Karlsruhe Institute of Technology

Astroteilchenphysik II: Gammastrahlung

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Grundlagen

- Einheiten
- Größenordnungen und Entfernungen
- Fluss, Wirkungsquerschnitt, Teilchendichte, Helligkeit
- Materiesäule und optische Dichte
- relativistische Kinematik

Vorlesung und Übungen : Daten

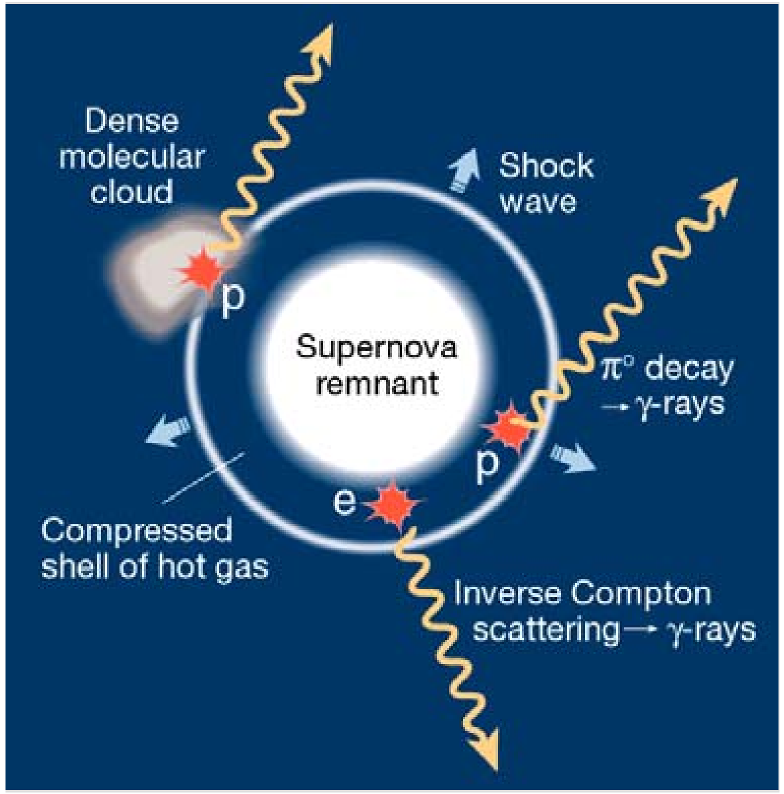
Übungen:

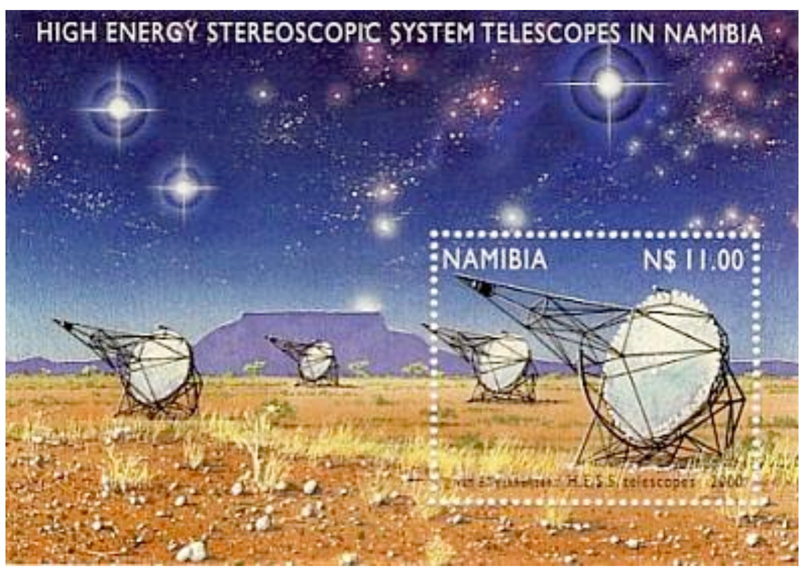
- Gehalten von David Schmidt
- 1 Übungsblatt alle 2-3 Wochen
- 1. Übungsblatt nächste Woche

21.04.2020
28.04.2020
05.05.2020
12.05.2020
19.05.2020
26.05.2020
02.06.2020
09.06.2020
16.06.2020
23.06.2020
30.06.2020
07.07.2020
14.07.2020
21.07.2020

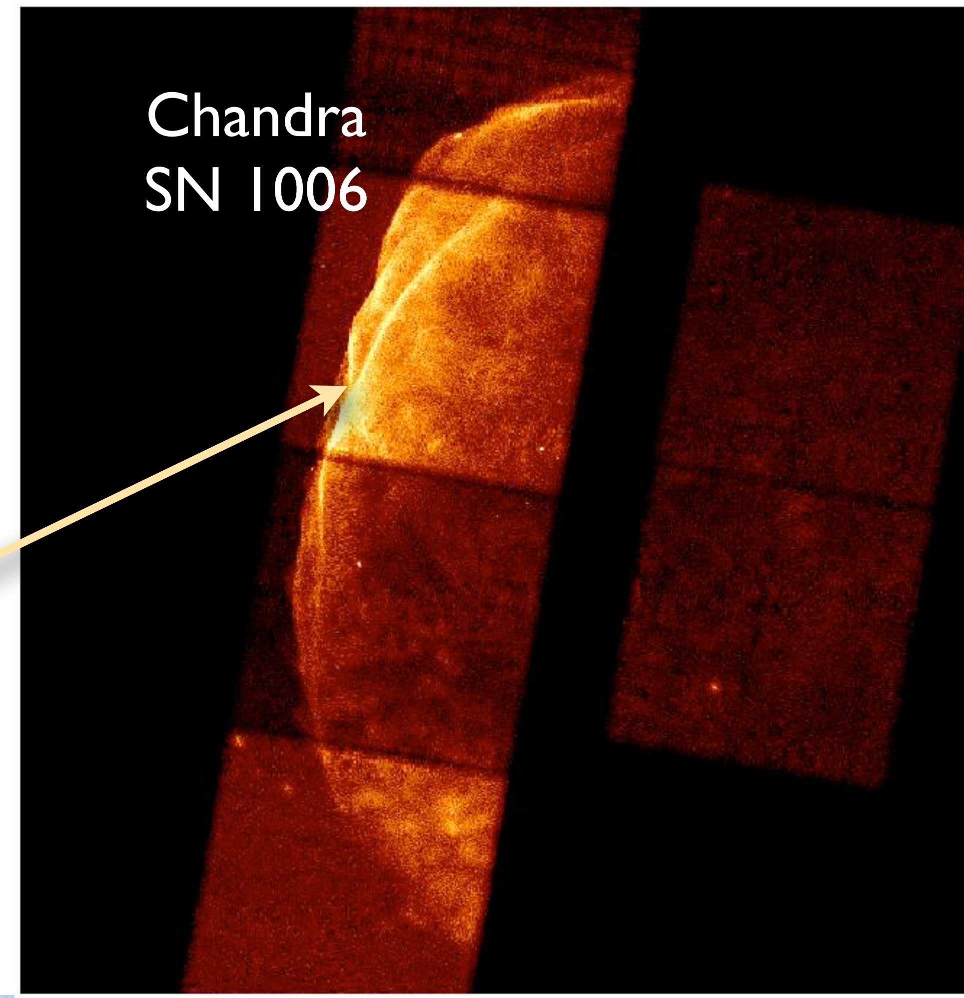
Dienstag		Donnerstag	
		23.04.2020	Vorlesung
		30.04.2020	Vorlesung
		07.05.2020	Vorlesung
12.05.2020	Übung	14.05.2020	Vorlesung
		-	Feiertag
		28.05.2020	Vorlesung
		04.06.2020	Vorlesung
09.06.2020	Übung	-	Feiertag
		18.06.2020	Vorlesung
23.06.2020	Übung	25.06.2020	Vorlesung
		02.07.2020	Vorlesung
07.07.2020	Übung	09.07.2020	Vorlesung
		16.07.2020	Vorlesung
21.07.2020	Übung	23.07.2020	Vorlesung

Indirekter Nachweis der Beschleunigung von Hadronen





Beispiel: Gamma-Strahlung
(Neutrinos wären eindeutiger!)

