIC NEBULAE



Hubble

The original Hubble diagram

Velocity

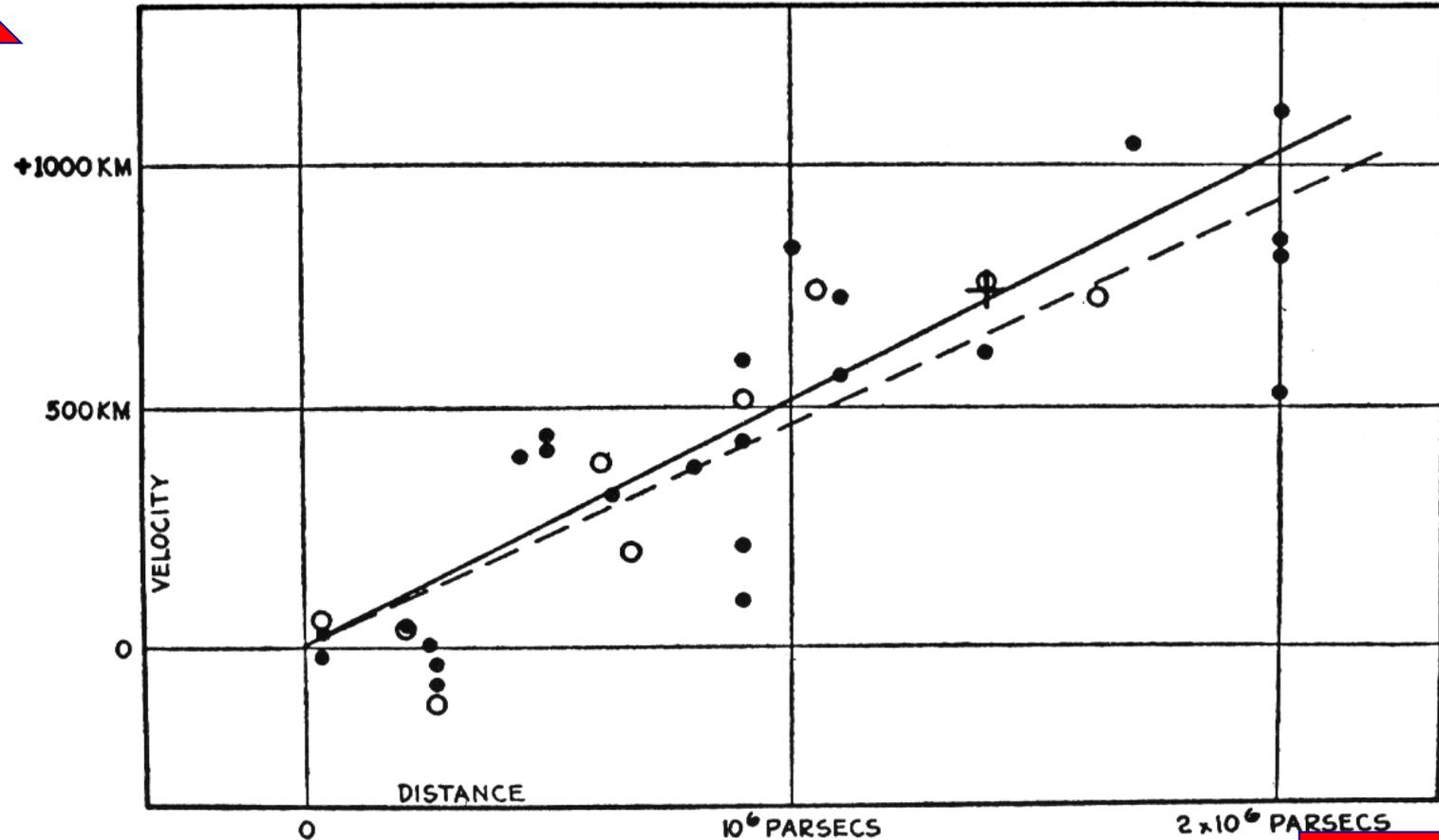
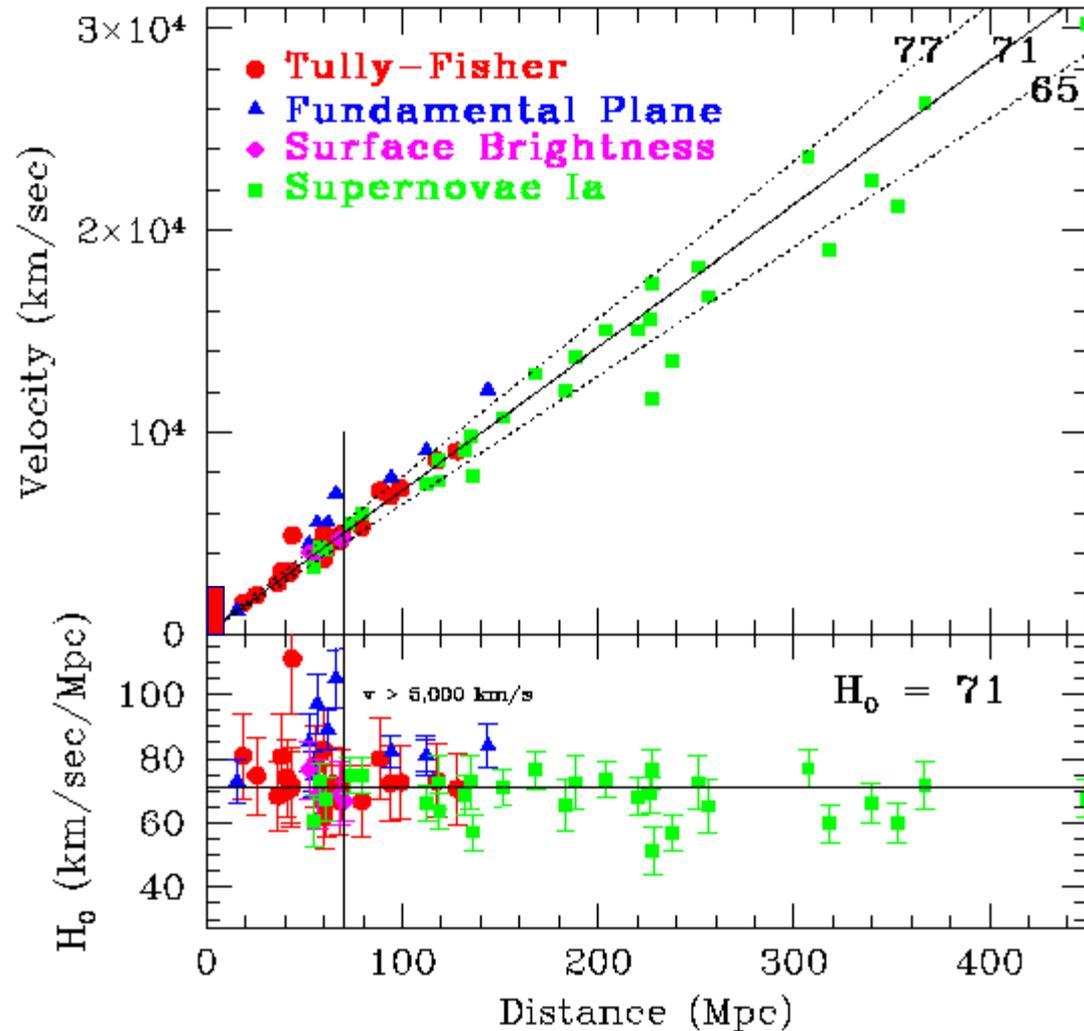


