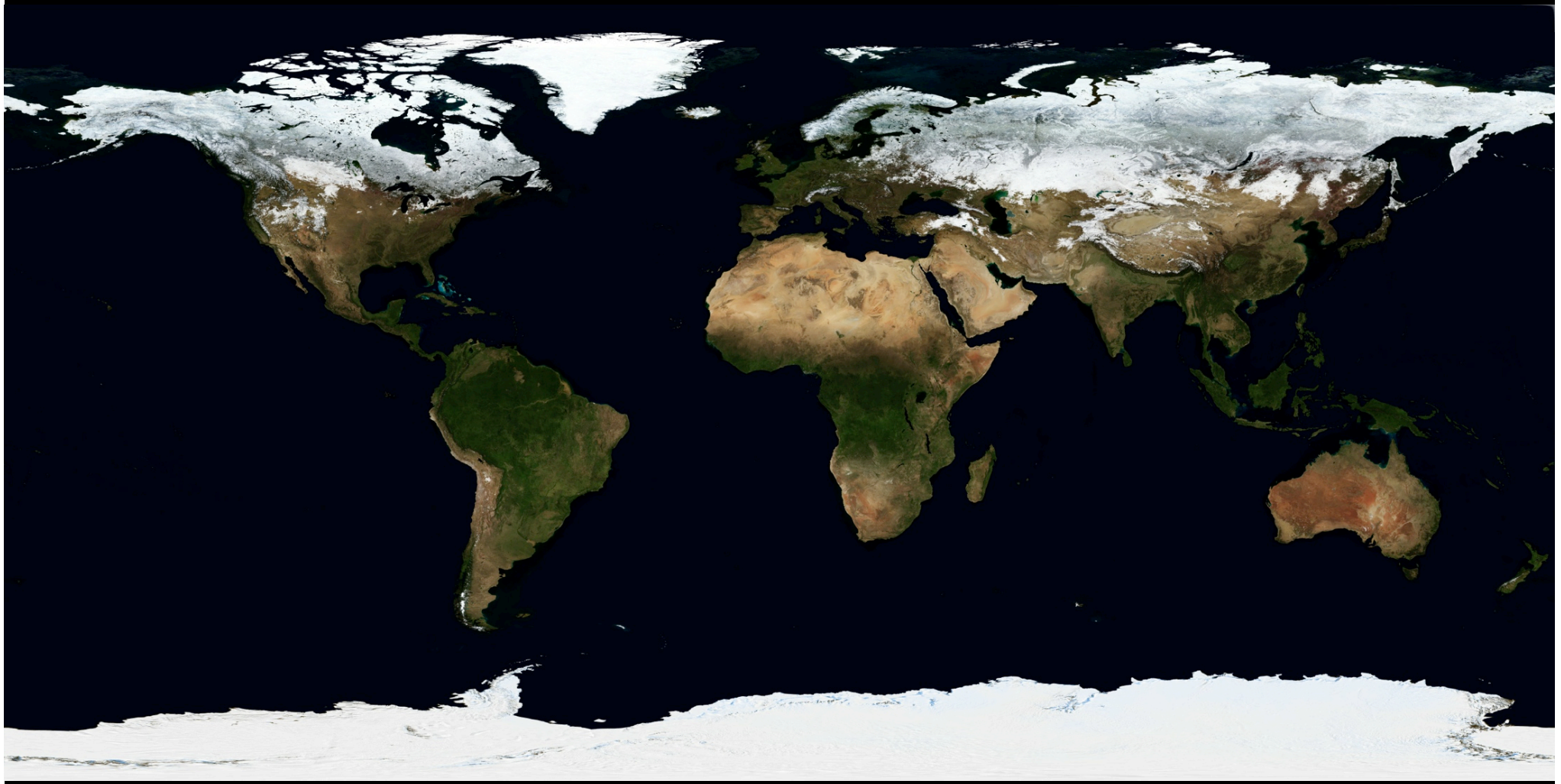
Die dunkle Seite des Universums

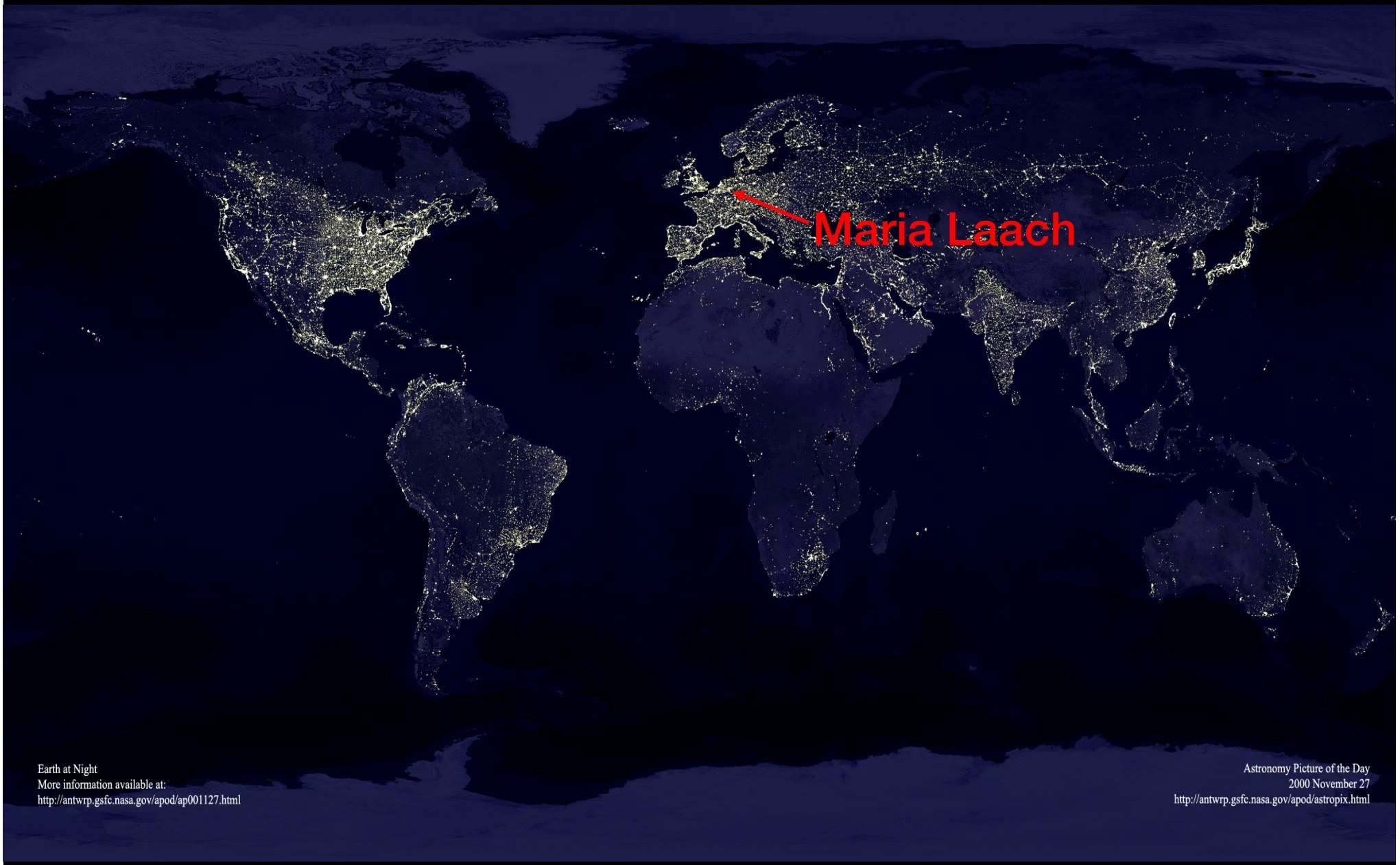
Bruno Leibundgut
European Southern Observatory (ESO)

Wie sehen wir unsere Welt?