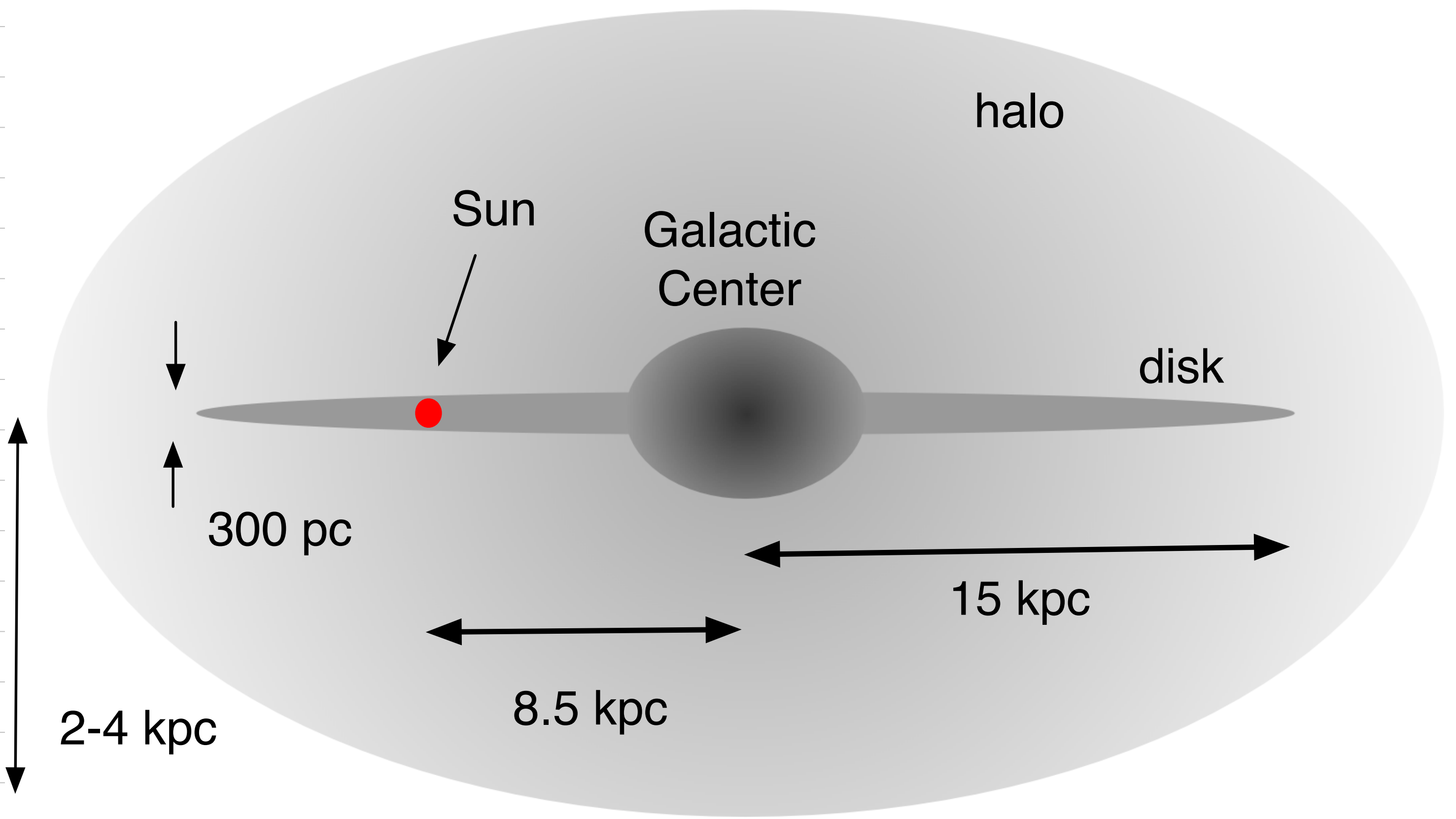


Filamente haben ca. 100 μG Feldstärke, indirekter Nachweis von Hadronen-beschleunigung

H.E.S.S.

(High Energy Sterescopic System, Namibia)

Abstände



Magnetfeld nicht gut bekannt,
B = 3 μG = 30 nT in der Nähe der Sonne

Parsec: 1 pc = 3.26 ly = 3.08 10^{18} cm
Astronomische Einheit: 1AU = 1.496 10^{13} cm
Lichtjahr: 1 ly = 0.3066 pc
Radius der Sonne: 6.961 10^{10} cm
Masse der Sonne: 1.989 10^{33} g
Luminosität der Sonne: 3.846 10^{33} erg/s

(1 erg = 0.1 μJ)

Typische Entfernungen & Luminosität

NB: 1 pc = 3.26 ly

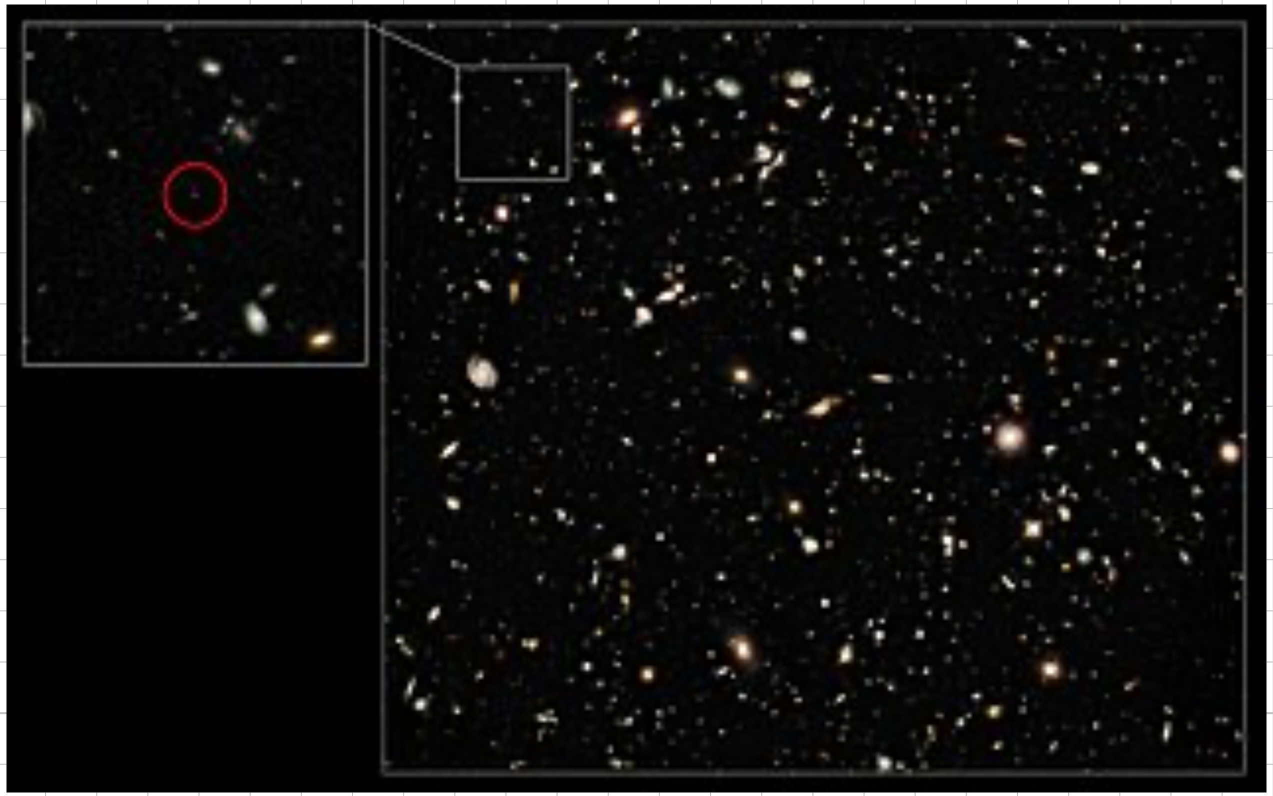
Sonne	$4.5\ 10^{-6}$ pc
Alpha Centauri	1.33 pc
Galaktisches Zentrum	8.5 kpc
Magellansche Wolken	48.7 kpc
Centaurus A (am Südhimmel)	3.8 Mpc
M87 (am Nordhimmel)	16.4 Mpc

