

# Exciting Astrophysics

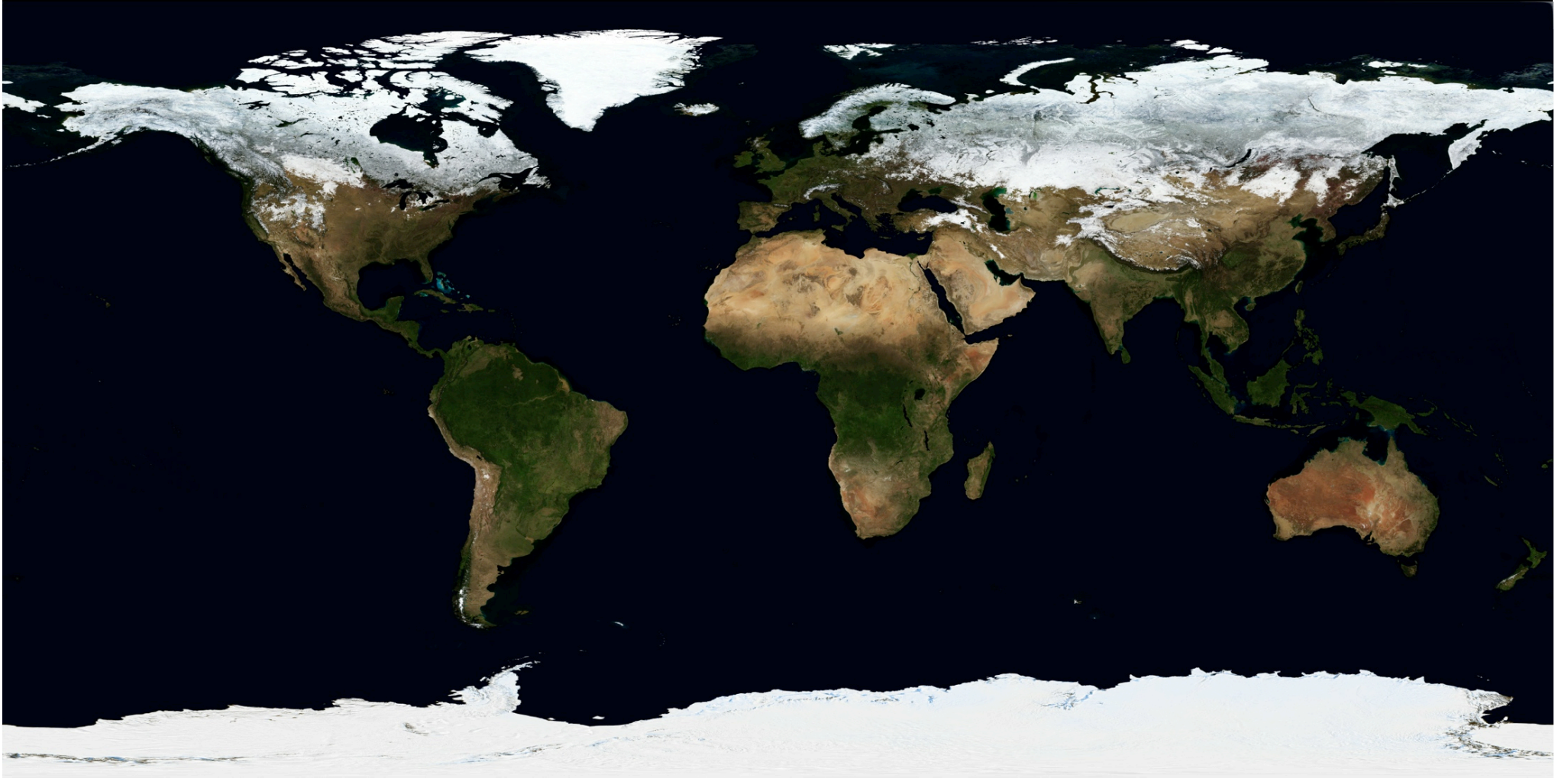


**Bruno Leibundgut**  
**European Southern Observatory (ESO)**

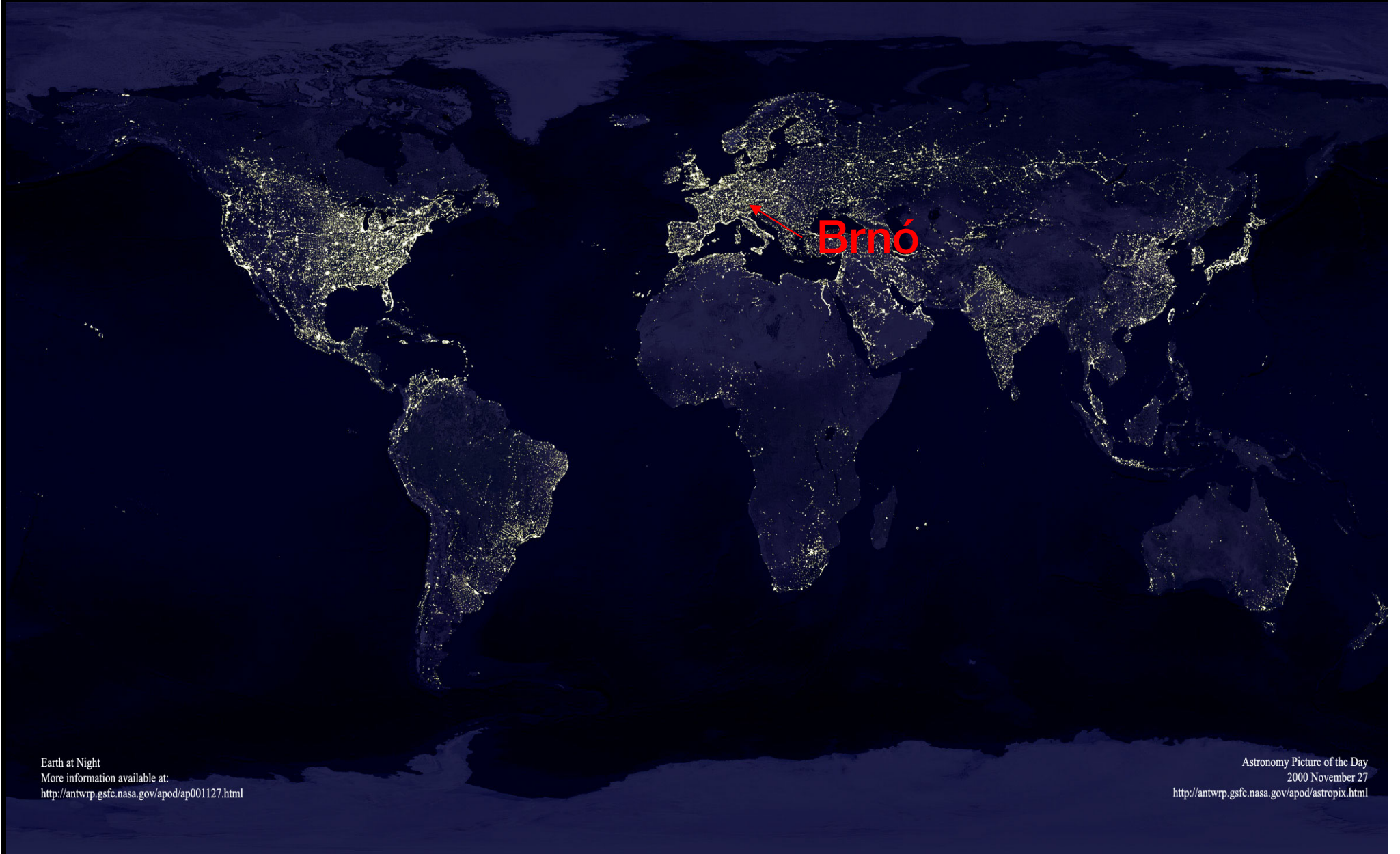