FIG. 9. *The Formulation of the Velocity-Distance Relation.*

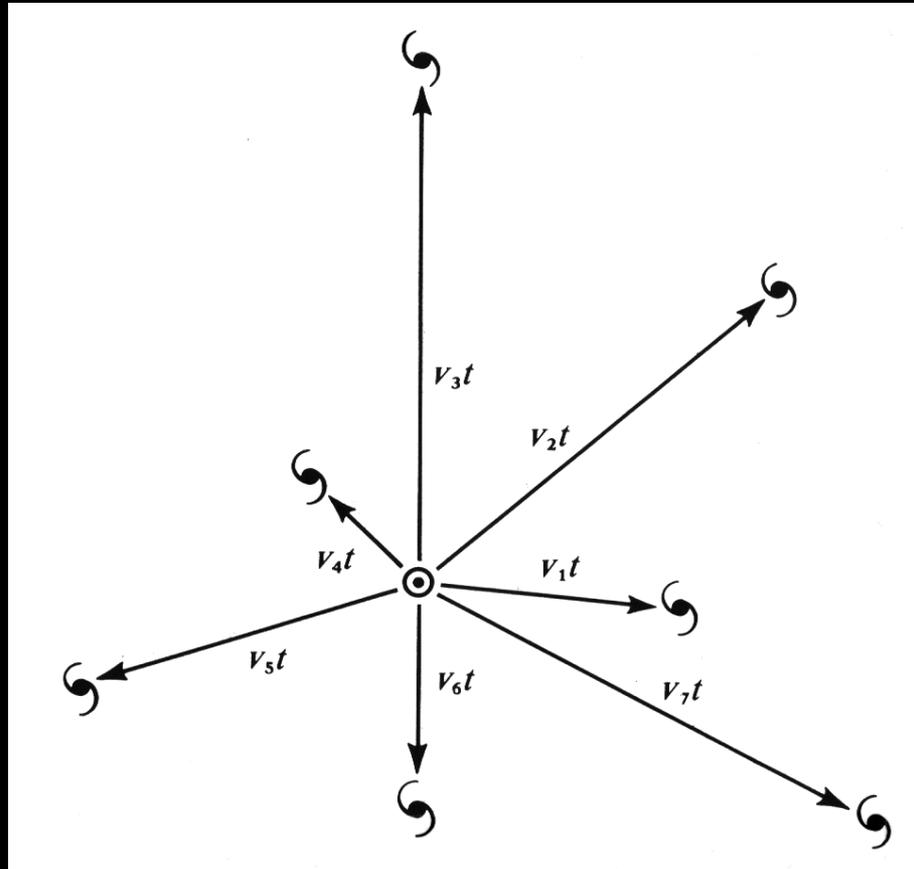
Distance