Entfernteste Galaxie UDFy-38135539

$z = 8.55$

$d_{\text{light travel time}} = 13.2$ Gly

$d_{\text{comoving distance}} = 30.3$ Gly

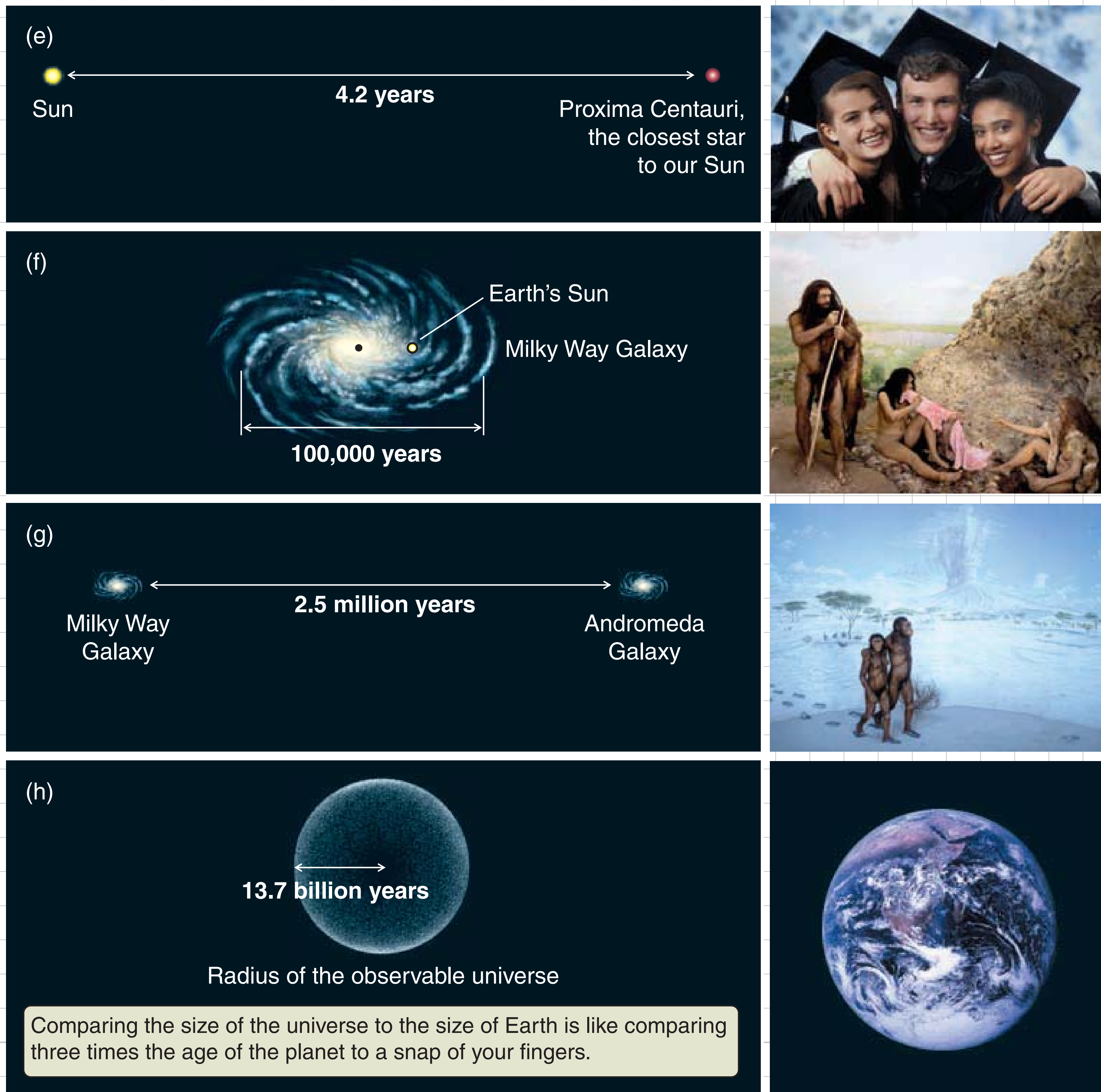


Rotverschiebung

0.004	16 Mpc
0.01	40 Mpc
0.05	200 Mpc
0.1	415 Mpc
1	4,750 Mpc
4	22,000 Mpc
8.55	98,778 Mpc

Distanzen im Universum

VISUAL ANALOGY FIGURE 1.2 Thinking about the time it takes for light to travel between objects helps us to better comprehend the vast distances in the universe.



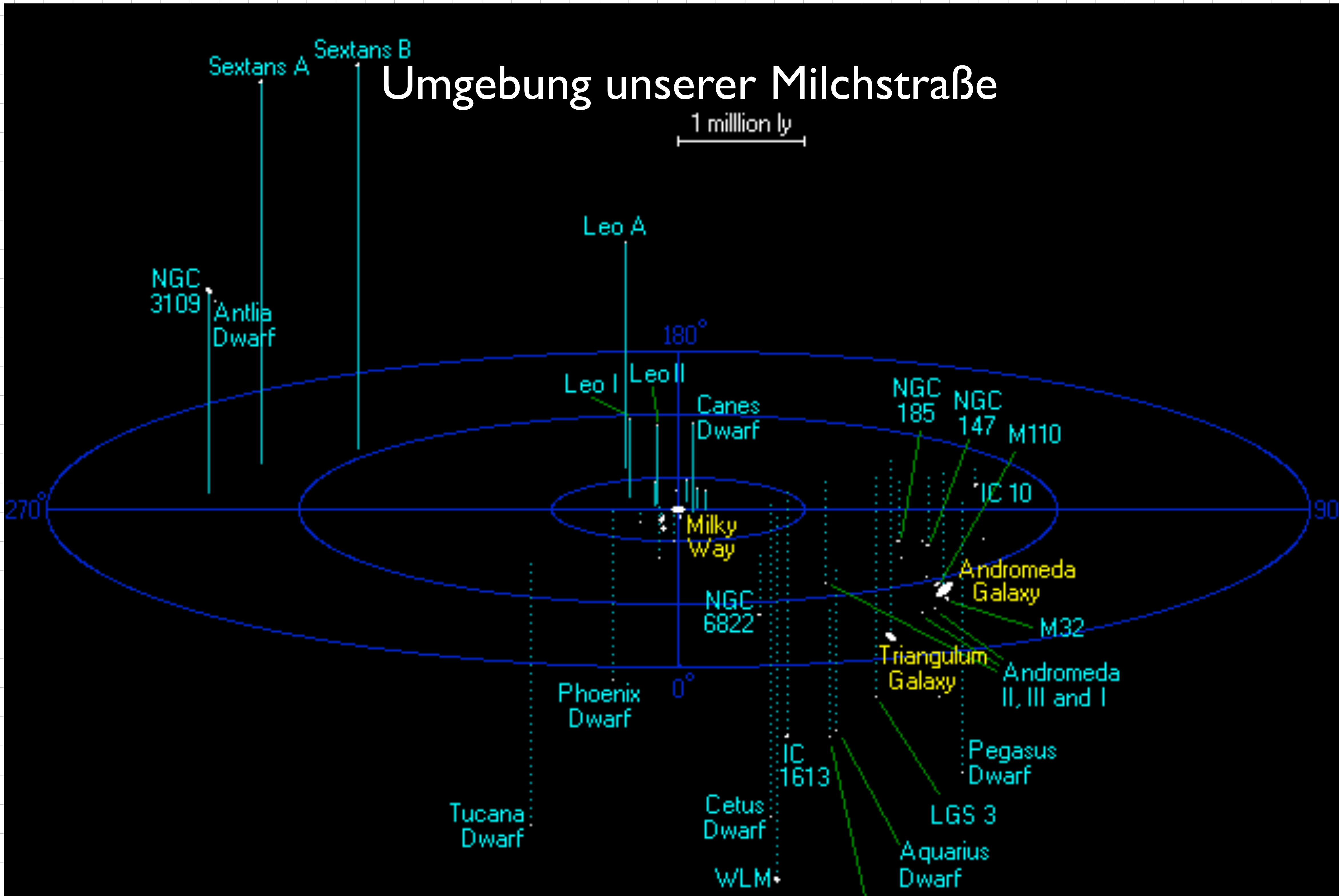
The distance to the nearest star is like the time you spend in high school,…

…the diameter of the galaxy is like the age of our species,…

…and the distance between galaxies is like the time since earliest human ancestors walked on Earth.

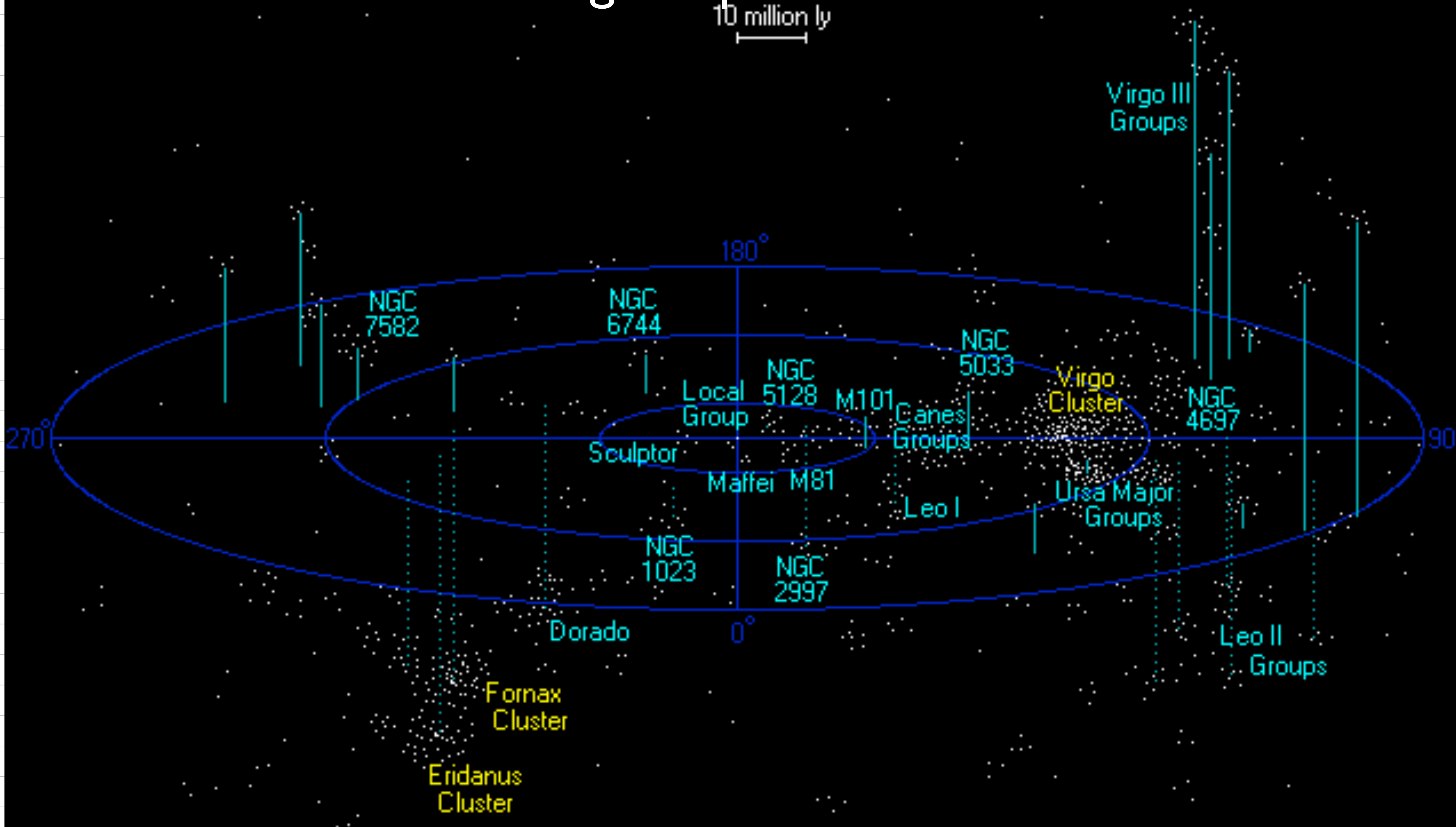
The size of the universe is like three times the age of Earth.