**How do we see our world?**



# A changing world



# The Earth at night



# Our place in the universe



# Our Home

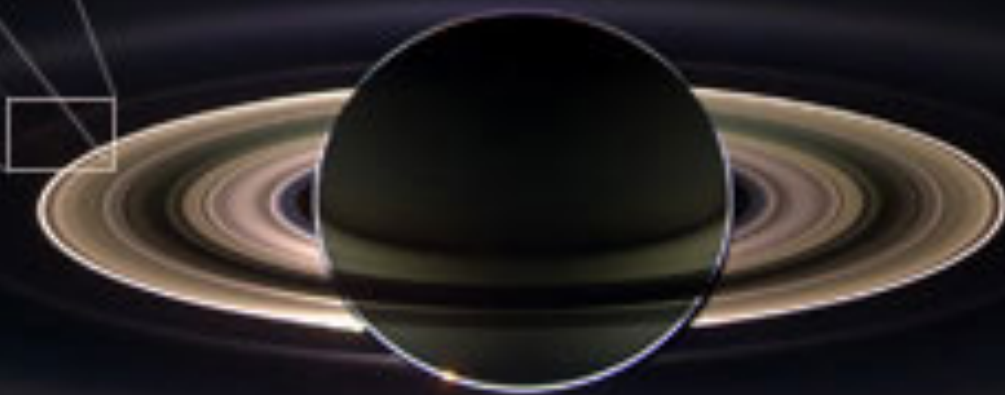
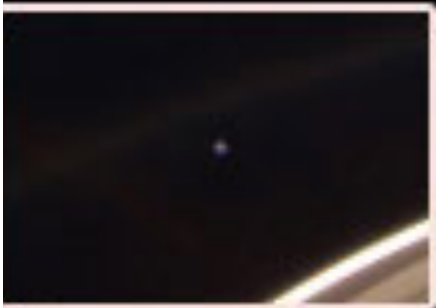
**Apollo 8**