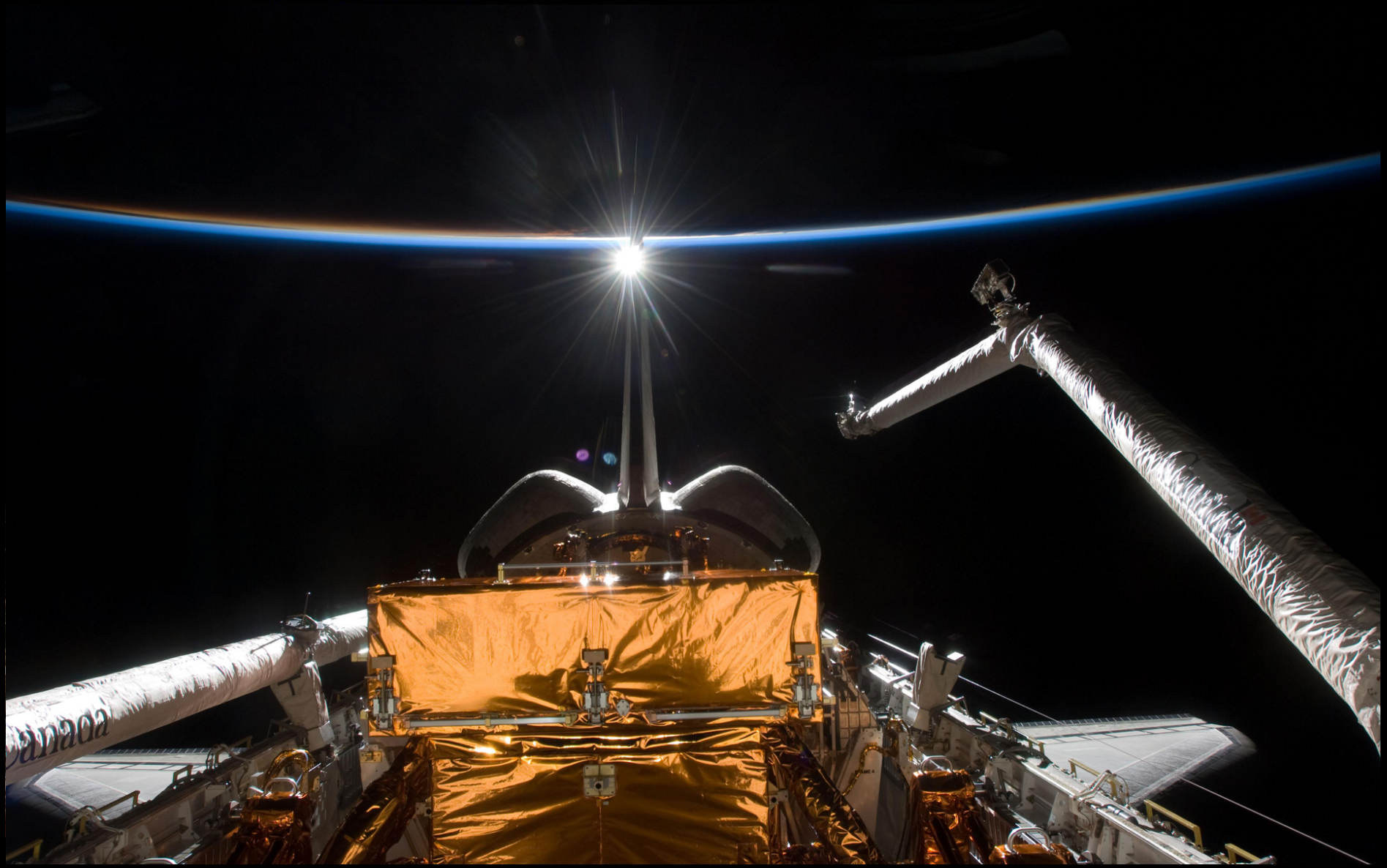
Die Welt im Wandel



Die dunkle Erde



Unser Ort im Universum

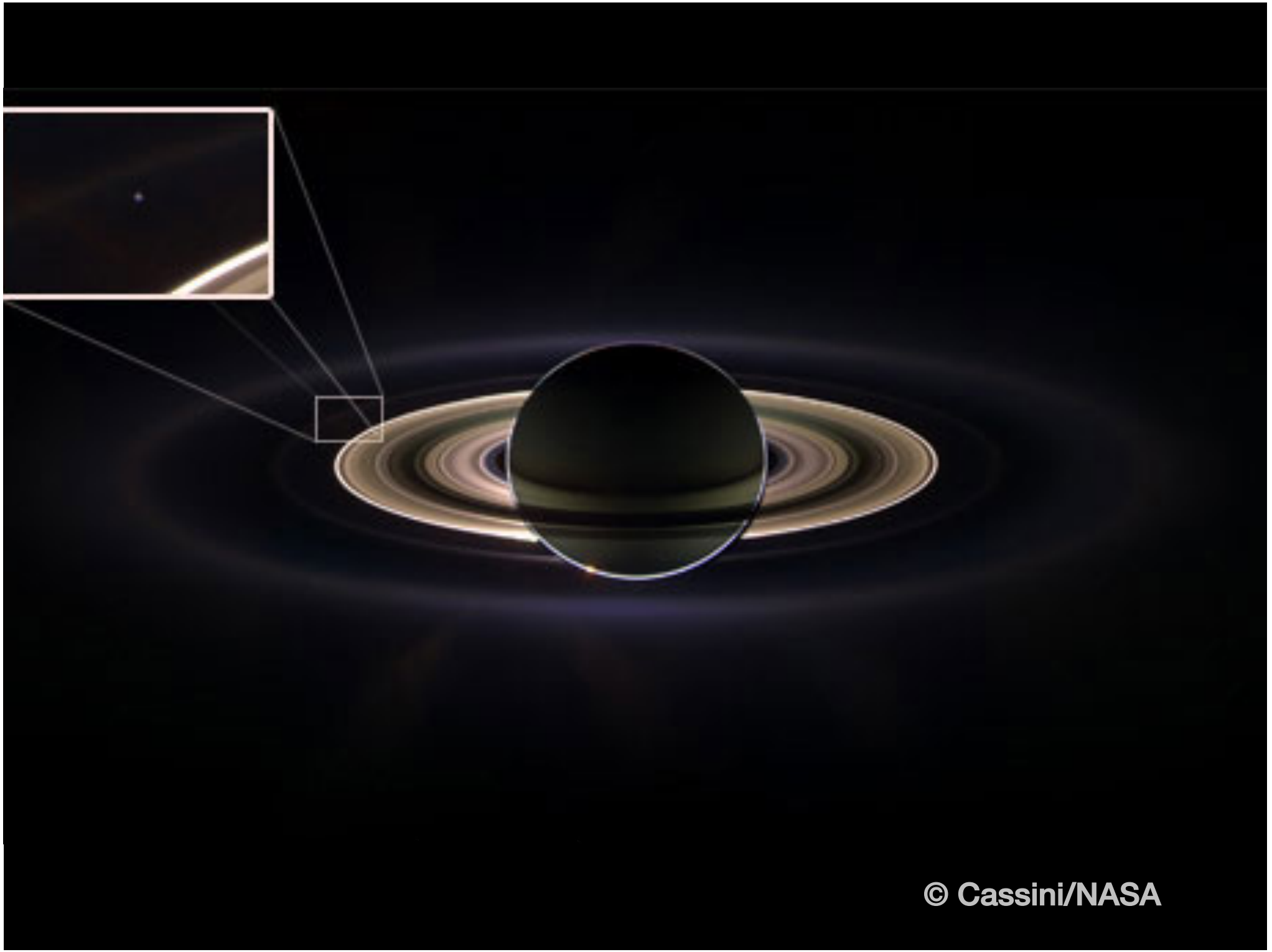


Unser Zuhause

Apollo 8

Heimat

MESSENGER (© NASA)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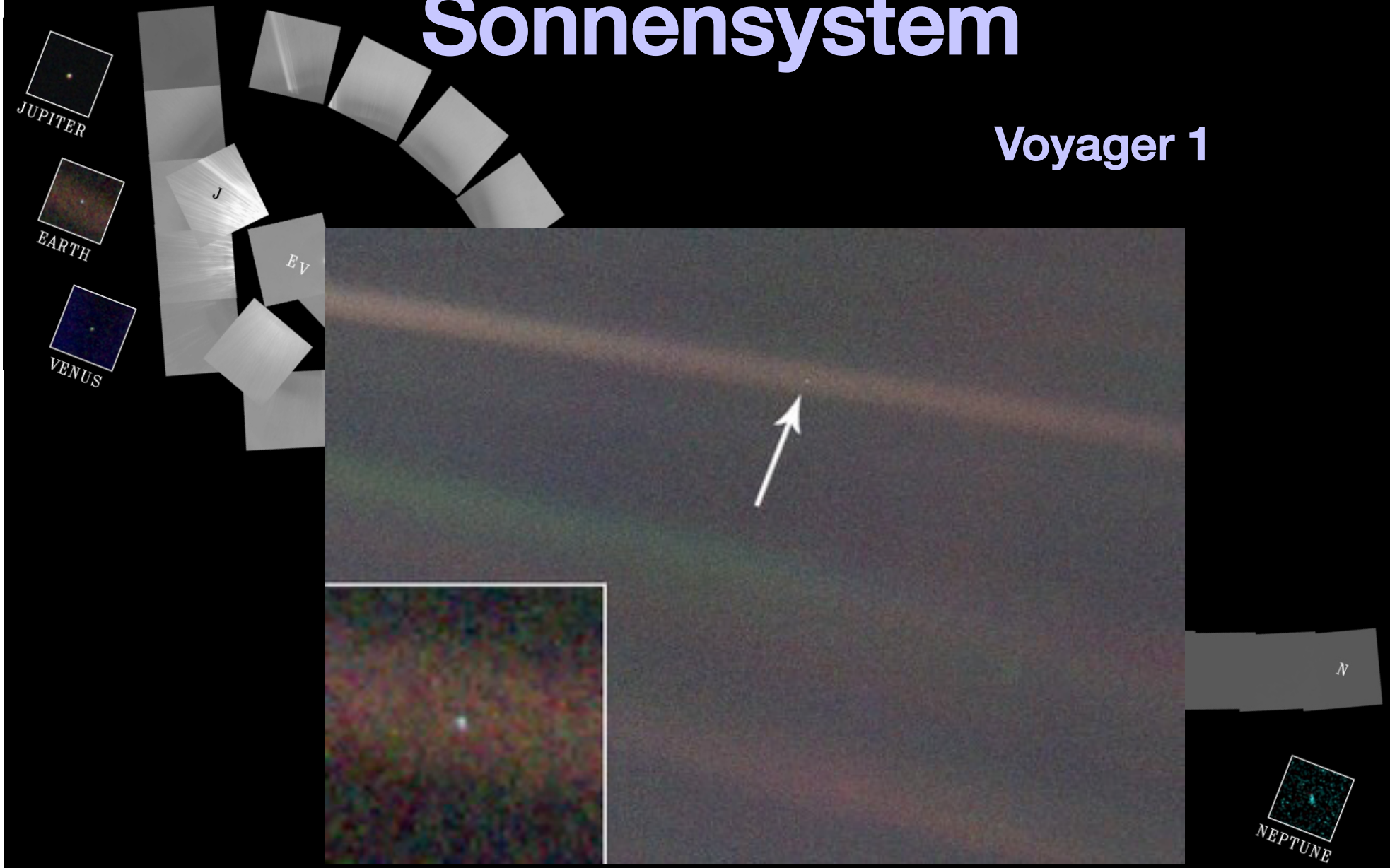
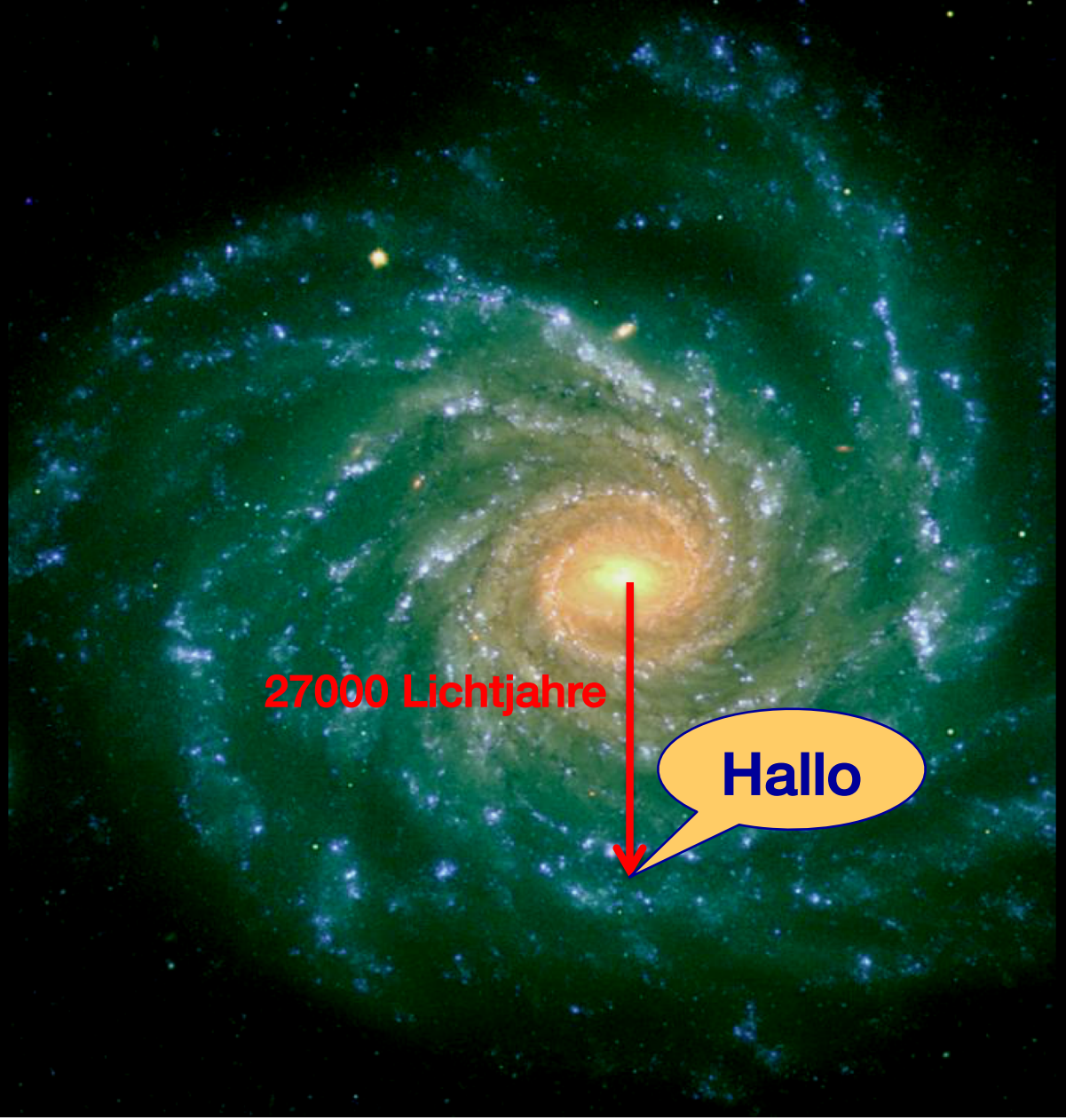
Die Planetenfamilie im Sonnensystem