Umgebung unserer Milchstraße



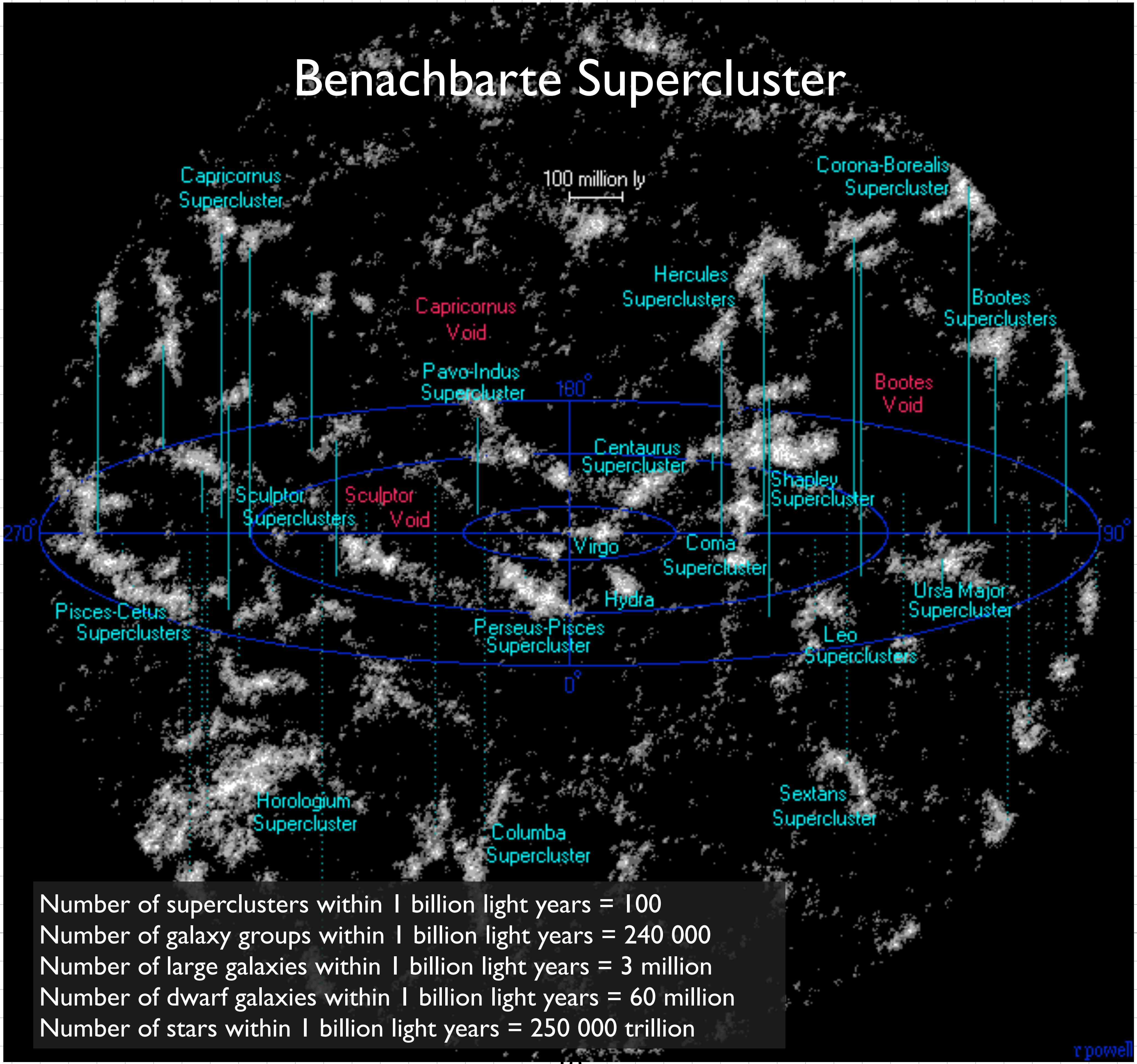
Number of large galaxies within 5 million light years = 3
Number of dwarf galaxies within 5 million light years = 46
Number of stars within 5 million light years = 700 billion

Virgo-Supercluster



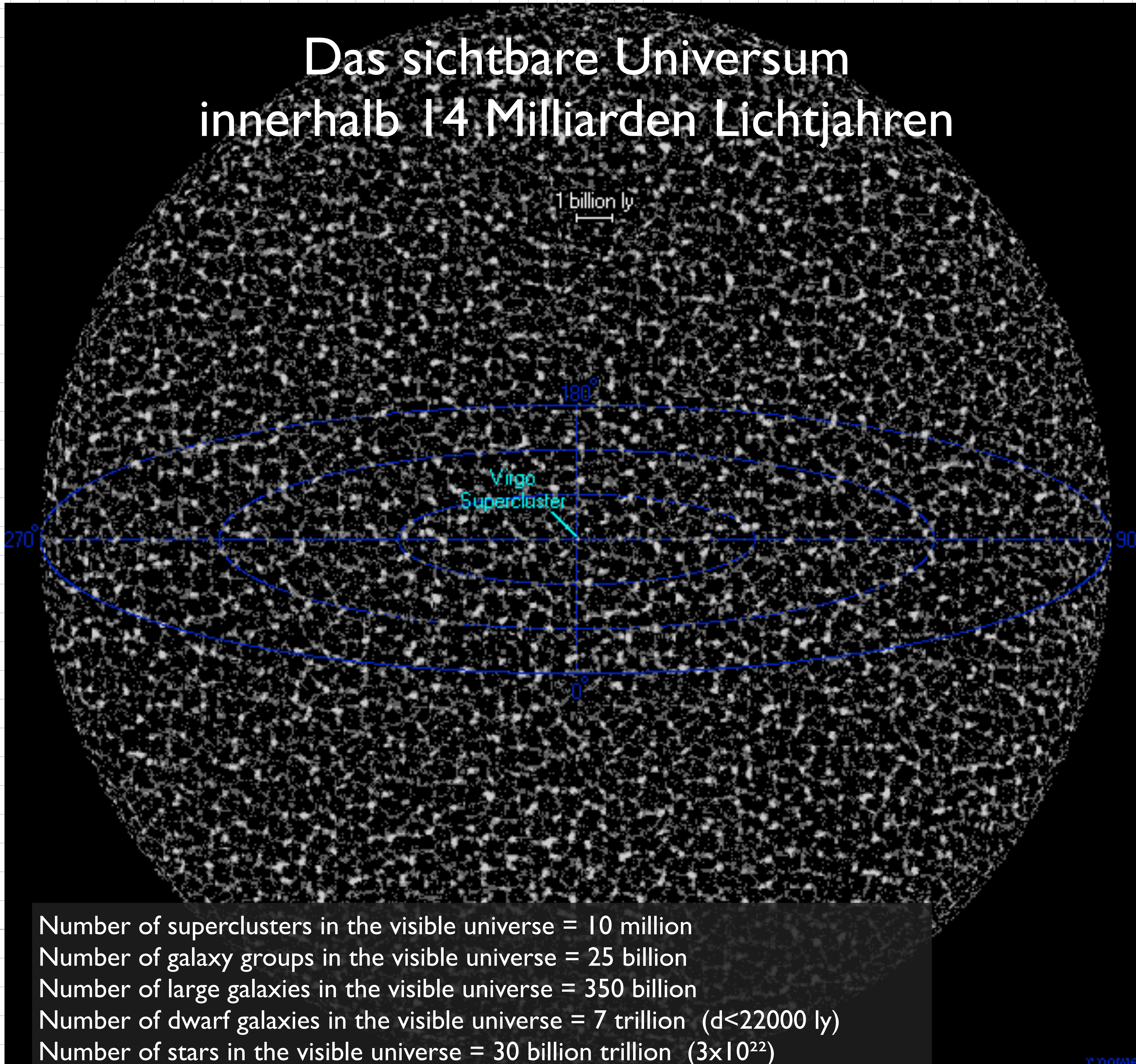
Number of galaxy groups within 100 million light years = 200
Number of large galaxies within 100 million light years = 2500
Number of dwarf galaxies within 100 million light years = 50 000
Number of stars within 100 million light years = 200 trillion

Benachbarte Supercluster



Number of superclusters within 1 billion light years = 100
Number of galaxy groups within 1 billion light years = 240 000
Number of large galaxies within 1 billion light years = 3 million
Number of dwarf galaxies within 1 billion light years = 60 million
Number of stars within 1 billion light years = 250 000 trillion