A modern Hubble diagram

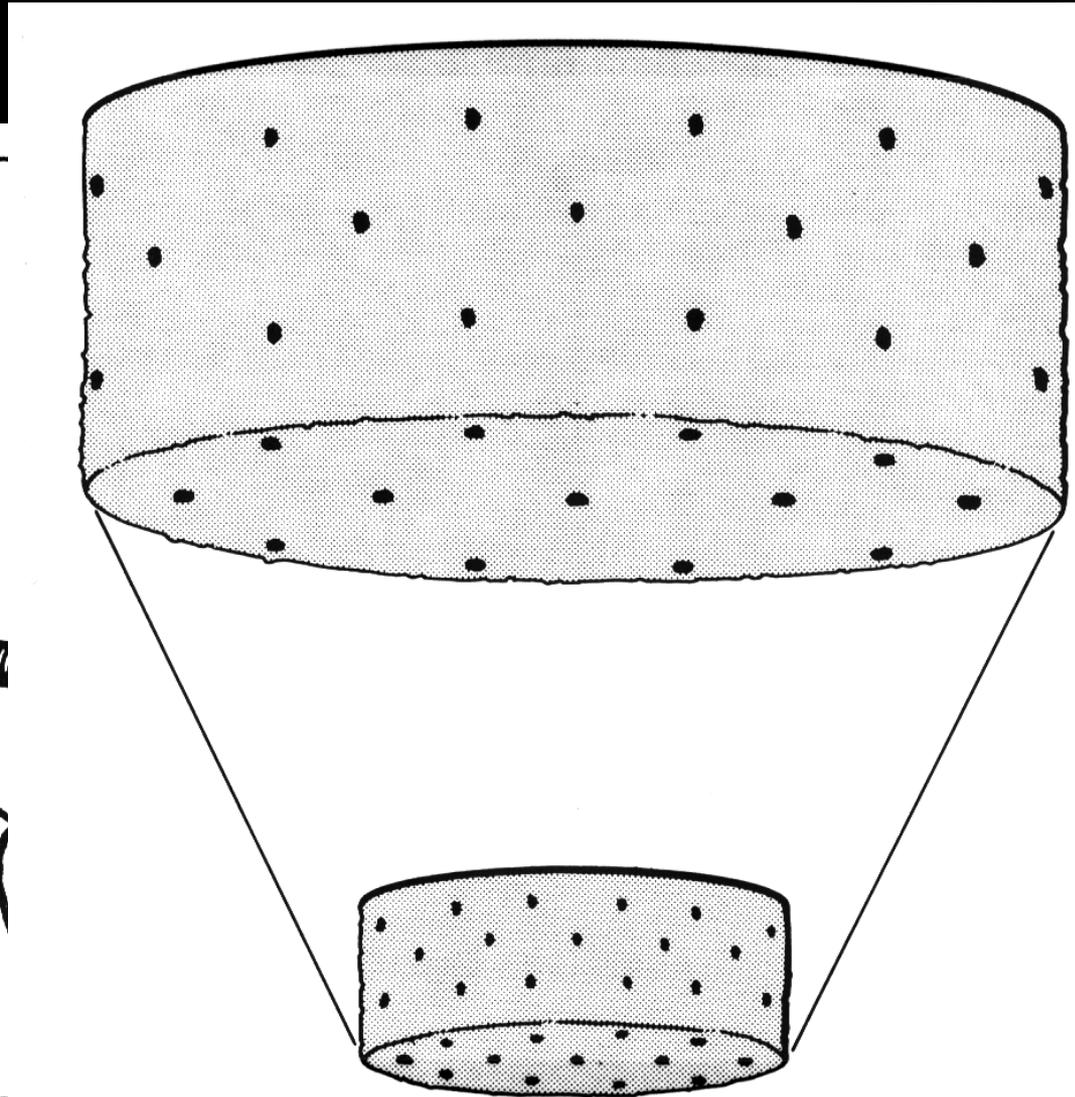
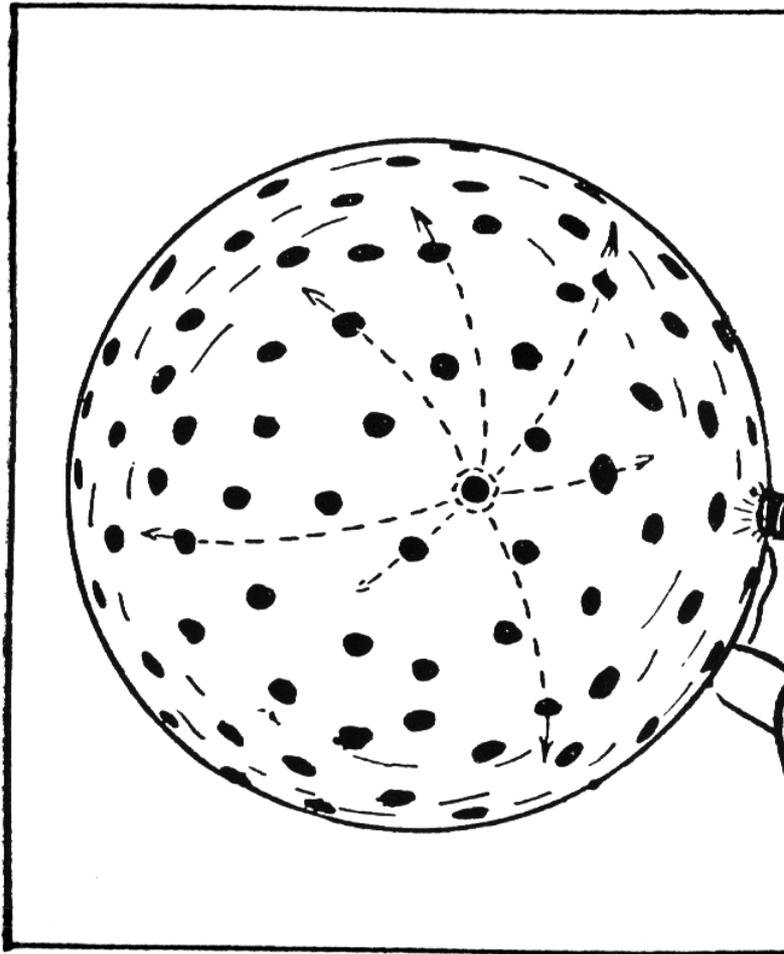