Voyager 1



Unser Platz in der Milchstrasse



1. Januar: Urknall

Die Milchstraße entsteht

Sonne und Planeten entstehen

Erste Einzeller

Erste mehrzellige Lebewesen

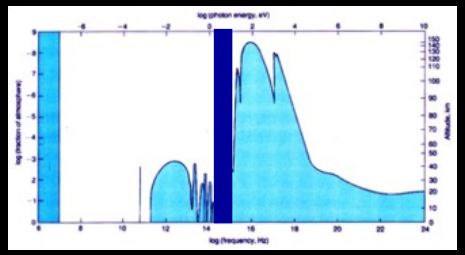
Januar	Februar	März	April	Mai	Juni	Juli	August	September	Oktober	November

Dezember

1	2	3	4	5	6	7
8	9	10	11	12	13	14
15 Kambrische Explosion	16	17 Erste Wirbeltiere	18 Erste Land-pflanzen	19	20 Erste vierfüssige Tiere	21 Insekten entwickeln sich
22	23	24 Erste Dinosaurier erscheinen	25 Die ersten Vorgänger der Säugetiere	26	27 Erste bekannte Vögel	28
29 Dinosaurier sterben aus	30	31 23:54 Moderne Menschen (homo sapiens) erscheinen 23:59:45 Erfindung der Schrift 23:59:50 Pyramiden in Ägypten werden gebaut 23:59:59 Galileo beobachtet den Himmel mit einem Fernrohr				

Die Erdatmosphäre

Schutzschild und Fenster zum All



„Sichtbar“


1. Januar: Urknall
Die Milchstraße entsteht
Sonne und Planeten entstehen
Erste Einzeller
Erste mehrzellige Lebewesen
Januar
Februar
April
Mai
Juni
Juli
August
September
Oktober
November
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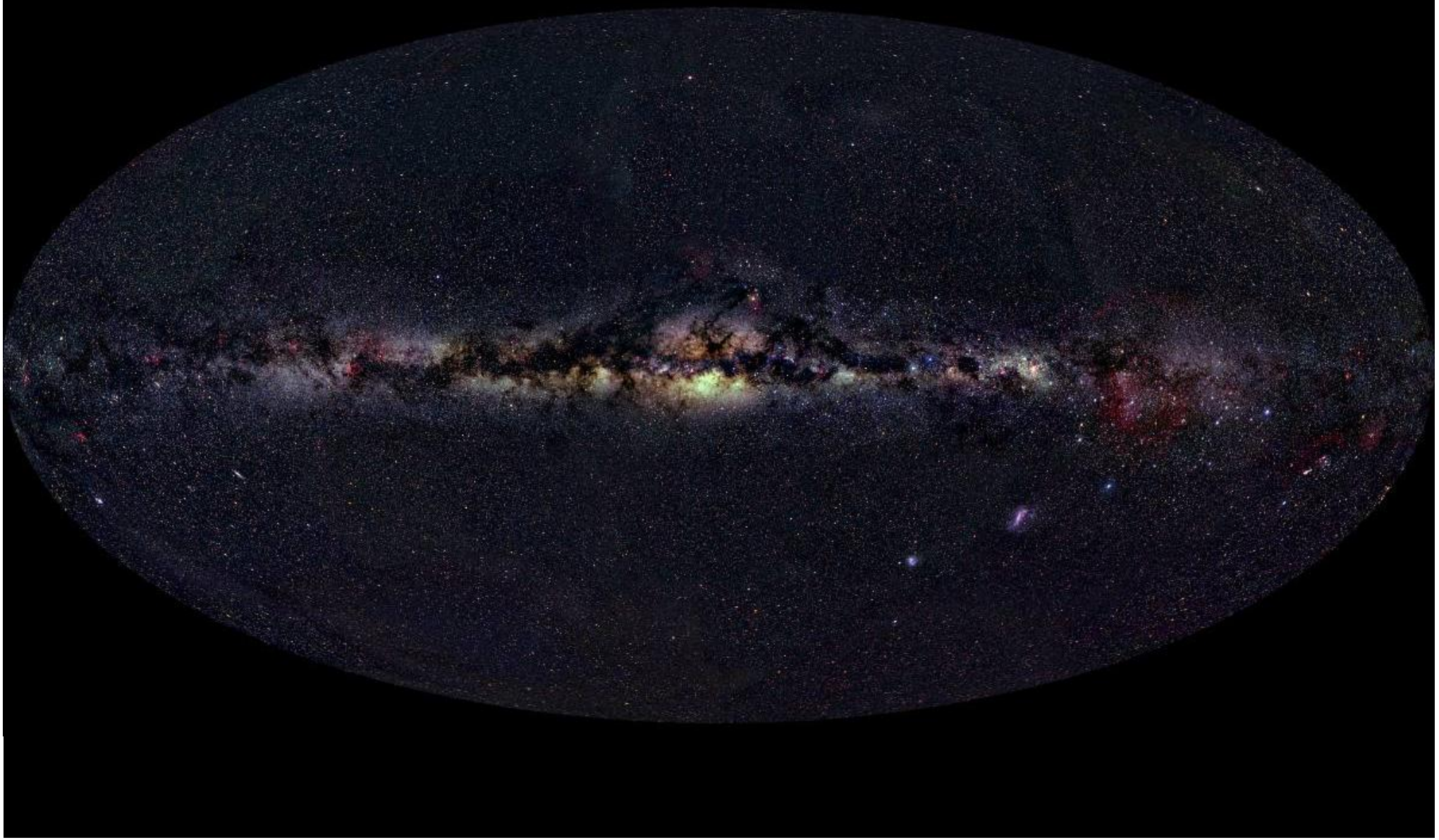

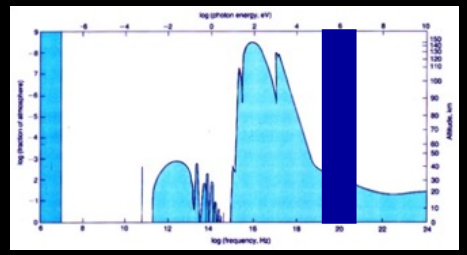

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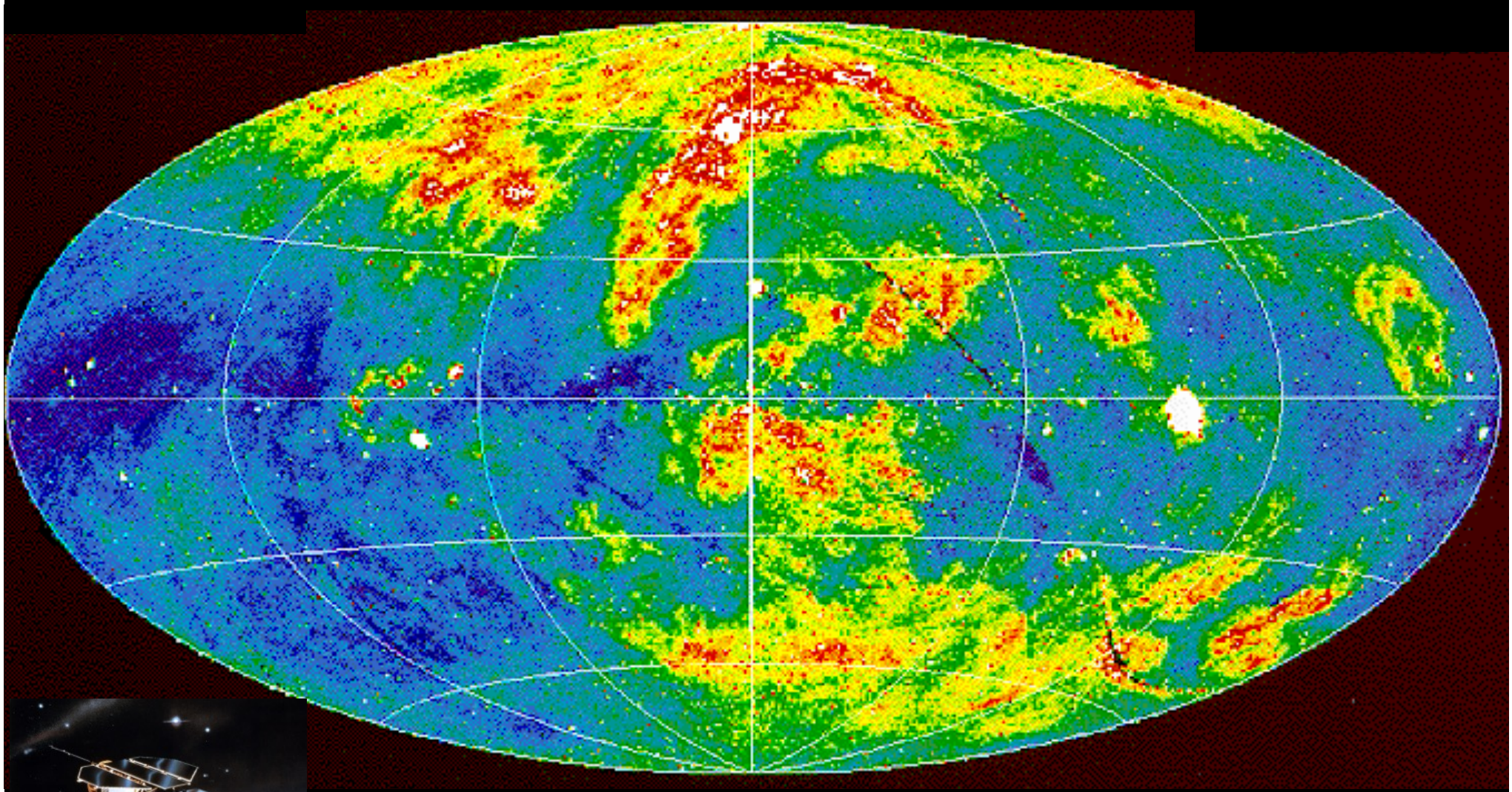
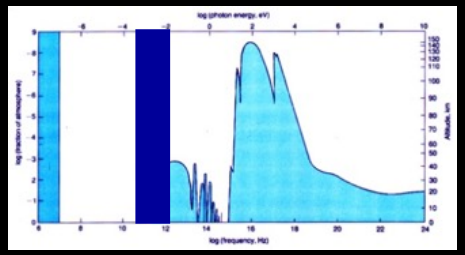
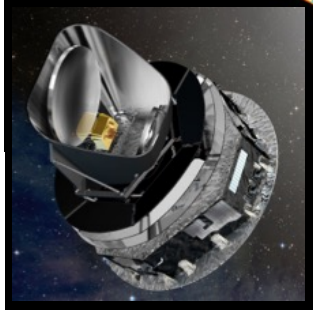


ROSAT



„Unsichtbar“



Planck/ESA

Die dunkle Seite des Universums

- Aus was besteht das Universum?
- Wie verstehen wir das Universum?
- Was sind Dunkle Materie und Dunkle Energie?