Das sichtbare Universum innerhalb 14 Milliarden Lichtjahren



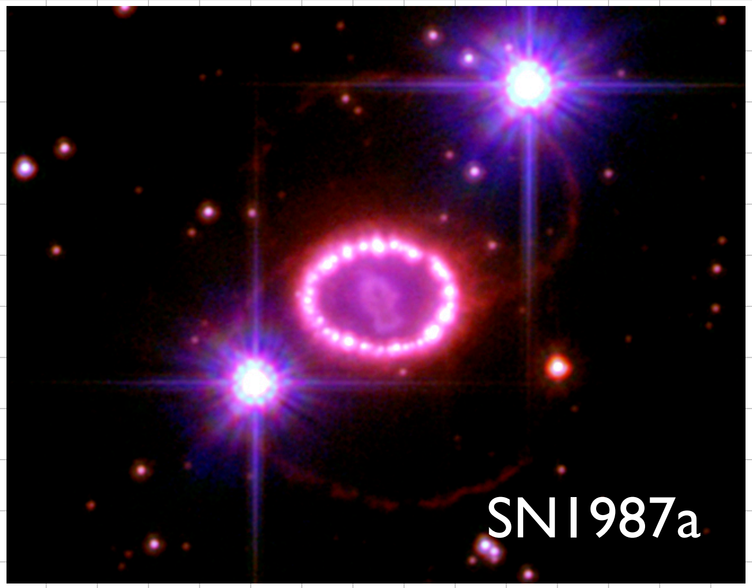
Number of superclusters in the visible universe = 10 million
Number of galaxy groups in the visible universe = 25 billion
Number of large galaxies in the visible universe = 350 billion
Number of dwarf galaxies in the visible universe = 7 trillion (d<22000 ly)
Number of stars in the visible universe = 30 billion trillion ($3x10^{22}$)

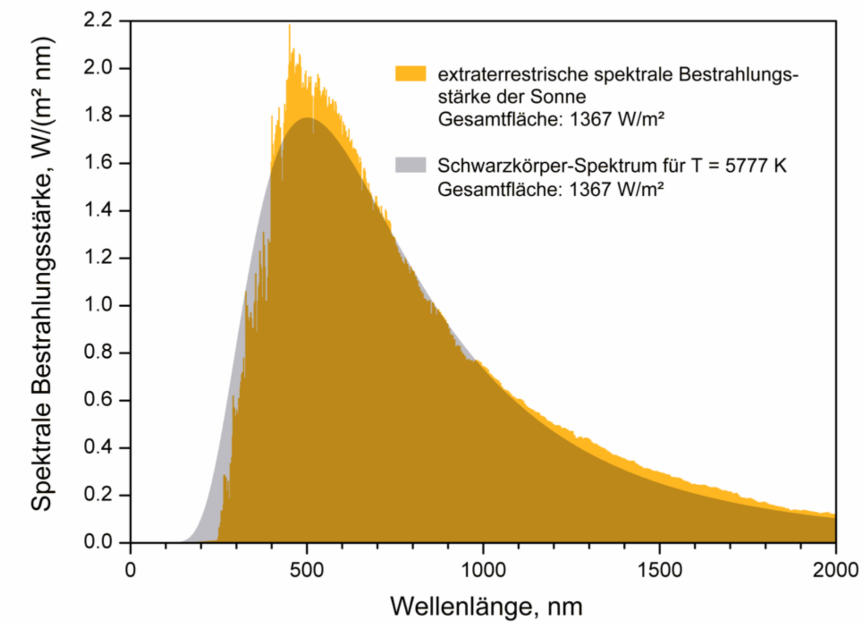
Fluss und Teilchendichte

Wirkungsquerschnitt und Reaktionsrate

Durchlaufene Materiesäule

Leuchtkraft L





Bsp: Evolution der Leuchtkraft von Blazern (FSRQs)

Fermi-LAT: 10 keV-100 GeV

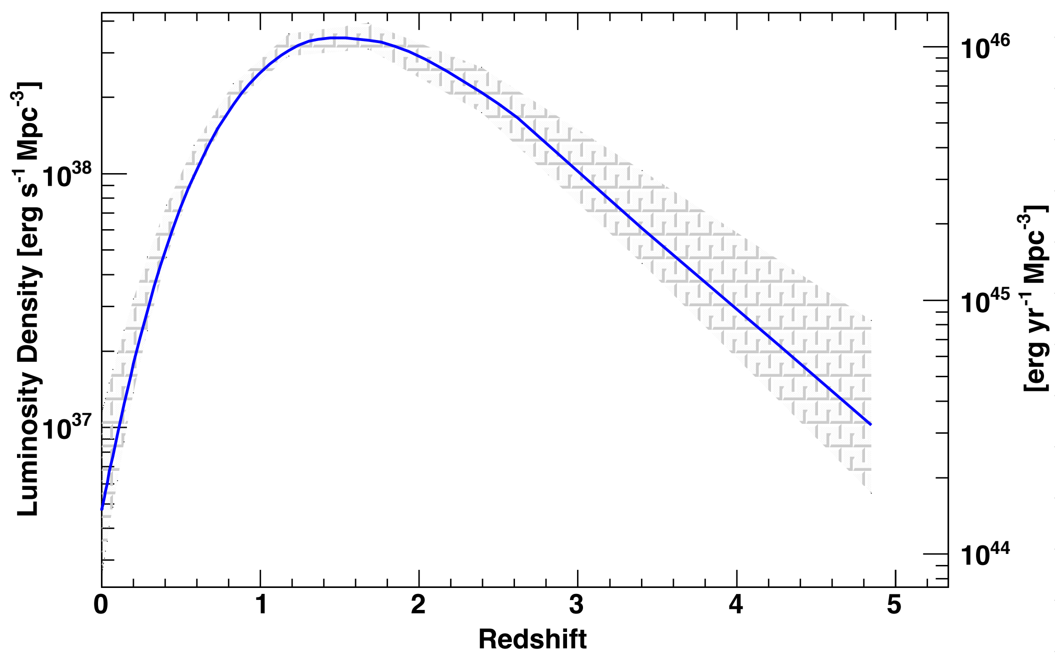
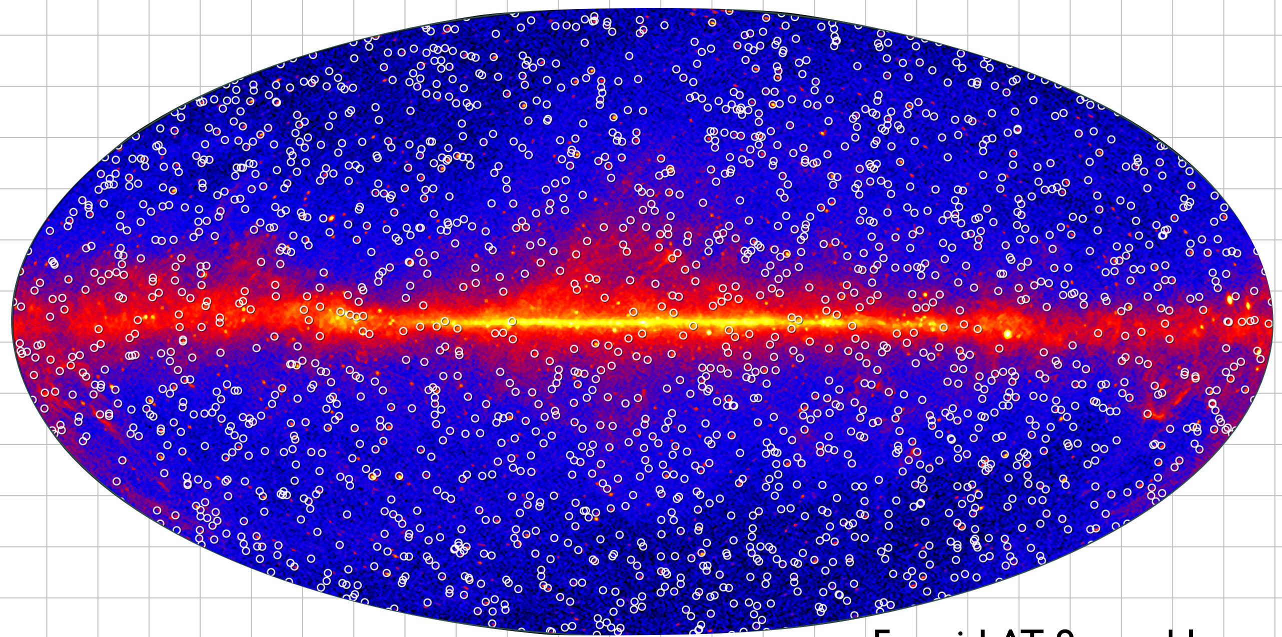


Fig. 14.— Luminosity density as a function of redshift produced by the *Fermi* FSRQs. The gray band represents the $1\,\sigma$ statistical uncertainty around the best-fit LF model.