# Our Home

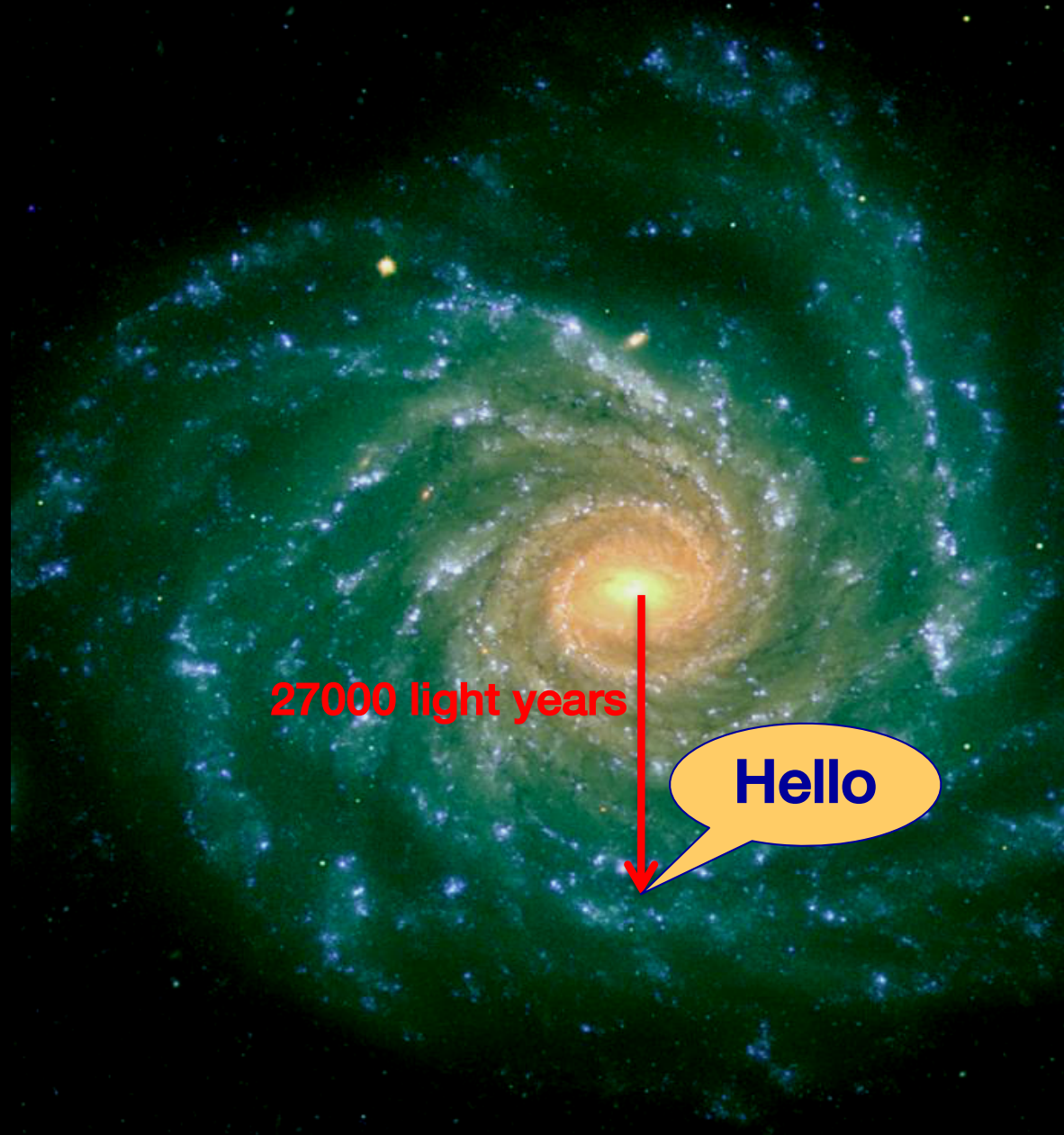


MESSENGER (© NASA)





# Our place in the Milky Way



27000 light years

Hello

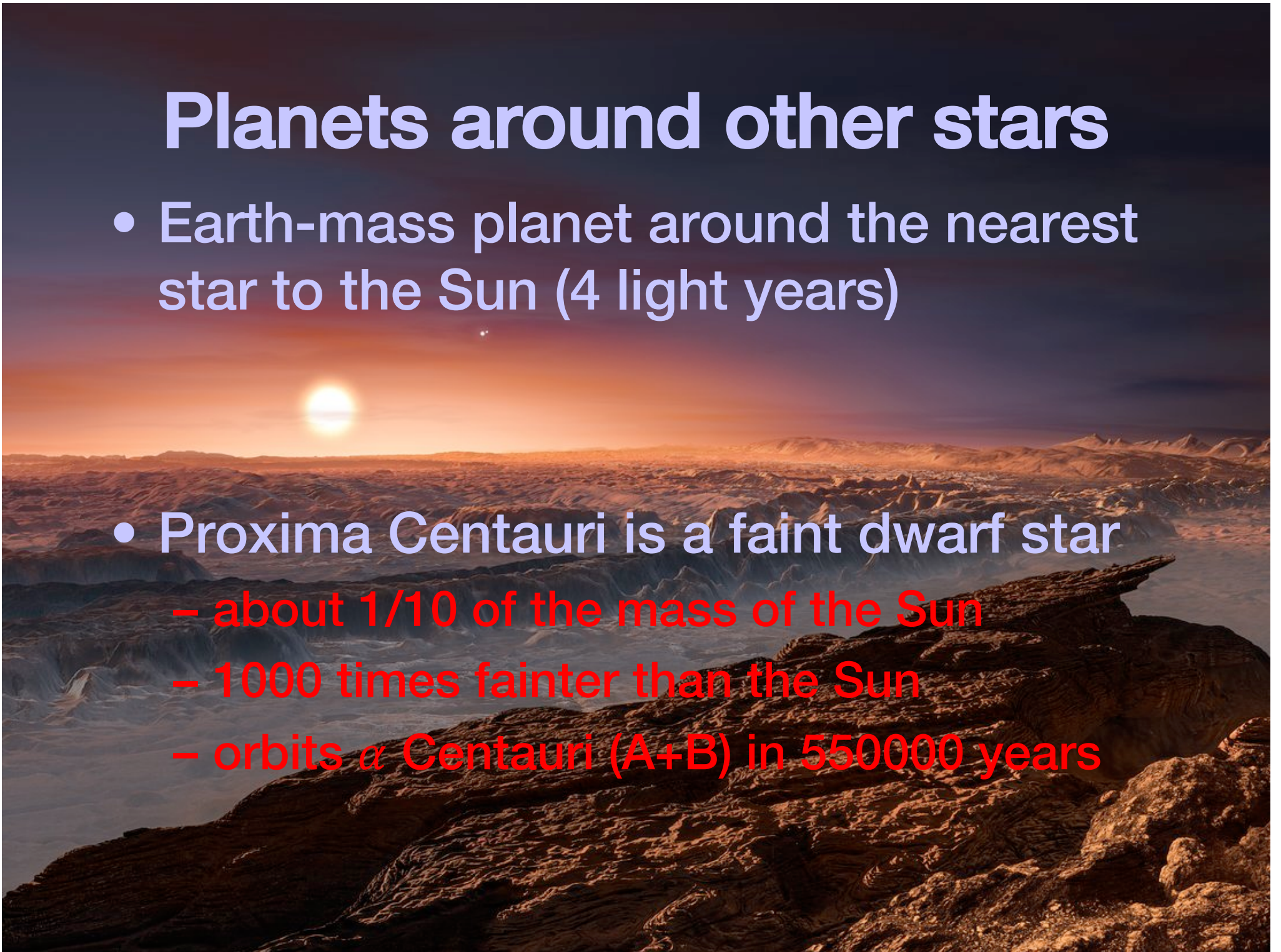
# 4 Topics

- Planets around other stars
  - Earth-like planets around Proxima B and TRAPPIST-1
- Black hole at the center of the Milky Way
- Stars falling into black holes
- The dark side of the universe

# Planets around other stars

- Earth-mass planet around the nearest star to the Sun (4 light years)

- Proxima Centauri is a faint dwarf star
  - about 1/10 of the mass of the Sun
  - 1000 times fainter than the Sun
  - orbits  $\alpha$  Centauri (A+B) in 550000 years