Das „unsichtbare” Universum

- Große Teile des Universums sind dunkel
- „Dunkle“ (nicht leuchtende) Materie ist überall
  - e.g. Planeten, Moleküle, Staub, kühles Gas
- Messungen durch indirekte Phänomene
  - Gravitation!
  - Model für die Entwicklung des Universums
    - Einsteins Relativitätstheorie

Fundamente der Kosmologie

(unseres Weltbildes)

Gravitationstheorie

- Einsteinsche Relativitätstheorie

Isotropie

- Es gibt keine bevorzugte Richtung im Universum

Homogeneität

- Es gibt keine bevorzugte Region
- (e.g. kein Zentrum des Universums)

Anthropisches Prinzip

- Das Universum hat uns erzeugt

Gravitation!

Eine der vier fundamentalen Wechselwirkungen

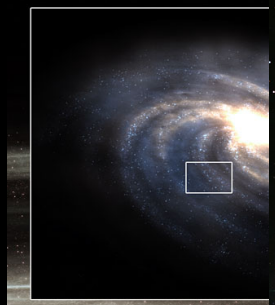
Gravitation, Elektromagnetismus, Schwache und Starke Kraft

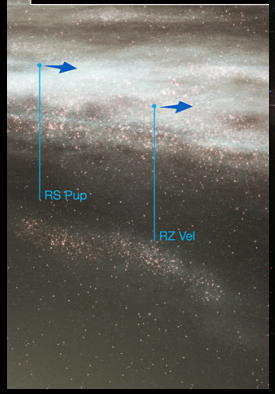
Nur Gravitation entscheidend für die Entwicklung des Universums


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

Was ist im Universum?

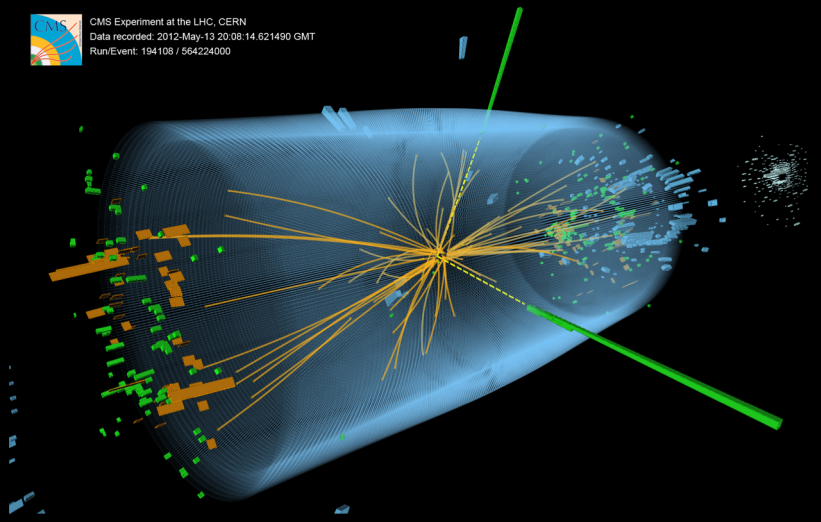
- Wir!

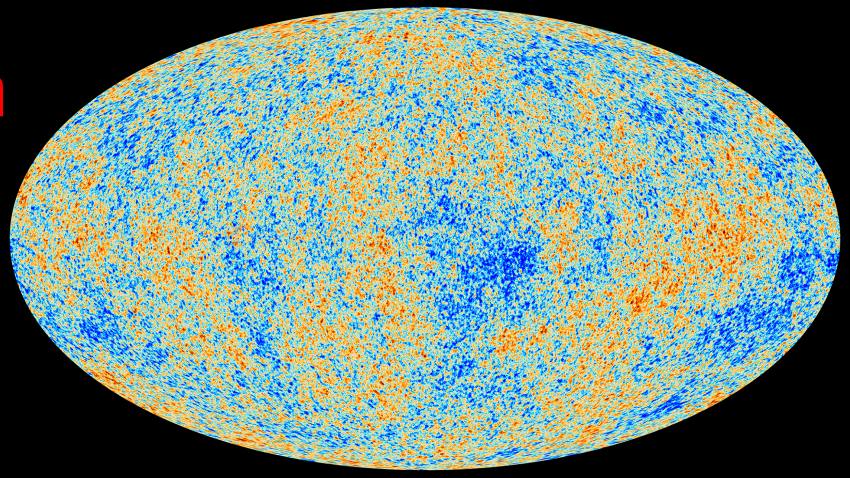


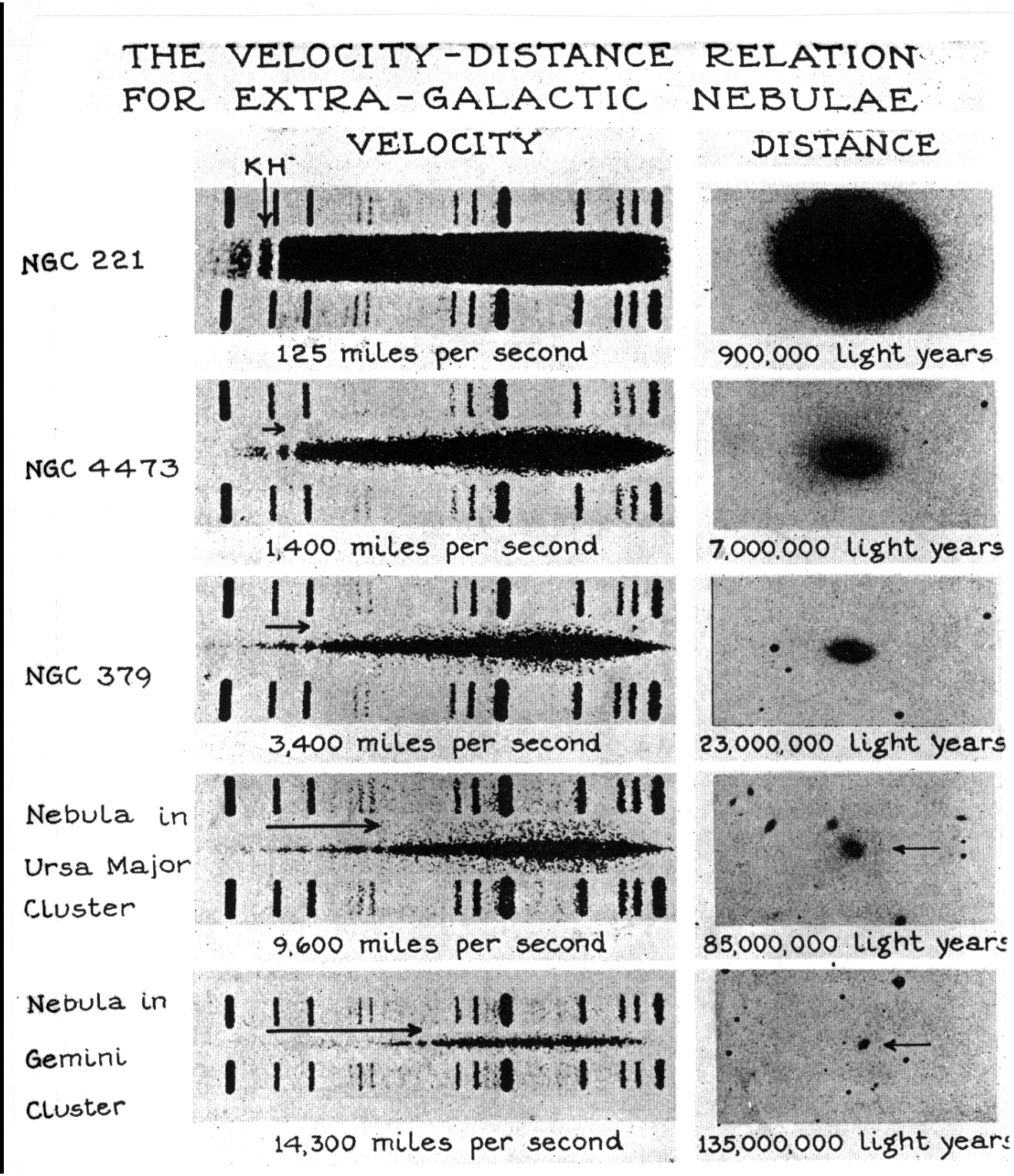


Was ist im Universum?

- Was sonst?
  - Elementarteilchen
    - Neutrinos
    - Higgs Teilchen
    - bisher unbekannte Teilchen
  - Andere Energieformen
    - Strahlung
    - ????






THE VELOCITY-DISTANCE RELATION
FOR EXTRA-GALACTIC NEBULAE
VELOCITY
DISTANCE
KH
NGC 221
125 miles per second
900,000 light years
NGC 4473
1,400 miles per second
7,000,000 light years
NGC 379
3,400 miles per second
23,000,000 light years
Nebula in
Ursa Major
Cluster
9,600 miles per second
85,000,000 light years
Nebula in
Gemini
Cluster
14,300 miles per second
135,000,000 light years