The age of the Universe

All galaxies start at the same point, which leads to the following picture



**The expansion is the same
for everybody (Isotropy)**



Supernova!



The Supernova of 1054



Cosmology with Supernovae

It is very difficult to measure distances in the universe. Supernovae are an essential tool to determine the expansion rate and its history.

Type Ia Supernovae are excellent distance indicators

Distance measurement with a constant light source

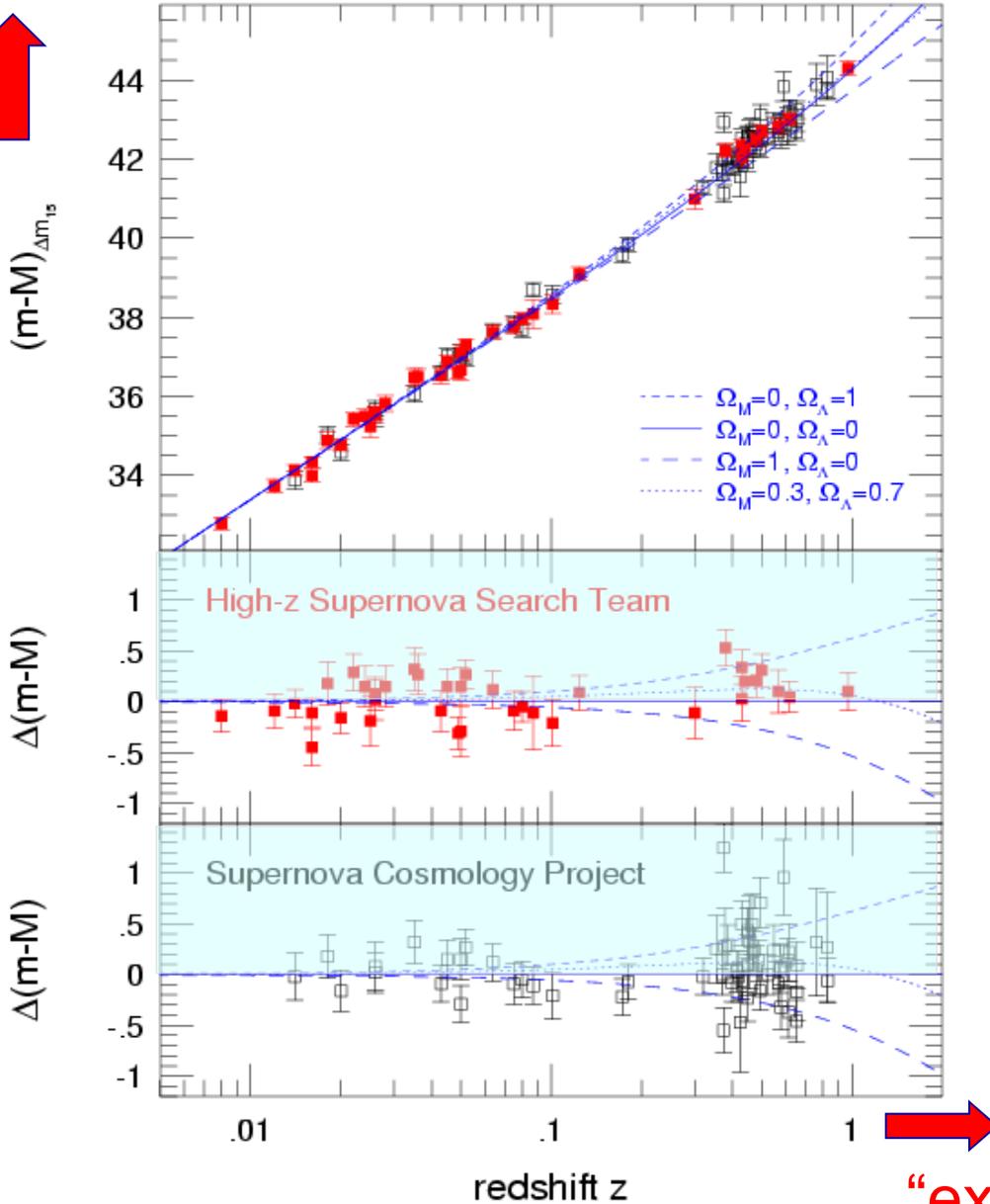


1000w

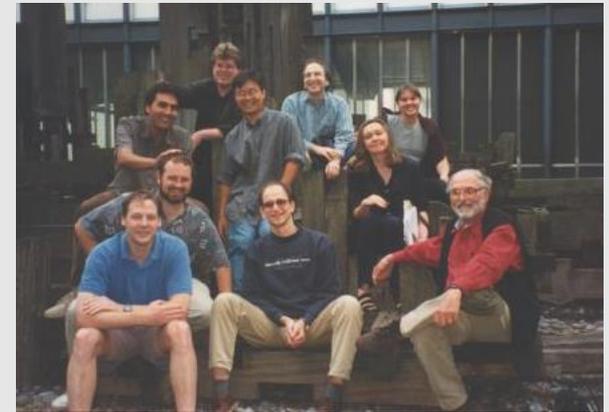


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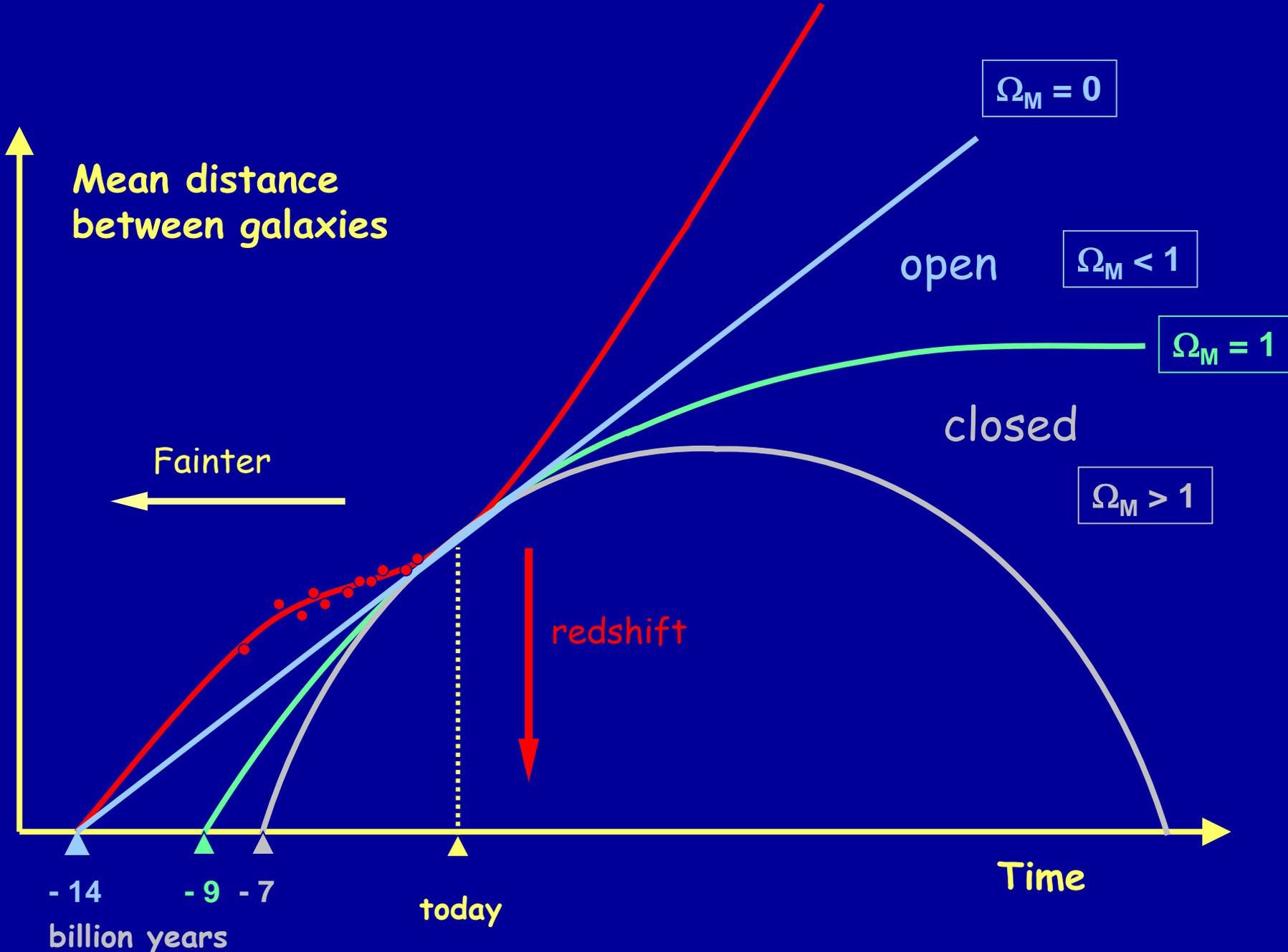
distance



The SN Hubble Diagram



“expansion”