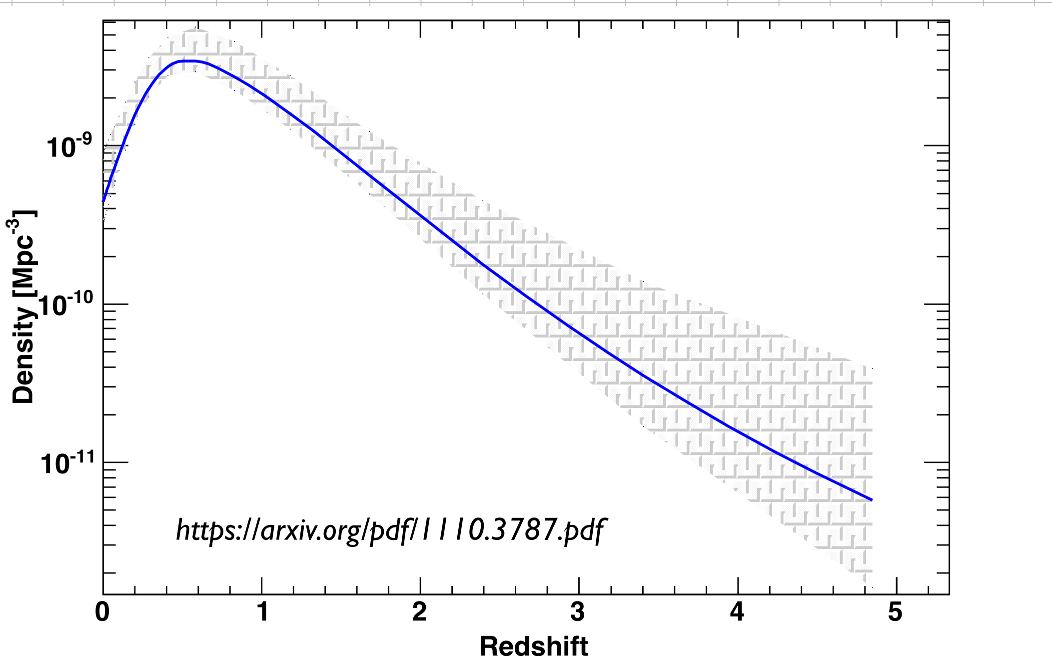
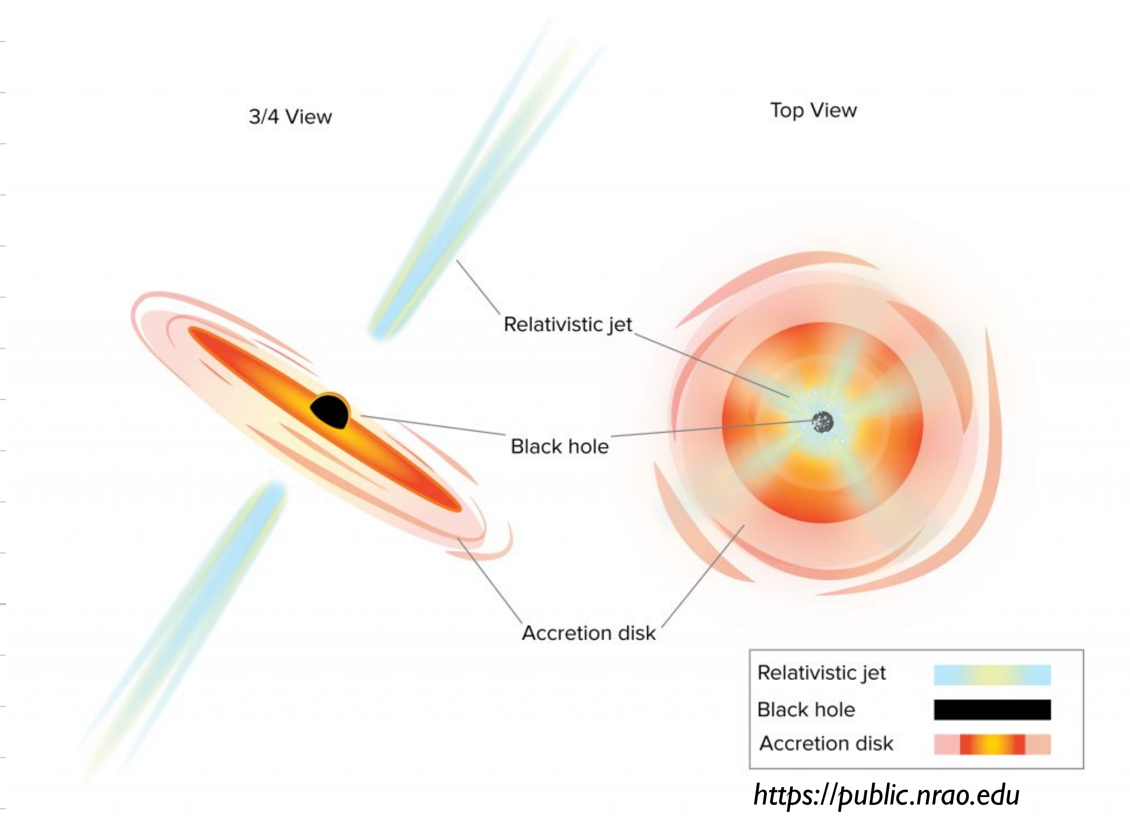
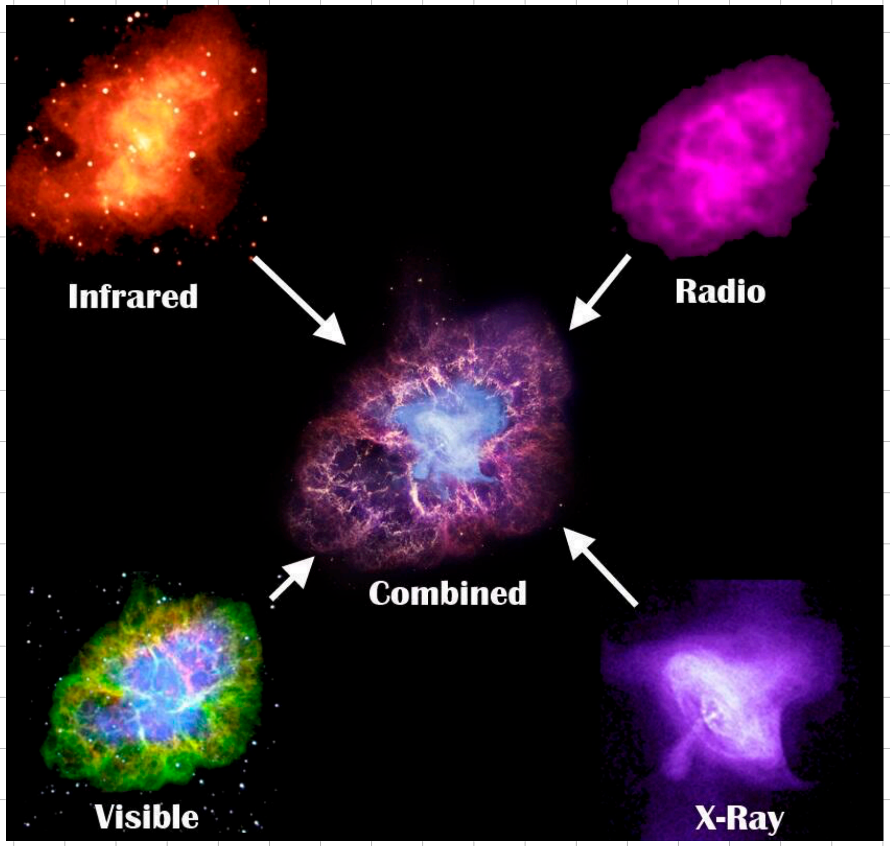


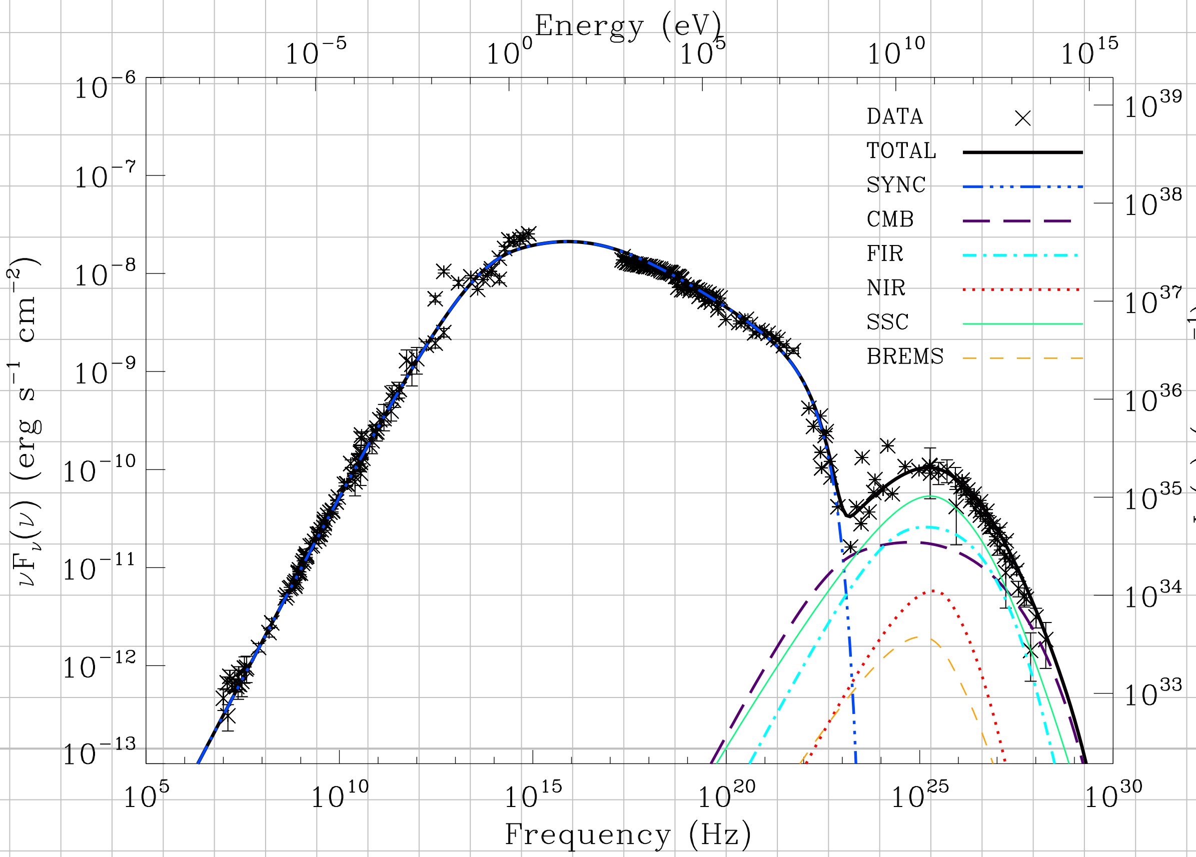
Fig. 15.— Number density of LAT-detected FSRQs as a function of redshift. The gray band represents the $1\,\sigma$ statistical uncertainty around the best-fit LF model.