Hubble 1936

Das Original Hubble Diagramm

Geschwindigkeit

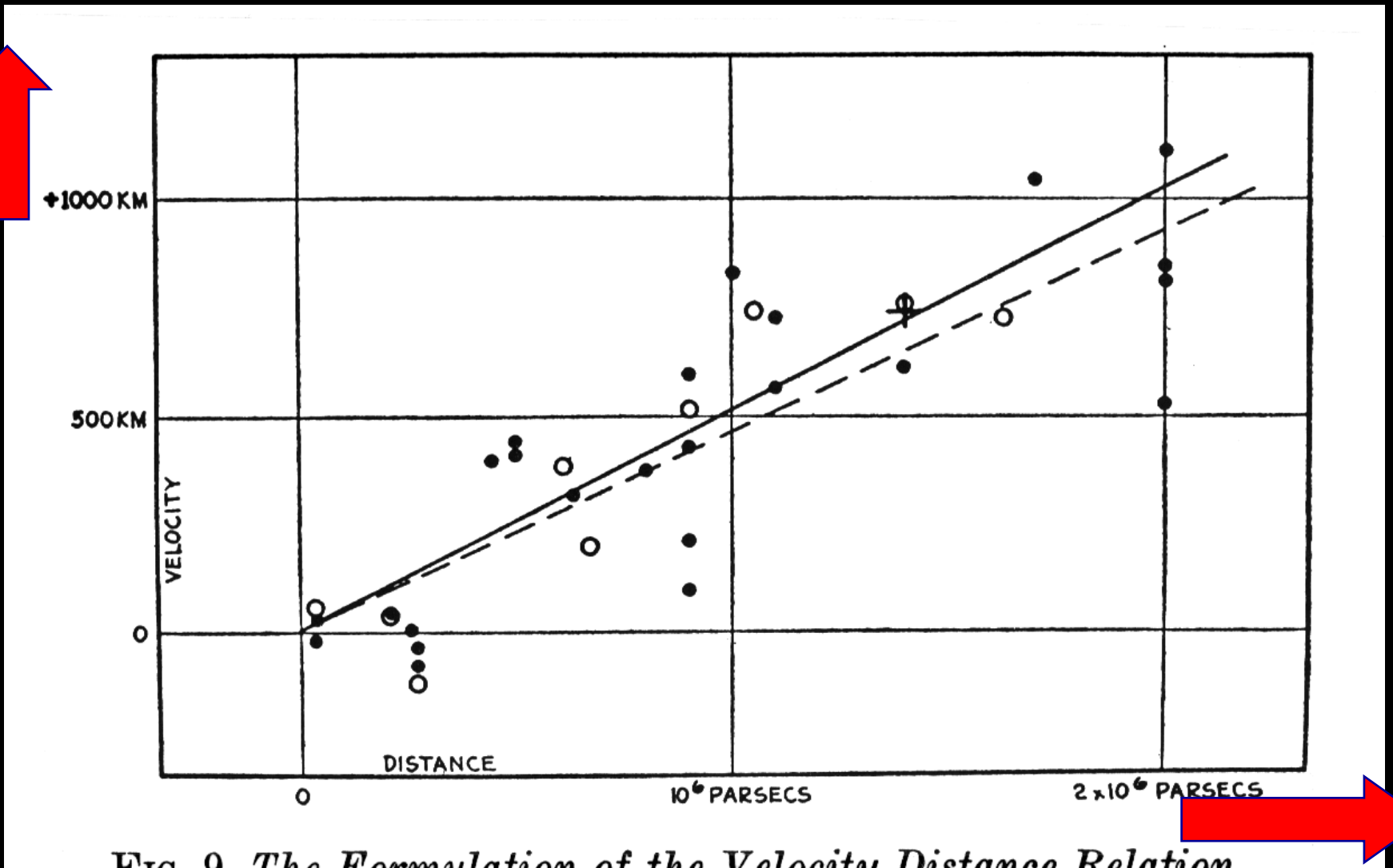
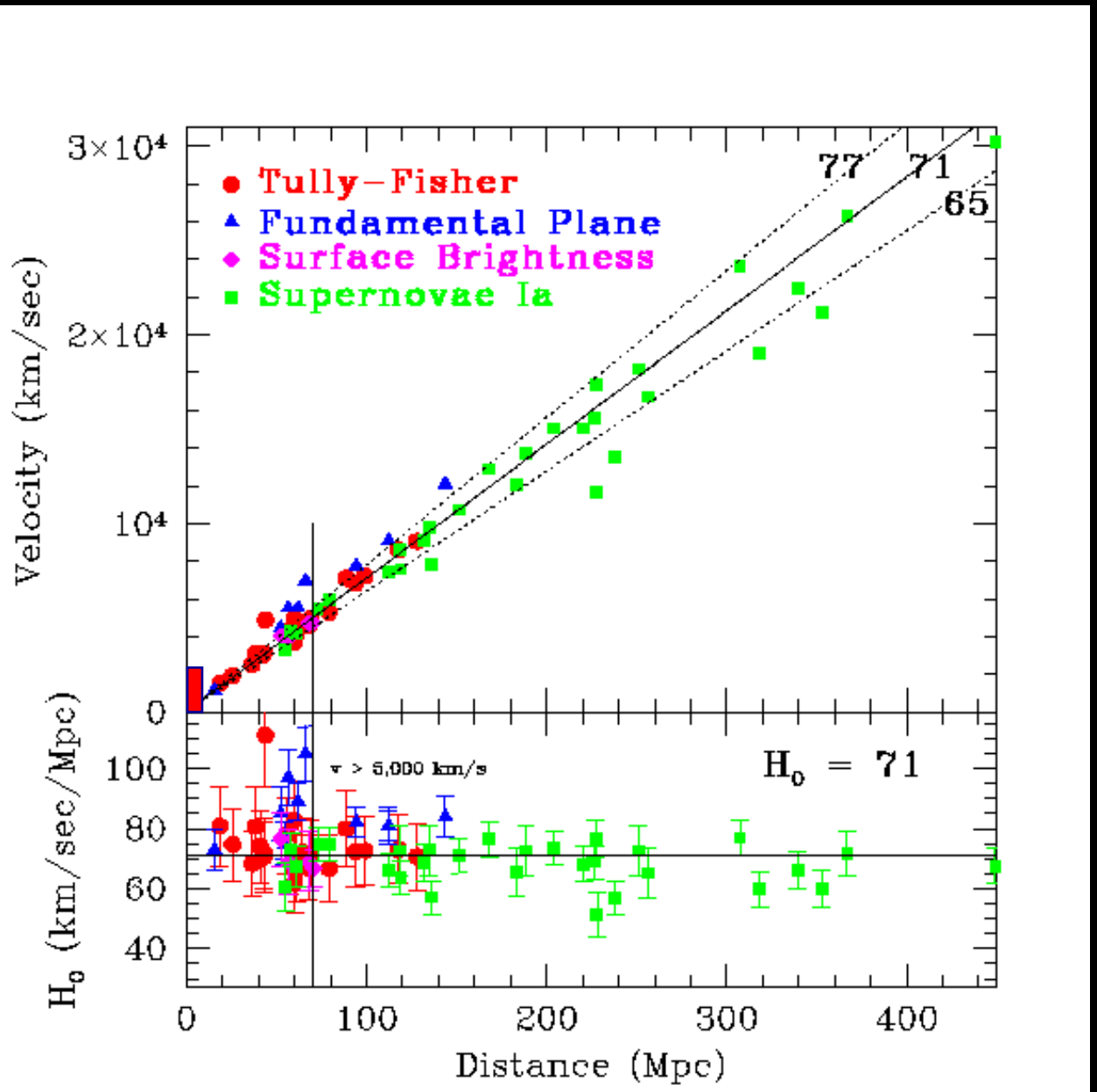