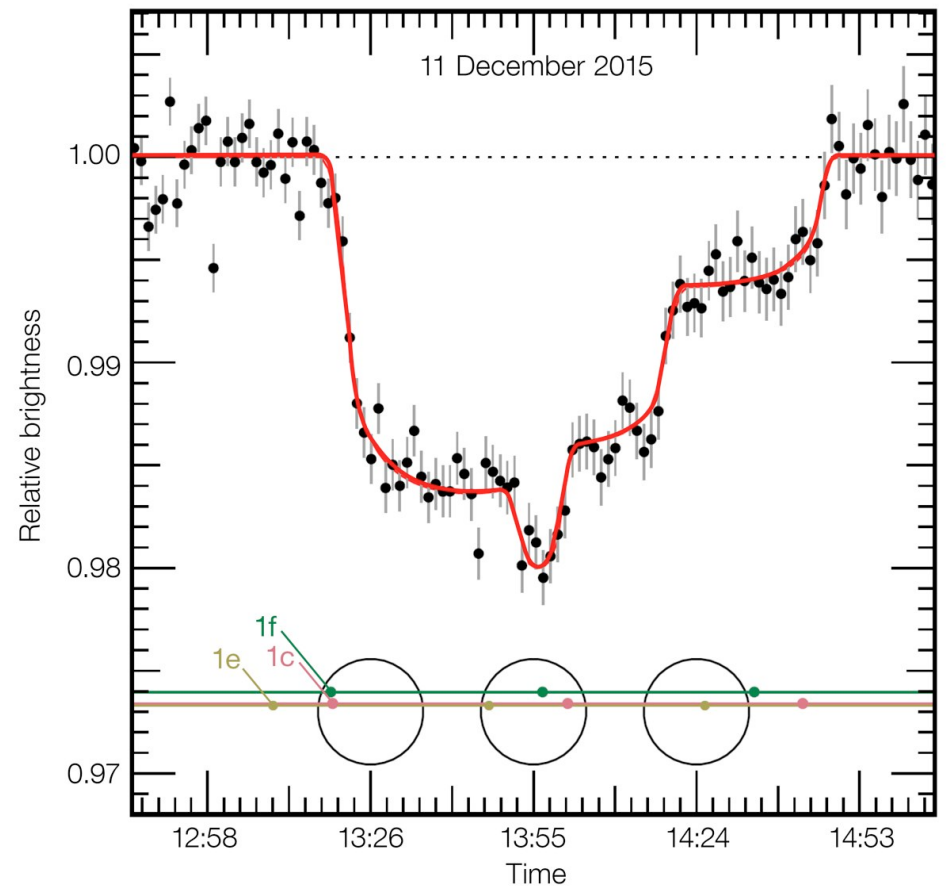
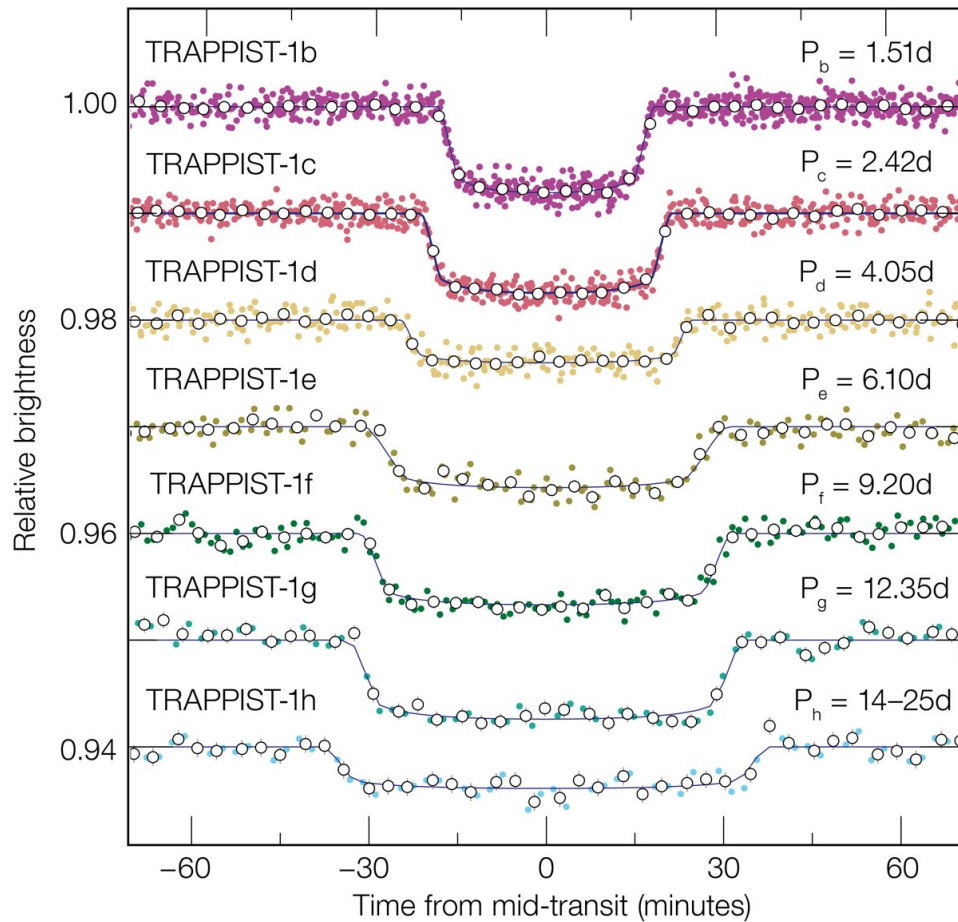