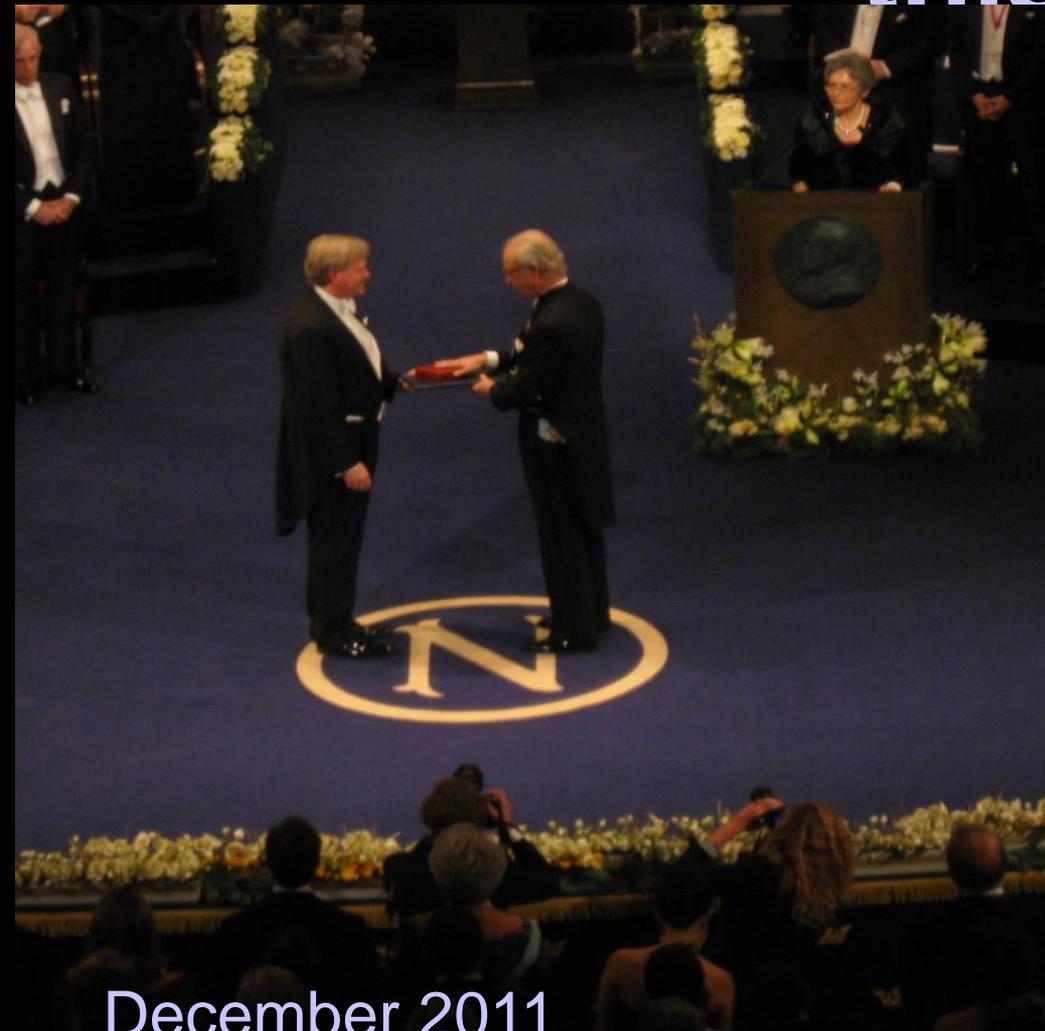
Physics Nobelprize 2011



Saul Perlmutter Brian Schmidt Adam Riess

"for the discovery of the accelerating expansion of the Universe through observations of distant supernovae"