FIG. 9. *The Formulation of the Velocity-Distance Relation.*

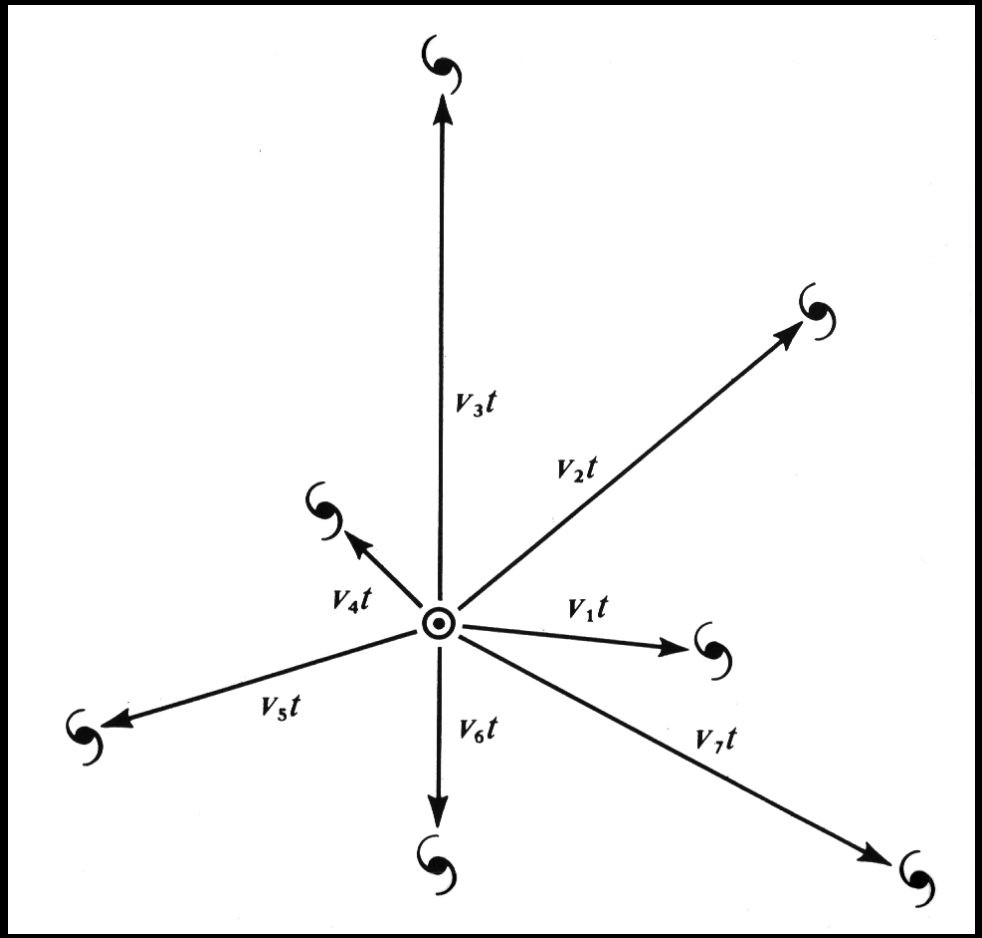
Entfernung

Ein modernes Hubble Diagramm

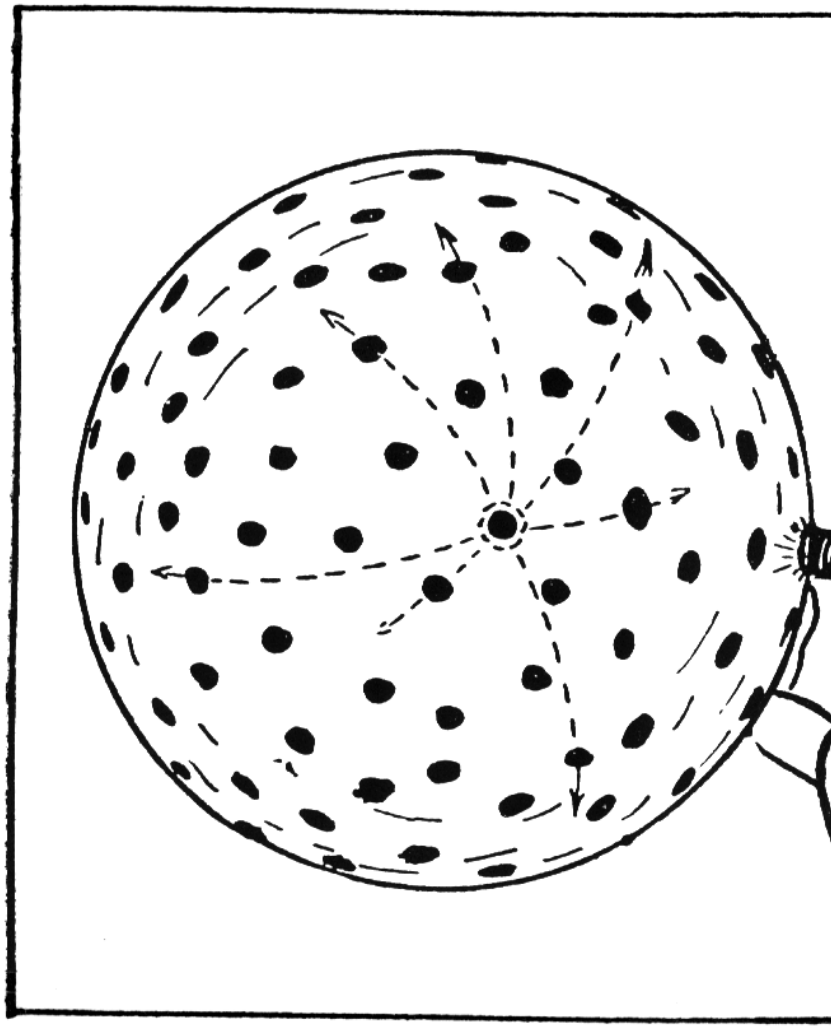


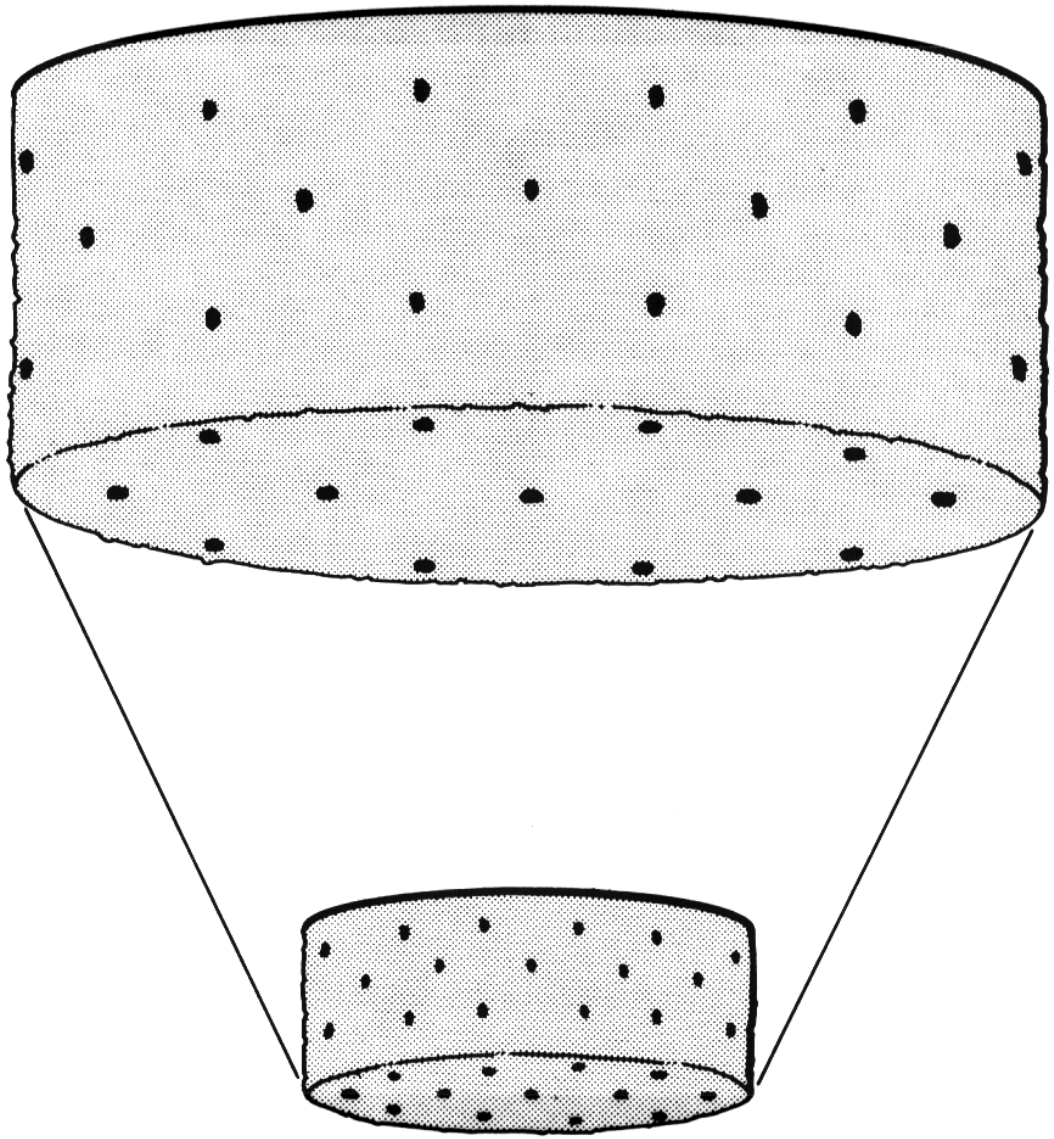
Das Alter des Universums

Alle Galaxien starten am selben Punkt



The Expansion ist für alle gleich (Isotropie)





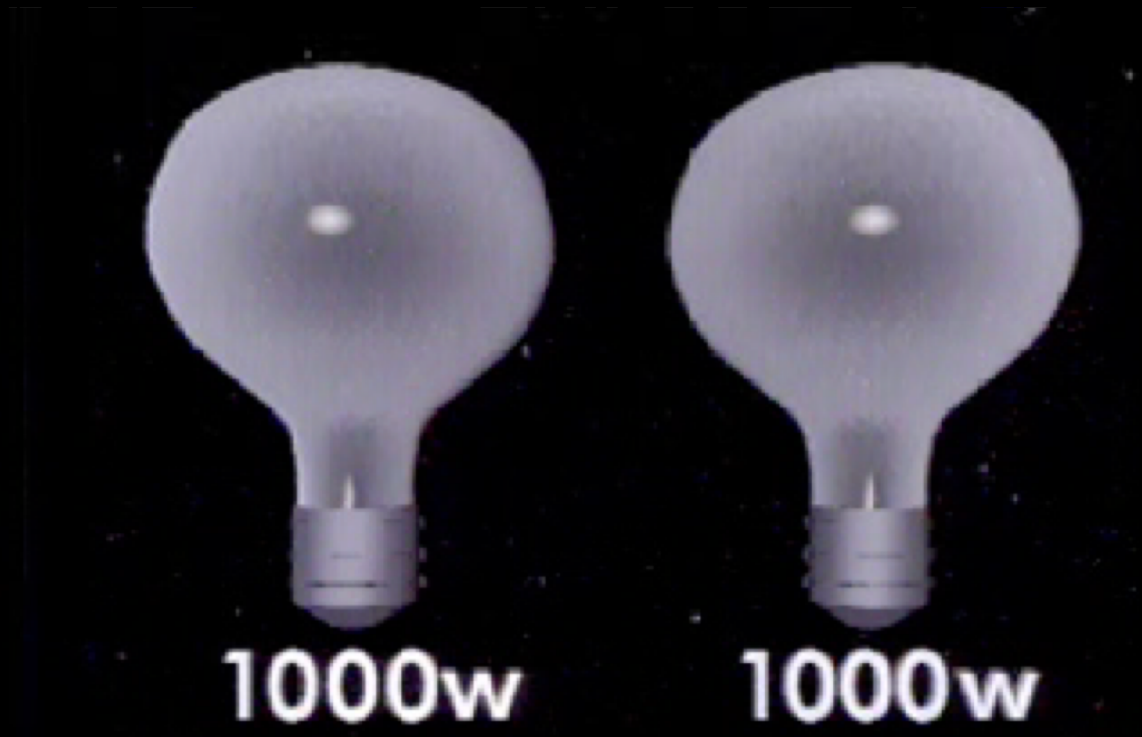

Supernova!
© Anglo-Australian Telescope

Kosmologie mit Supernovae

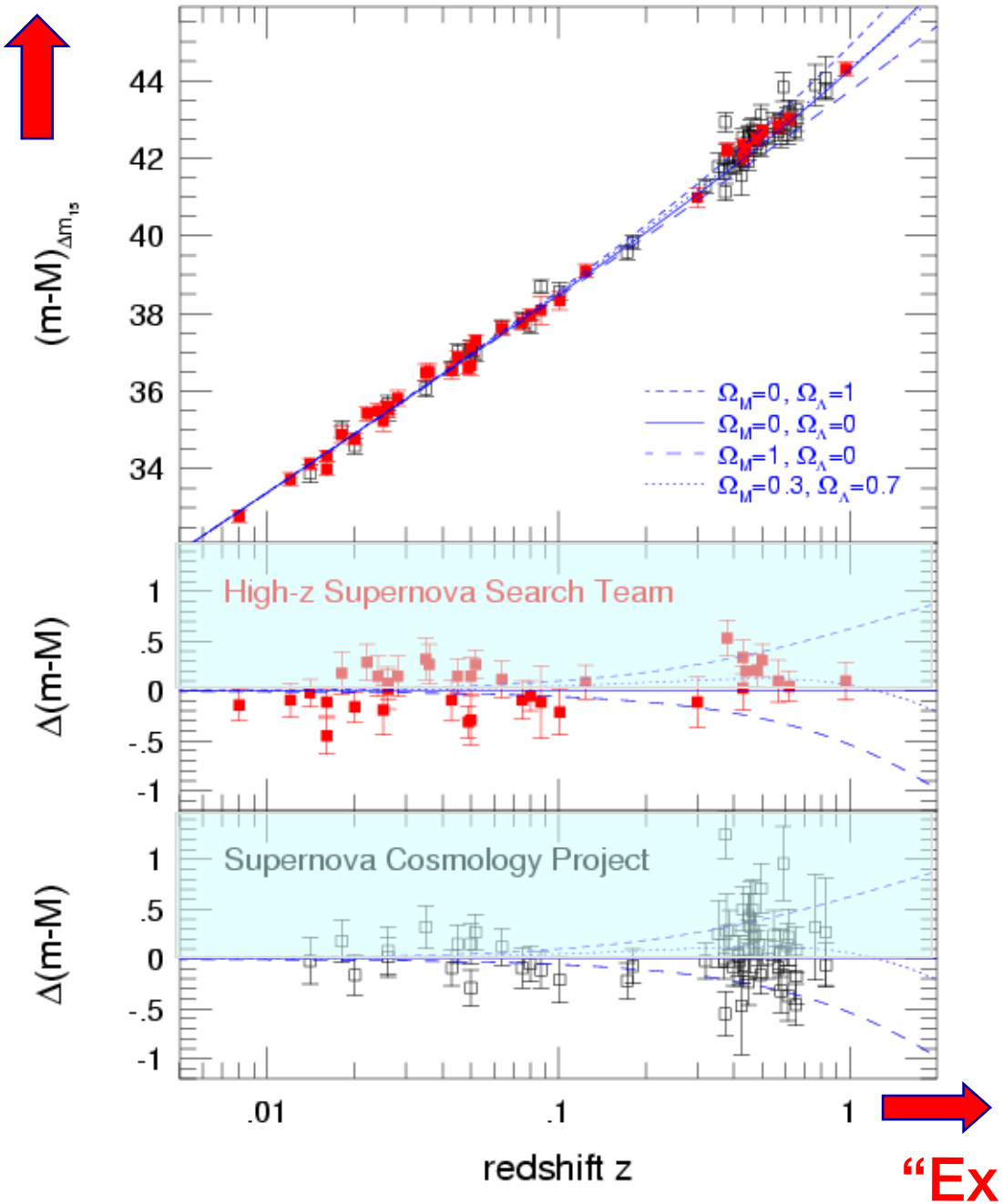
Entfernungen sind im Universum schwer zu messen. Sie sind aber essentiell, um die Expansionsrate und deren Geschichte bestimmen zu können.

Typ Ia Supernovae sind ausgezeichnete Entfernungsindikatoren, die im nahen Universum geeicht werden.