# Venus Transit



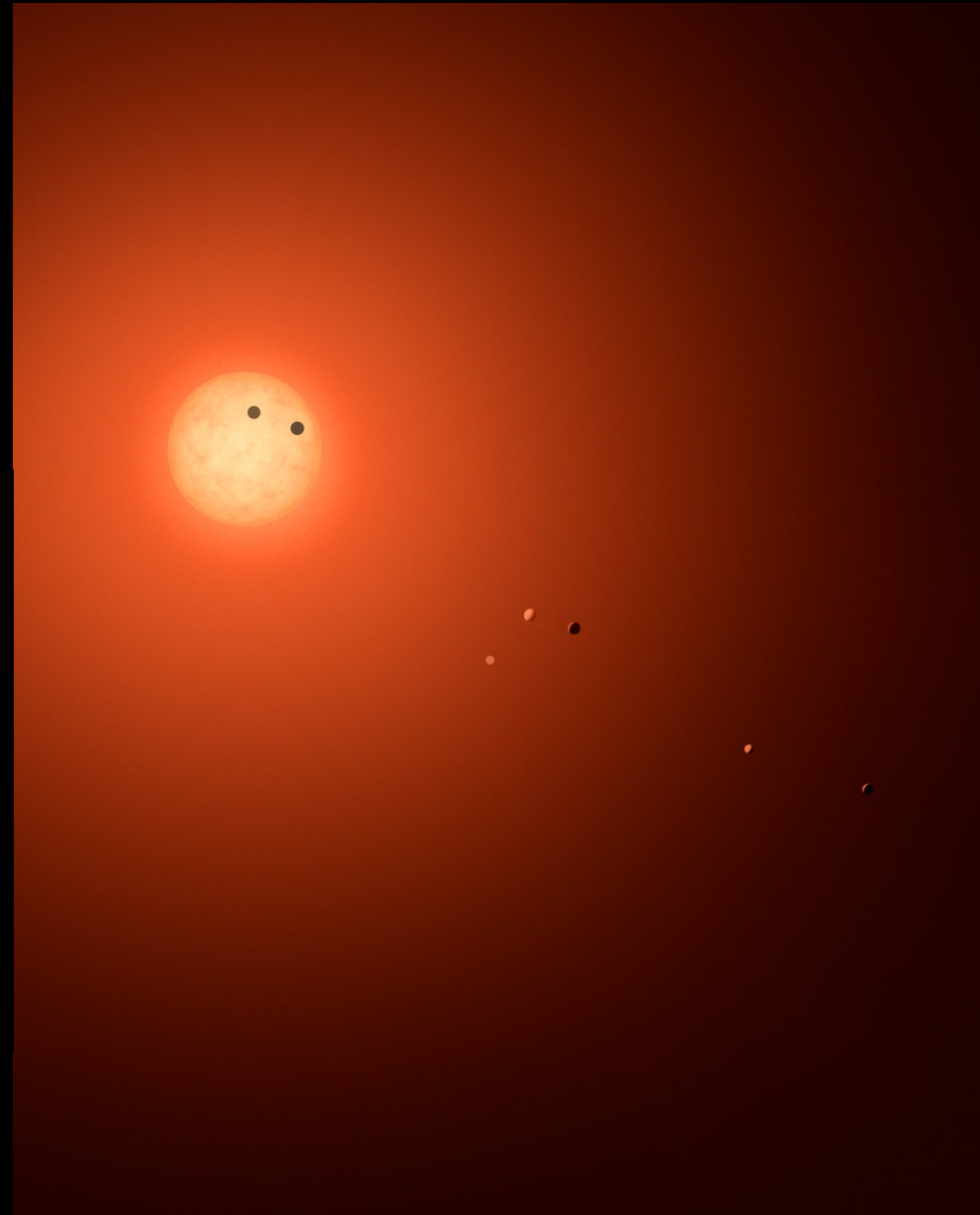
**NASA**  
**Venus and the**  
**ISS**

# Smaller star – bigger planet



# A Planetary System

Seven Earth-mass planets orbiting a small star



TRAPPIST-1 System

	b	c	d	e	f	g	h
Orbital Period <small>days</small>	1.51	2.42	4.05	6.10	9.21	12.35	~20
Distance to Star <small>Astronomical Units (AU)</small>	0.011	0.015	0.021	0.028	0.037	0.045	~0.06
Planet Radius <small>relative to Earth</small>	1.09 $R_{\text{earth}}$	1.06 $R_{\text{earth}}$	0.77 $R_{\text{earth}}$	0.92 $R_{\text{earth}}$	1.04 $R_{\text{earth}}$	1.13 $R_{\text{earth}}$	0.76 $R_{\text{earth}}$
Planet Mass <small>relative to Earth</small>	0.85 $M_{\text{earth}}$	1.38 $M_{\text{earth}}$	0.41 $M_{\text{earth}}$	0.62 $M_{\text{earth}}$	0.68 $M_{\text{earth}}$	1.34 $M_{\text{earth}}$	-

Solar System  
Rocky Planets

	Mercury	Venus	Earth	Mars
Orbital Period <small>days</small>	87.97	224.70	365.26	686.98
Distance to Star <small>Astronomical Units (AU)</small>	0.387	0.723	1.000	1.524
Planet Radius <small>relative to Earth</small>	0.38 $R_{\text{earth}}$	0.95 $R_{\text{earth}}$	1.00 $R_{\text{earth}}$	0.53 $R_{\text{earth}}$
Planet Mass <small>relative to Earth</small>	0.06 $M_{\text{earth}}$	0.82 $M_{\text{earth}}$	1.00 $M_{\text{earth}}$	0.11 $M_{\text{earth}}$

# Size Comparison

between TRAPPIST-1 system, Galilean moons of Jupiter and the inner Solar System



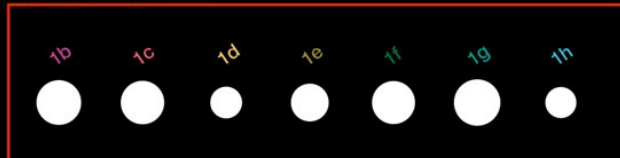
Jupiter  
Ø 139 822 km

Galilean moons of Jupiter



TRAPPIST-1  
Ø 162 793 km

TRAPPIST-1 planets



Inner Solar System



Sun  
Ø 1 391 400 km

**How this could look like**





# Big Question

... jsou-li tam žáby taky!

...and will there be frogs there too?



from the poem  
Frogs sat around a puddle  
by Jan Neruda

# Black hole at the center of the Milky Way



# Star falling into a black hole





# 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?

# 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.**



S116E07141





WALK OFF  
ALL BENEATH  
FOR WORLD  
CUP  
LHO, MAM 2003

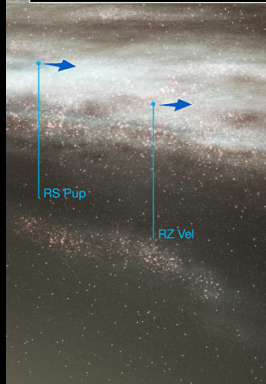
$$R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R = -\frac{8\pi G}{c^4} T_{\mu\nu}$$

A. EINSTEIN

THE HOLLANDAM  
VOLK  
D1  
D2  
D3  
D4  
D5  
D6  
D7  
D8  
D9  
D10

# What is in the Universe?

- We are!