Energiefluss F

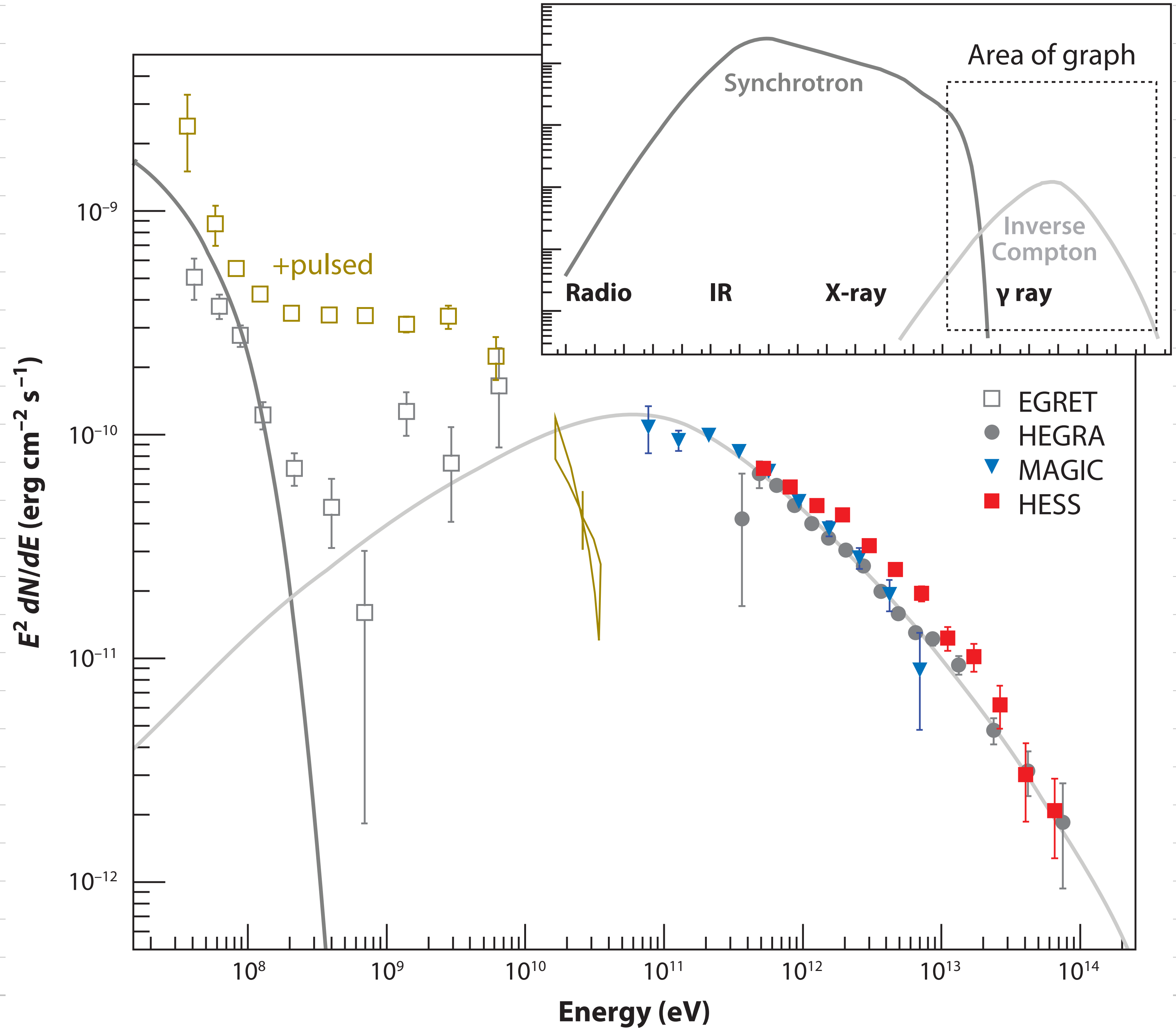
Bsp: Energiefluss des Krebsnebels



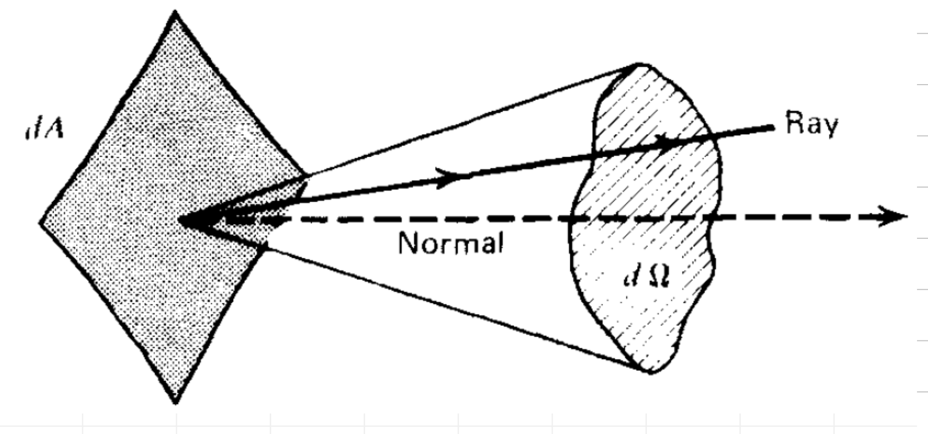


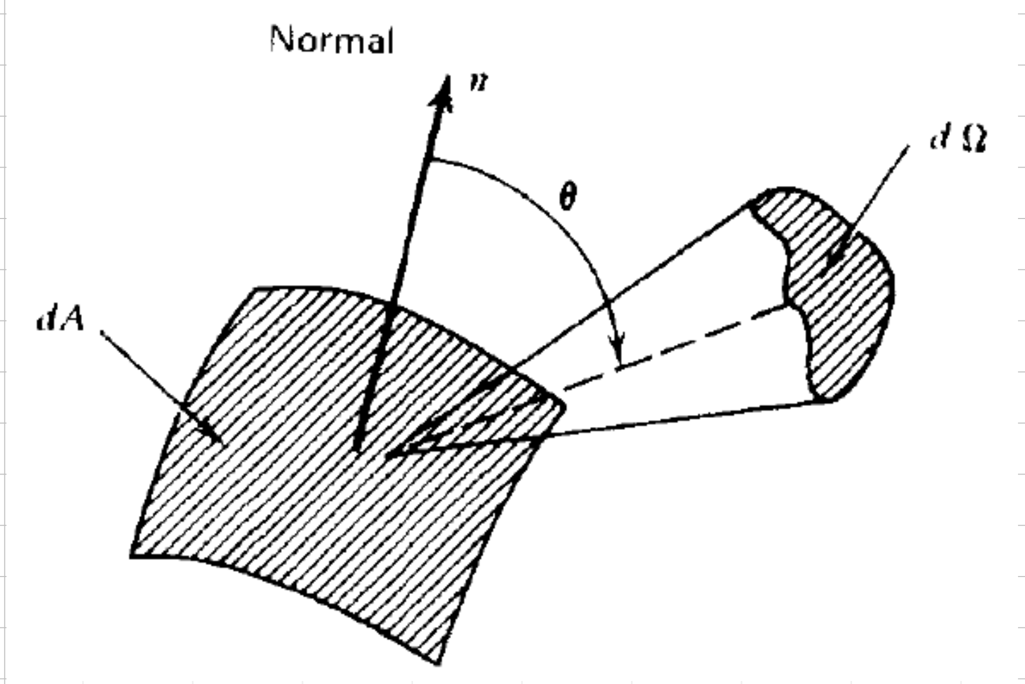
https://arxiv.org/pdf/1209.0300.pdf

Gamma-Strahlung des Krebsnebels



Helligkeit, Intensität *I* (manchmal *B*)





Relativistische Rechnung: Impuls & Energie

Teilchenzoo und Zerfallskanäle

particle	main decay mode	life-time $t_{1/2}$	range $ct_{1/2}$
γ	–	∞	∞
e^-	–	∞	∞
p	–	∞	∞
n	$n \to p + e^- + \bar{\nu}_e$	886s	2.65×10^{13} cm
μ^-	$\mu^- \to e^- + \bar{\nu}_e + \nu_\mu$	$t_{1/2} \sim 2.20 \times 10^{-6}$s	659 m
π^-	$\pi^- \to \mu^- + \bar{\nu}_\mu$	$t_{1/2} \sim 2.60 \times 10^{-8}$ s	780 cm
π^0	$\pi^0 \to 2\gamma$	$t_{1/2} \sim 8.4 \times 10^{-17}$ s	25.1 nm
ν	–	∞	∞