Entfernungsmessung mittels einer (bekannten) Lichtquelle

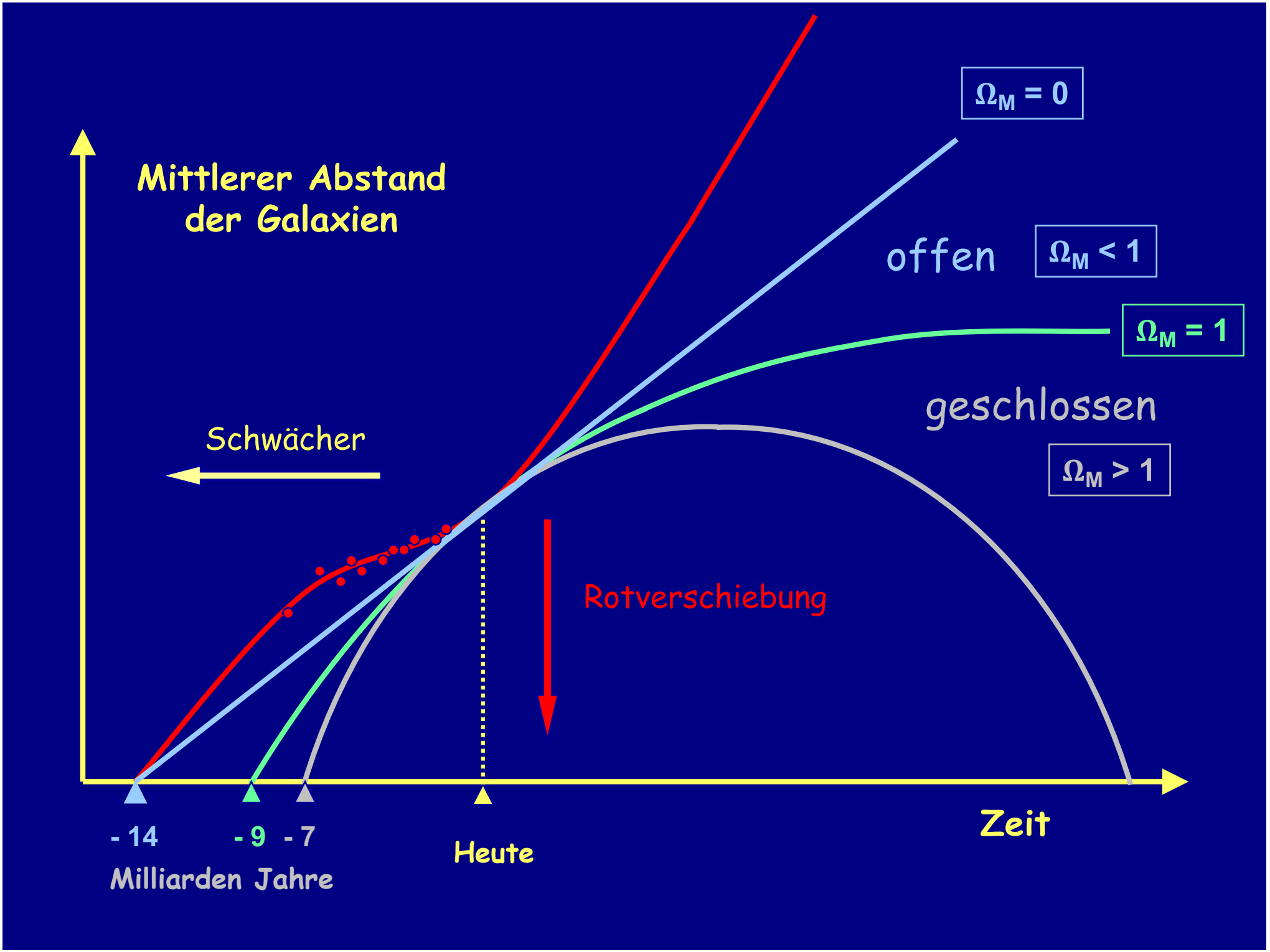


Entfernung



Das SN Hubble Diagramm

"Expansion"


Mittlerer Abstand der Galaxien
$\Omega_M = 0$
offen
$\Omega_M < 1$
$\Omega_M = 1$
geschlossen
$\Omega_M > 1$
Schwächer
Rotverschiebung
- 14
- 9
- 7
Milliarden Jahre
Heute
Zeit

This is a very interesting paper that makes me very nervous. Ultimately the solution is to publish it and let the world take its shots.

OBSERVATIONAL EVIDENCE FROM SUPERNOVAE FOR AN ACCELERATING UNIVERSE AND A COSMOLOGICAL CONSTANT

Adam G. Riess,[1] Alexei V. Filippenko,[2] Peter Challis,[3] Alejandro Clocchiatti,[3] Alan Diercks,[4] Peter M. Garnavich,[5] Ron L. Gilliland,[6] Craig J. Hogan,[4] Saurabh Jha,[3] Robert P. Kirshner,[3] B. Leibundgut,[6] M. M. Phillips,[7] David Reiss,[4] Brian P. Schmidt,[8,9] Robert A. Schommer,[7] R. Chris Smith,[7,10] J. Spyromilio,[6] Christopher Stubbs,[4] Nicholas B. Suntzeff,[7] and John Tonry[11]

Received 1998 March 13; revised 1998 May 6

ABSTRACT

We present spectral and photometric observations of 10 Type Ia supernovae (SNe Ia) in the redshift range $0.16 \leq z \leq 0.62$. The luminosity distances of these objects are determined by methods that employ relations between SN Ia luminosity and light curve shape. Combined with previous data from our High-z Supernova Search Team and recent results by Riess et al., this expanded set of 16 high-redshift supernovae and a set of 34 nearby supernovae are used to place constraints on the following cosmological parameters: the Hubble constant (H_0), the mass density (Ω_M), the cosmological constant (i.e., the vacuum energy density, Ω_Λ), the deceleration parameter (q_0), and the dynamical age of the universe (t_0). The distances of the high-redshift SNe Ia are, on average, 10%–15% farther than expected in a low mass density ($\Omega_M = 0.2$) universe without a cosmological constant. Different light curve fitting methods, SN Ia subsamples, and prior constraints unanimously favor eternally expanding models with positive cosmological constant (i.e., $\Omega_\Lambda > 0$) and a current acceleration of the expansion (i.e., $q_0 < 0$). With no prior constraint on mass density other than $\Omega_M \geq 0$, the spectroscopically confirmed SNe Ia are statistically consistent with $q_0 < 0$ at the 2.8 σ and 3.9 σ confidence levels, and with $\Omega_\Lambda > 0$ at the 3.0 σ and 4.0 σ confidence levels, for two different fitting methods, respectively. Fixing a "minimal" mass density, $\Omega_M = 0.2$, results in the weakest detection, $\Omega_\Lambda > 0$ at the 3.0 σ confidence level from one of the two methods. For a flat universe prior ($\Omega_M + \Omega_\Lambda = 1$), the spectroscopically confirmed SNe Ia require $\Omega_\Lambda > 0$ at 7 σ and 9 σ formal statistical significance for the two different fitting methods. A universe closed by ordinary matter (i.e., $\Omega_M = 1$) is formally ruled out at the 7 σ to 8 σ confidence level for the two different fitting methods. We estimate the dynamical age of the universe to be 14.2 ± 1.7 Gyr including systematic uncertainties in the current Cepheid distance scale. We estimate the likely effect of several sources of systematic error, including progenitor and metallicity evolution, extinction, sample selection bias, local perturbations in the expansion rate, gravitational lensing, and sample contamination. Presently, none of these effects appear to reconcile the data with $\Omega_\Lambda = 0$ and $q_0 \geq 0$.

Key words: cosmology: observations — supernovae: general

1. INTRODUCTION

This paper reports observations of 10 new high-redshift Type Ia supernovae (SNe Ia) and the values of the cosmological parameters derived from them. Together with the four high-redshift supernovae previously reported by our High-z Supernova Search Team (Schmidt et al. 1998; Garnavich et al. 1998a) and two others (Riess et al. 1998b), the sample of 16 is now large enough to yield interesting cosmological results of high statistical significance. Confidence in these results depends not on increasing the sample size but on improving our understanding of systematic uncertainties.

The time evolution of the cosmic scale factor depends on the composition of mass-energy in the universe. While the universe is known to contain a significant amount of ordinary matter, Ω_M, which decelerates the expansion, its dynamics may also be significantly affected by more exotic forms of energy. Preeminent among these is a possible energy of the vacuum (Ω_Λ), Einstein's "cosmological con-

[1] Department of Astronomy, University of California at Berkeley, Berkeley, CA 94720-3411.
[2] Harvard-Smithsonian Center for Astrophysics, 60 Garden Street, Cambridge, MA 02138.
[3] Departamento de Astronomía y Astrofísica, Pontificia Universidad Católica, Casilla 104, Santiago 22, Chile.
[4] Department of Astronomy, University of Washington, Box 351580, Seattle, WA 98195.
[5] Space Telescope Science Institute, 3700 San Martin Drive, Baltimore, MD 21218.
[6] European Southern Observatory, Karl-Schwarzschild-Strasse 2, D-85748 Garching bei München, Germany.
[7] Cerro Tololo Inter-American Observatory, National Optical Astronomy Observatories, Casilla 603, La Serena, Chile. NOAO is operated by the Association of Universities for Research in Astronomy, Inc., under cooperative agreement with the National Science Foundation.
[8] Mount Stromlo and Siding Spring Observatories, Private Bag, Weston Creek, ACT 2611, Australia.
[9] Visiting Astronomer, Cerro Tololo Inter-American Observatory.
[10] Department of Astronomy, University of Michigan, 834 Dennison Building, Ann Arbor, MI 48109.
[11] Institute for Astronomy, University of Hawaii, 2680 Woodlawn Drive, Honolulu, HI 96822.