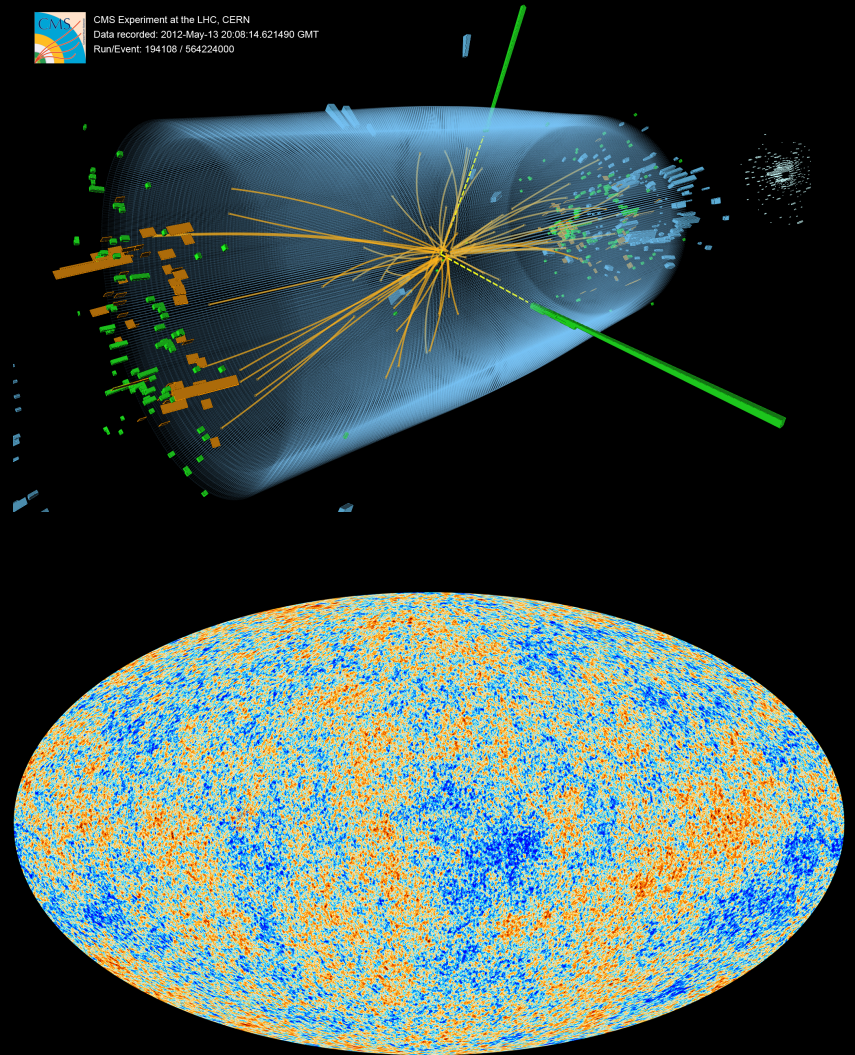


# What is in the Universe?

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



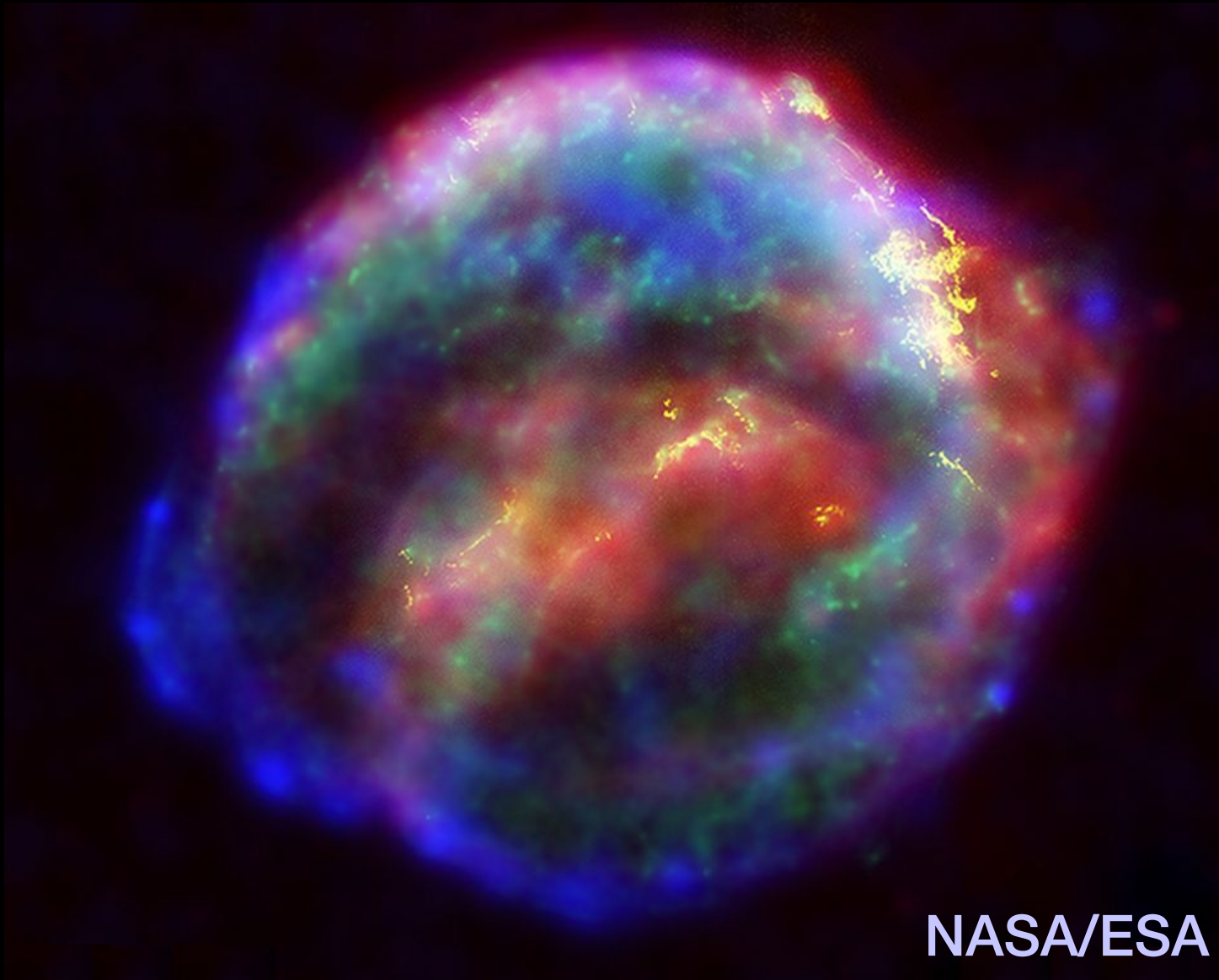
CMS Experiment at the LHC, CERN  
Data recorded: 2012-May-13 20:08:14.621490 GMT  
Run/Event: 194108 / 584224000