You need to dress up for this



December 2011

The High-z Supernova Search Team

December 2011



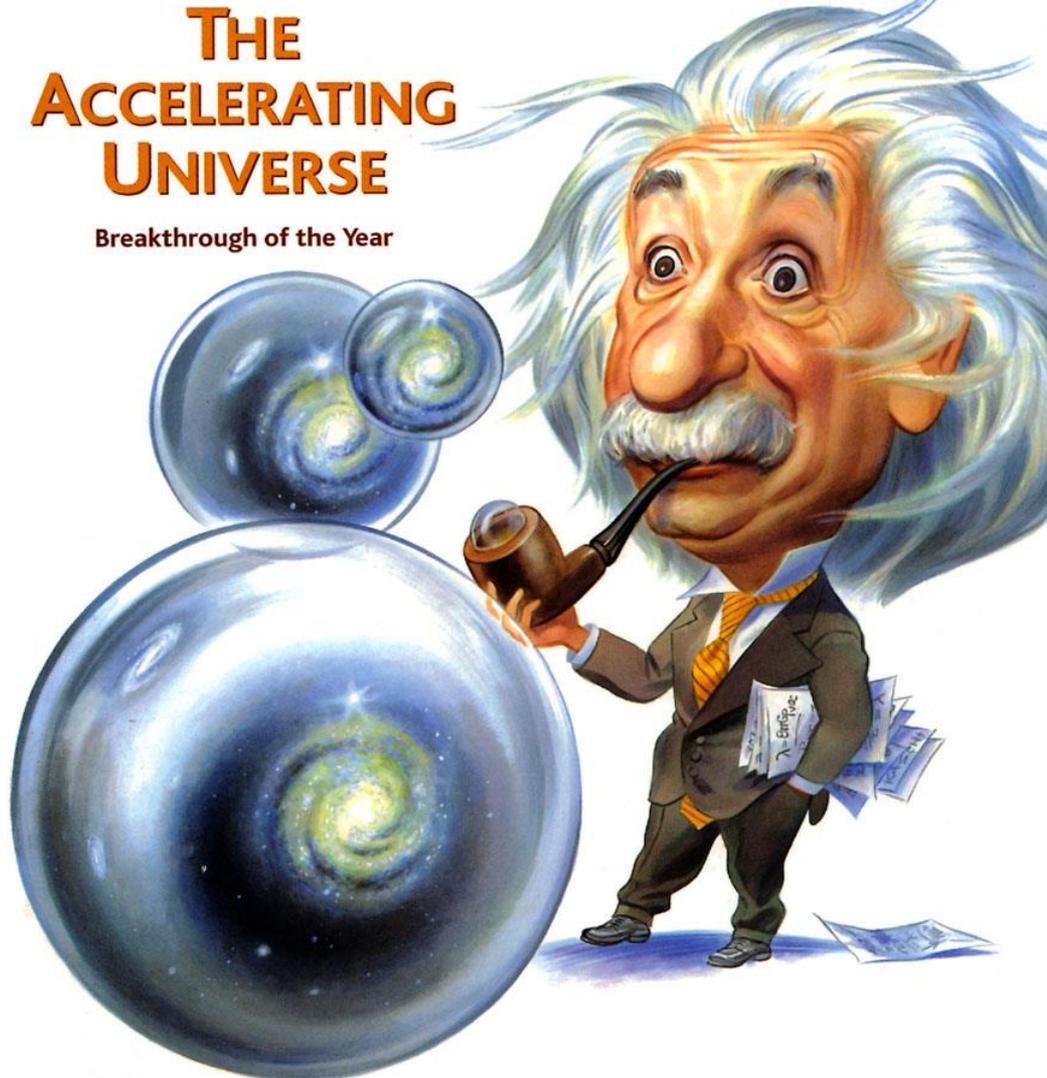
18 December 1998

Science

Vol. 282 No. 5397
Pages 2141-2336 \$7

THE ACCELERATING UNIVERSE

Breakthrough of the Year



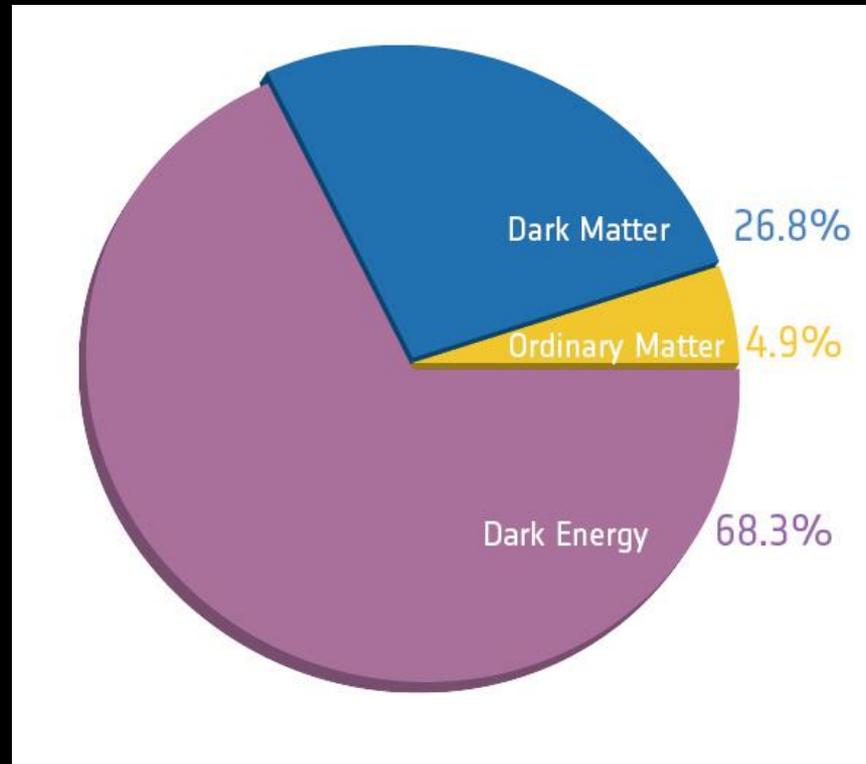
AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE

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Contents of the universe

Dark Matter and Dark Energy are the dominant energy components in the universe.