Physik Nobelpreis 2011

KUNGL. VETENSKAPS-AKADEMIEN
THE ROYAL SWEDISH ACADEMY OF SCIENCES

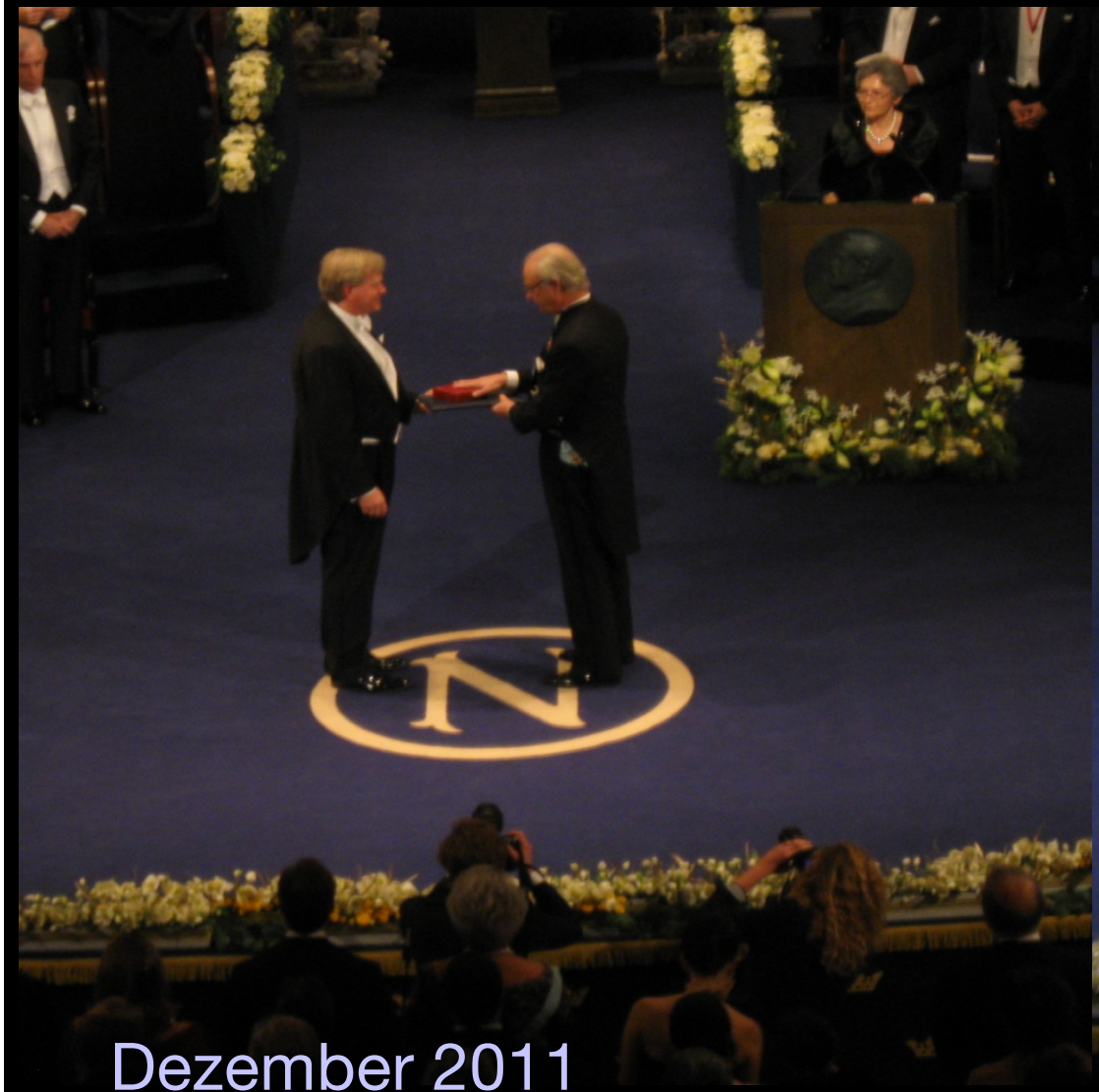
Saul Perlmutter

Brian Schmidt

Adam Riess

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

… und die Konsequenz

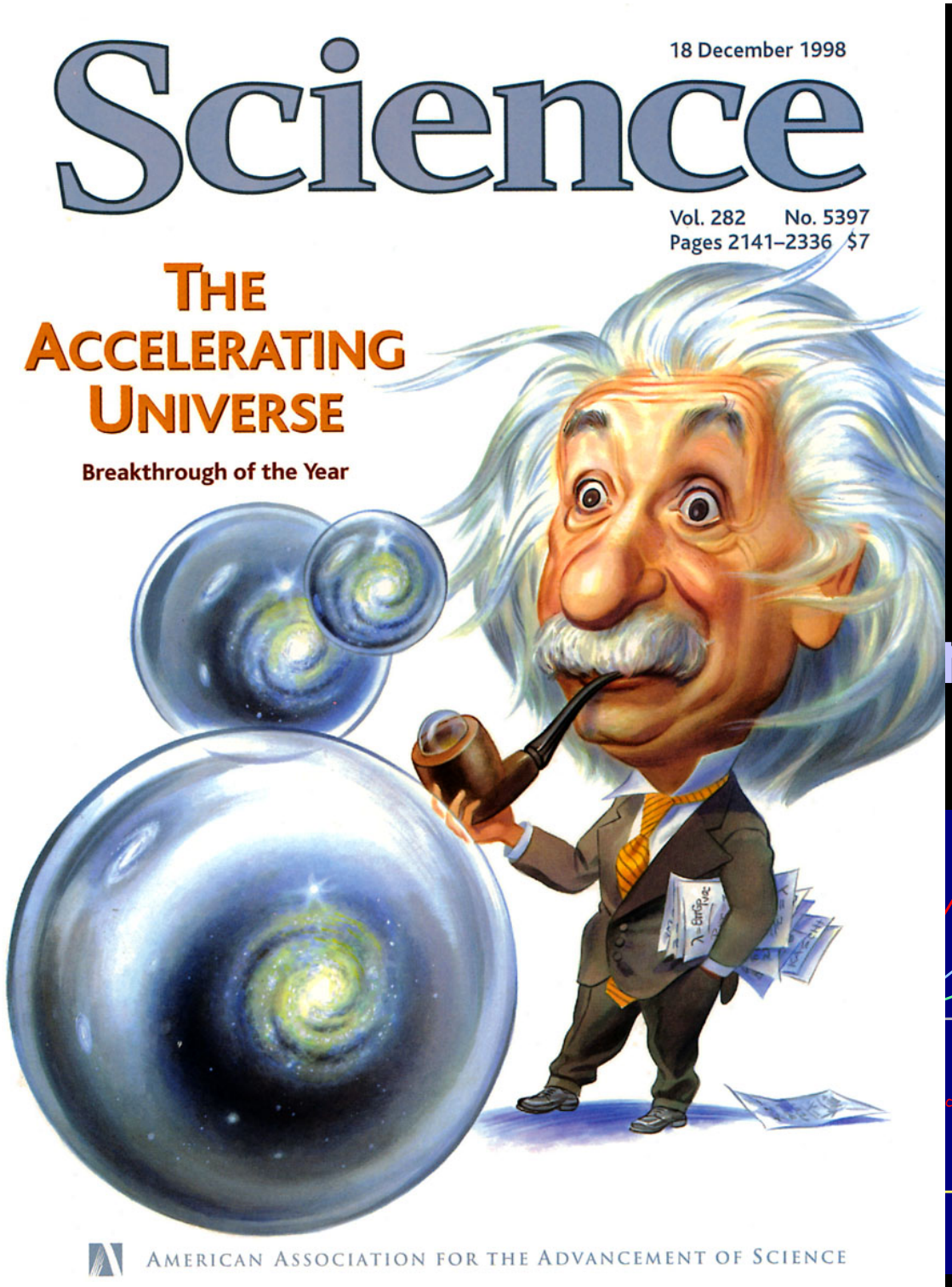


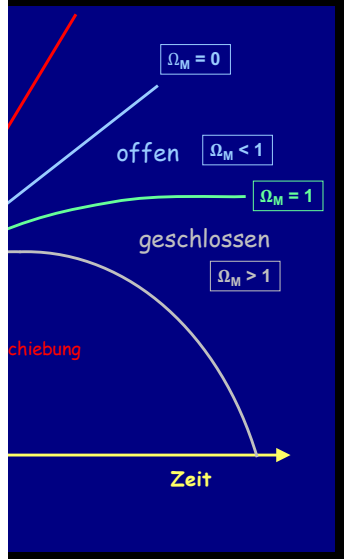
Dezember 2011

Das High-z Supernova Search Team
Dezember 2011

Entfern
entfern
expand
Univers
abstoss
werden

ne

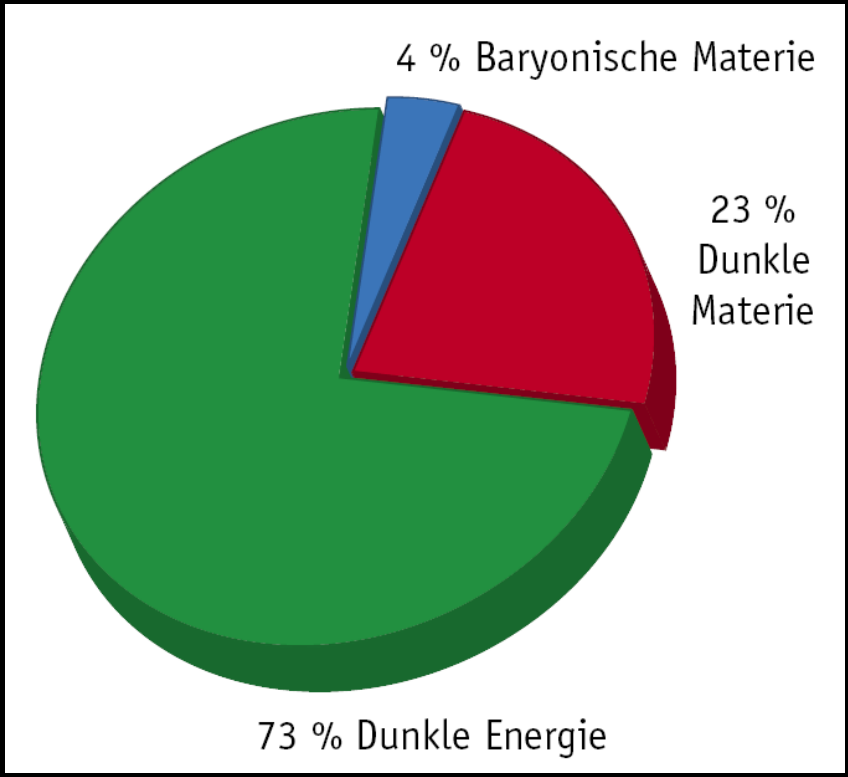




Der Inhalt des Universums

Dunkle Materie und Dunkle Energie sind die bestimmenden Energiebeiträge des Universums.

Was sind sie?



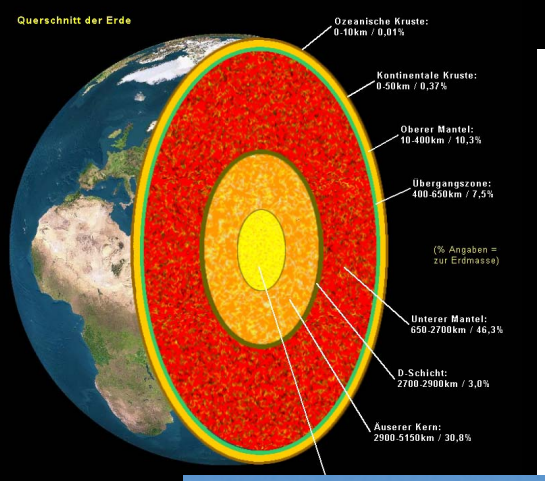
Was bedeutet das?

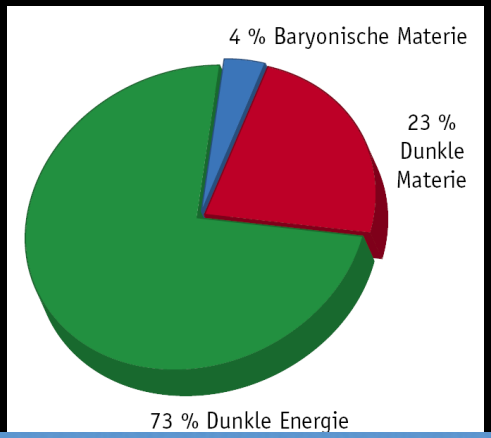
Das Universum besteht im wesentlichen aus nichts.

Das Universum expandiert für immer.

Im Moment existiert keine überzeugende physikalische Interpretation der Vakuumsenergie (Dunkle Energie).

Nur 4% des Universums sind aus demselben „Stoff“ wie wir (und alles, das wir kennen).





Unser Universum
Unsere Welt