PDG: Physikalische Konstanten

Quantity	Symbol, equation	Value	Uncertainty (ppb)
speed of light in vacuum	c	$299\ 792\ 458$ m s^{-1}	exact*
Planck constant	h	$6.626\ 068\ 96(33)\times10^{-34}$ J s	50
Planck constant, reduced	$\hbar \equiv h/2\pi$	$1.054\ 571\ 628(53)\times10^{-34}$ J s	50
		$= 6.582\ 118\ 99(16)\times10^{-22}$ MeV s	25
electron charge magnitude	e	$1.602\ 176\ 487(40)\times10^{-19}$ C $= 4.803\ 204\ 27(12)\times10^{-10}$ esu	25, 25
conversion constant	$\hbar c$	$197.326\ 9631(49)$ MeV fm	25
conversion constant	$(\hbar c)^2$	$0.389\ 379\ 304(19)$ GeV^2 mbarn	50
electron mass	m_e	$0.510\ 998\ 910(13)$ MeV$/c^2 = 9.109\ 382\ 15(45)\times10^{-31}$ kg	25, 50
proton mass	m_p	$938.272\ 013(23)$ MeV$/c^2 = 1.672\ 621\ 637(83)\times10^{-27}$ kg	25, 50
		$= 1.007\ 276\ 466\ 77(10)$ u $= 1836.152\ 672\ 47(80)\ m_e$	0.10, 0.43
deuteron mass	m_d	$1875.612\ 793(47)$ MeV$/c^2$	25
unified atomic mass unit (u)	(mass ^{12}C atom)$/12 = (1$ g$)/(N_A$ mol$)$	$931.494\ 028(23)$ MeV$/c^2 = 1.660\ 538\ 782(83)\times10^{-27}$ kg	25, 50
permittivity of free space	$\epsilon_0 = 1/\mu_0 c^2$	$8.854\ 187\ 817 \ldots \times10^{-12}$ F m^{-1}	exact
permeability of free space	μ_0	$4\pi \times 10^{-7}$ N A^{-2} $= 12.566\ 370\ 614 \ldots \times10^{-7}$ N A^{-2}	exact
fine-structure constant	$\alpha = e^2/4\pi\epsilon_0\hbar c$	$7.297\ 352\ 5376(50)\times10^{-3} = 1/137.035\ 999\ 679(94)^\dagger$	0.68, 0.68
classical electron radius	$r_e = e^2/4\pi\epsilon_0 m_e c^2$	$2.817\ 940\ 2894(58)\times10^{-15}$ m	2.1
(e^- Compton wavelength)$/2\pi$	$\lambda\!\!\!^{-}_e = \hbar/m_e c = r_e\alpha^{-1}$	$3.861\ 592\ 6459(53)\times10^{-13}$ m	1.4
Bohr radius ($m_{\text{nucleus}} = \infty$)	$a_\infty = 4\pi\epsilon_0\hbar^2/m_e e^2 = r_e\alpha^{-2}$	$0.529\ 177\ 208\ 59(36)\times10^{-10}$ m	0.68
wavelength of 1 eV$/c$ particle	$hc/(1$ eV$)$	$1.239\ 841\ 875(31)\times10^{-6}$ m	25
Rydberg energy	$hcR_\infty = m_e e^4/2(4\pi\epsilon_0)^2\hbar^2 = m_e c^2\alpha^2/2$	$13.605\ 691\ 93(34)$ eV	25
Thomson cross section	$\sigma_T = 8\pi r_e^2/3$	$0.665\ 245\ 8558(27)$ barn	4.1

http://pdg.lbl.gov

PDG: Physikalische Konstanten

Bohr magneton	$\mu_B = e\hbar/2m_e$	$5.788\,381\,7555(79)\times10^{-11}$ MeV T^{-1}	1.4
nuclear magneton	$\mu_N = e\hbar/2m_p$	$3.152\,451\,2326(45)\times10^{-14}$ MeV T^{-1}	1.4
electron cyclotron freq./field	$\omega^e_{\mathrm{cycl}}/B = e/m_e$	$1.758\,820\,150(44)\times10^{11}$ rad s^{-1} T^{-1}	25
proton cyclotron freq./field	$\omega^p_{\mathrm{cycl}}/B = e/m_p$	$9.578\,833\,92(24)\times10^{7}$ rad s^{-1} T^{-1}	25
gravitational constant‡	G_N	$6.674\,28(67)\times10^{-11}$ m^3 kg^{-1} s^{-2}	1.0×10^5
		$= 6.708\,81(67)\times10^{-39}$ $\hbar c$ $(\mathrm{GeV}/c^2)^{-2}$	1.0×10^5
standard gravitational accel.	g_N	$9.806\,65$ m s^{-2}	exact
Avogadro constant	N_A	$6.022\,141\,79(30)\times10^{23}$ mol^{-1}	50
Boltzmann constant	k	$1.380\,6504(24)\times10^{-23}$ J K^{-1}	1700
		$= 8.617\,343(15)\times10^{-5}$ eV K^{-1}	1700
molar volume, ideal gas at STP	$N_A k(273.15\ \mathrm{K})/(101\,325\ \mathrm{Pa})$	$22.413\,996(39)\times10^{-3}$ m^3 mol^{-1}	1700
Wien displacement law constant	$b = \lambda_{\max}T$	$2.897\,7685(51)\times10^{-3}$ m K	1700
Stefan-Boltzmann constant	$\sigma = \pi^2 k^4/60\hbar^3 c^2$	$5.670\,400(40)\times10^{-8}$ W m^{-2} K^{-4}	7000
Fermi coupling constant**	$G_F/(\hbar c)^3$	$1.166\,37(1)\times10^{-5}$ GeV^{-2}	9000
weak-mixing angle	$\sin^2\widehat{\theta}(M_Z)$ ($\overline{\mathrm{MS}}$)	0.231 16(13)††	5.6×10^5
$W^\pm$ boson mass	m_W	80.399(23) GeV/c^2	2.9×10^5
Z^0 boson mass	m_Z	91.1876(21) GeV/c^2	2.3×10^4
strong coupling constant	$\alpha_s(m_Z)$	0.1184(7)	5.9×10^6

$\pi = 3.141\,592\,653\,589\,793\,238$ $\qquad$ $e = 2.718\,281\,828\,459\,045\,235$ $\qquad$ $\gamma = 0.577\,215\,664\,901\,532\,861$

$1\ \mathrm{in} \equiv 0.0254\ \mathrm{m}$	$1\ \mathrm{G} \equiv 10^{-4}\ \mathrm{T}$	$1\ \mathrm{eV} = 1.602\ 176\ 487(40)\times10^{-19}\ \mathrm{J}$	kT at $300\ \mathrm{K} = [38.681\ 685(68)]^{-1}\ \mathrm{eV}$
$1\ \mathrm{Å} \equiv 0.1\ \mathrm{nm}$	$1\ \mathrm{dyne} \equiv 10^{-5}\ \mathrm{N}$	$1\ \mathrm{eV}/c^2 = 1.782\ 661\ 758(44)\times10^{-36}\ \mathrm{kg}$	$0\ ^\circ\mathrm{C} \equiv 273.15\ \mathrm{K}$
$1\ \mathrm{barn} \equiv 10^{-28}\ \mathrm{m}^2$	$1\ \mathrm{erg} \equiv 10^{-7}\ \mathrm{J}$	$2.997\ 924\ 58\times10^{9}\ \mathrm{esu} = 1\ \mathrm{C}$	$1\ \mathrm{atmosphere} \equiv 760\ \mathrm{Torr} \equiv 101\ 325\ \mathrm{Pa}$

Natürliche und CGS-Einheiten

$$\hbar = 1 \quad c = 1 \quad q_\mathrm{e} = 1$$

Schrödingergleichung:

$$i\hbar \frac{\partial}{\partial t} \Psi(x,t) = \hat{H} \Psi(x,t)$$

Die natürliche Einheit einiger physikalischer Größen in SI-Einheiten

Größe	geschriebene Einheit	tatsächliche Einheit	Wert in SI-Einheiten
Energie	$1\ \mathrm{eV}$		$1{,}60218 \cdot 10^{-19}$ J
Länge	$\frac{1}{1\ \mathrm{eV}}$	$\frac{c\hbar}{1\ \mathrm{eV}}$	$1{,}97327 \cdot 10^{-7}$ m
Zeit	$\frac{1}{1\ \mathrm{eV}}$	$\frac{\hbar}{1\ \mathrm{eV}}$	$6{,}58212 \cdot 10^{-16}$ s
Masse	$1\ \mathrm{eV}$	$\frac{1\ \mathrm{eV}}{c^2}$	$1{,}78266 \cdot 10^{-36}$ kg
Temperatur	$1\ \mathrm{eV}$	$\frac{1\ \mathrm{eV}}{k_B}$	$1{,}16044 \cdot 10^{4}$ K

Wellengleichung:

$$\frac{1}{c^2}\frac{\partial^2}{\partial t^2}\vec{E}(x,t) + \frac{\partial^2}{\partial x^2}\vec{E}(x,t) = 0$$

Elektrische Arbeit:

$$W = UIt$$

Traditionell: CGS-Einheiten (cm, g, s)

$1\,\mathrm{erg} = 10^{-7}\,\mathrm{J}$