# Supernova!



# Kepler's supernova today

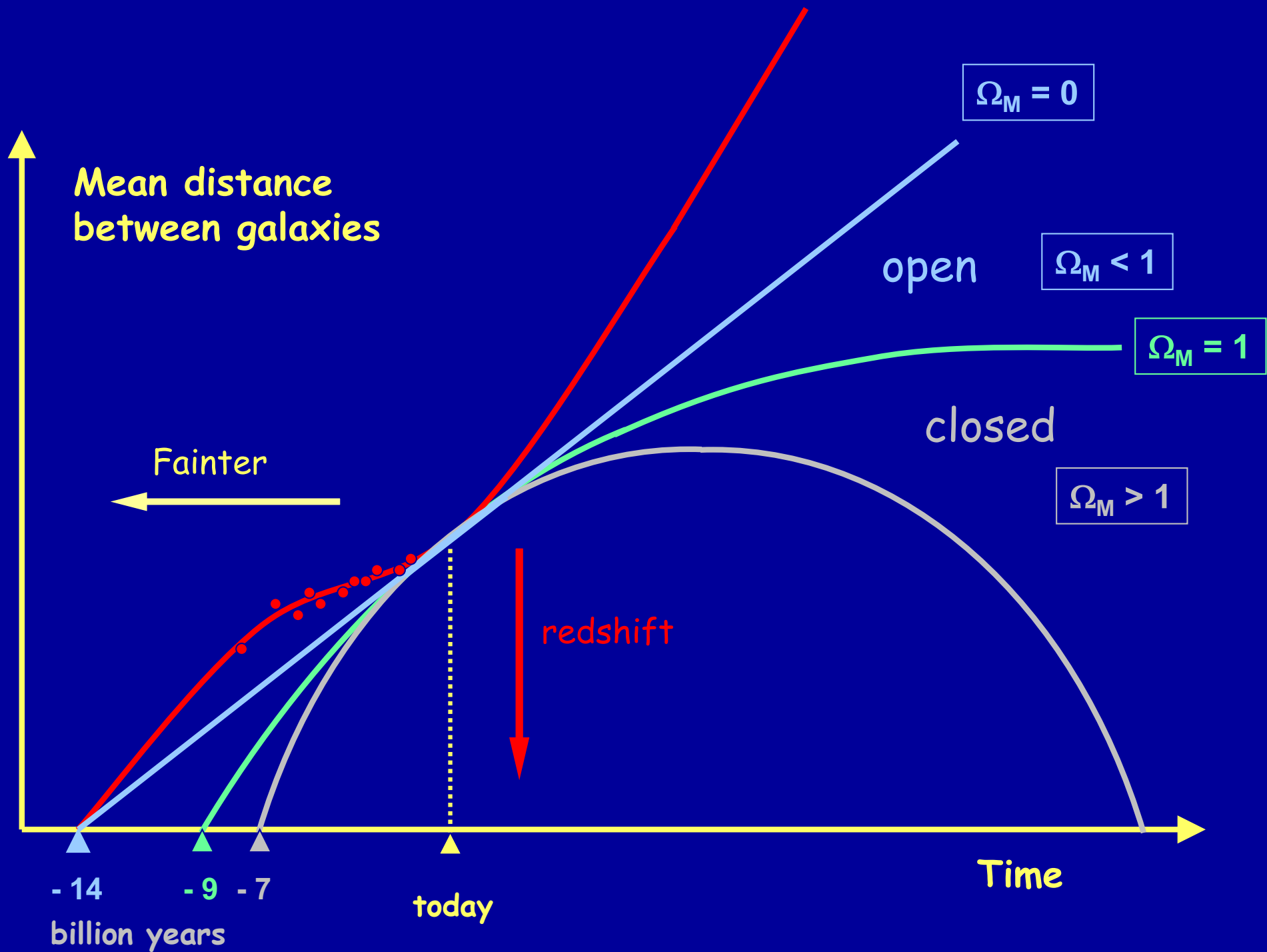


NASA/ESA

# 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**



# Physics Nobelprize 2011



Saul Perlmutter



Brian Schmidt



Adam Riess

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

# The High-z Supernova Search Team

## December 2011



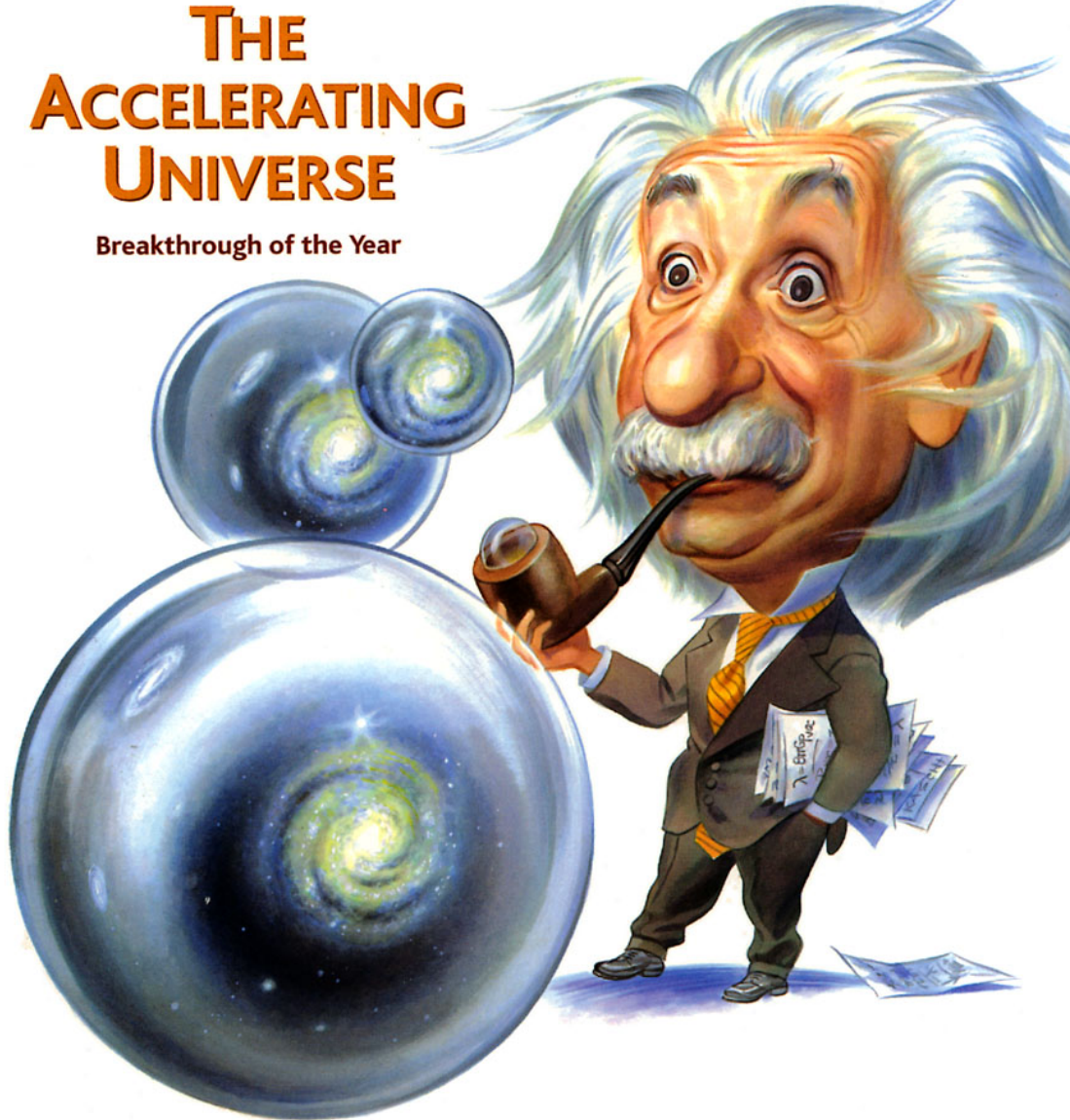
# Science

18 December 1998

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

## THE ACCELERATING UNIVERSE

Breakthrough of the Year



AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE

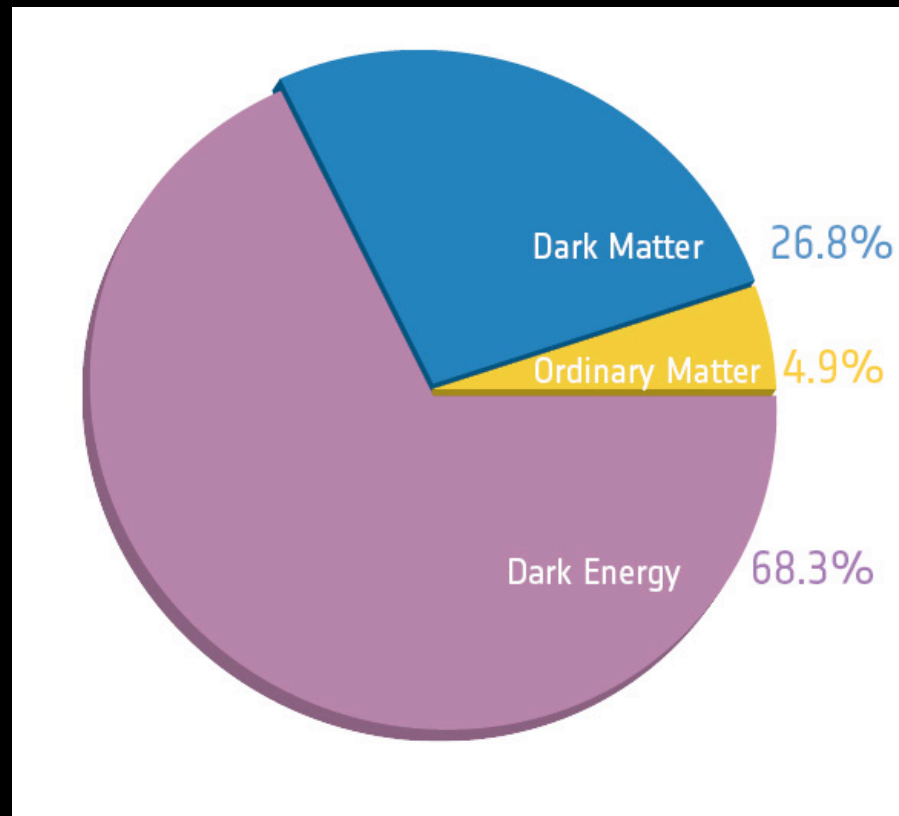
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Distant  
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This rec

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ponent



# Contents of the universe

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



# What does this mean?

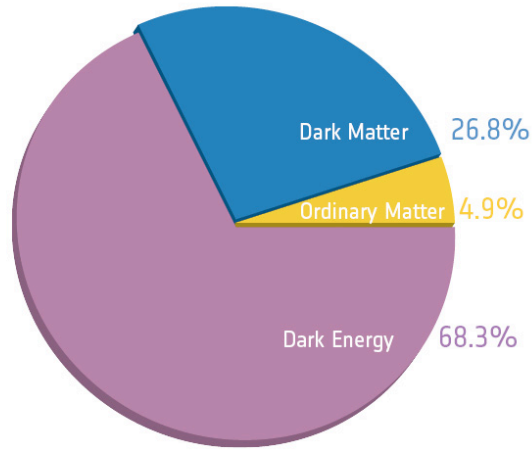
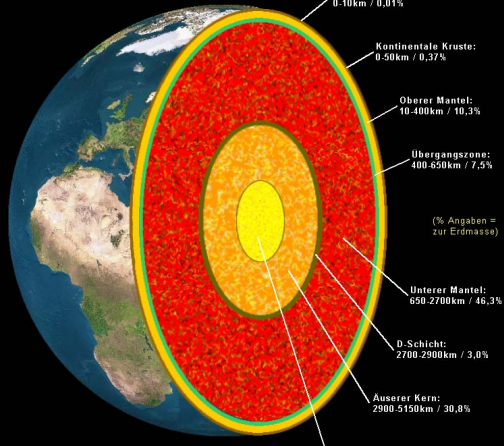
The universe is essentially  
**empty**

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)

Querschnitt der Erde



# Our universe Our world