What does this mean?

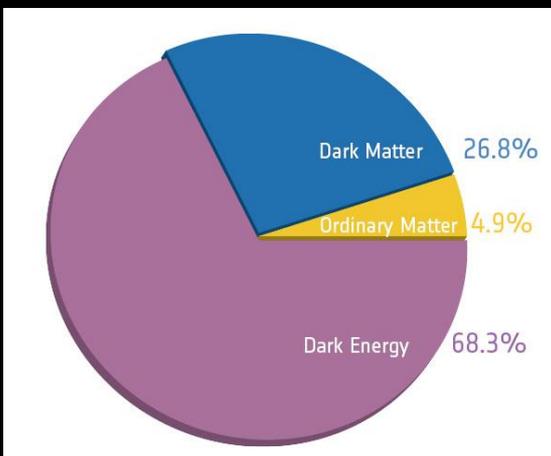
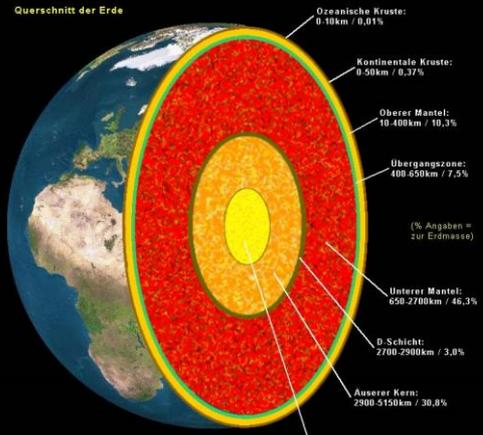
The universe is essentially

empty

The universe expands forever

No convincing physical interpretation of the cosmological constant or the vacuum energy (**Dark Energy**)

Only 4% of the universe are of the same matter as we are (and that we know)



Our universe Our world



The true age of discovery in astronomy is only just starting.

F. Zwicky