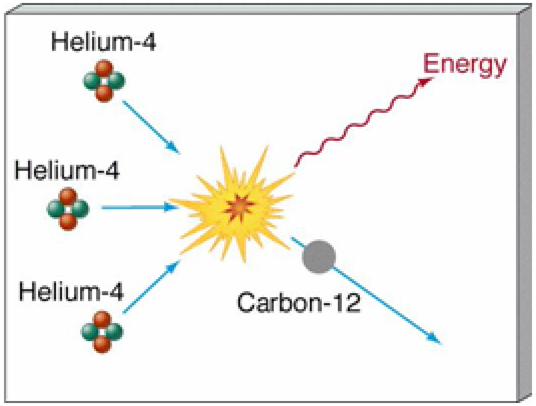
Weißer Zwerg

$$0.25 \cdot M_\odot < M < M_{Ch} = 1.4 \cdot M_\odot$$

bei He-Zündtemperatur (~10^8 K)

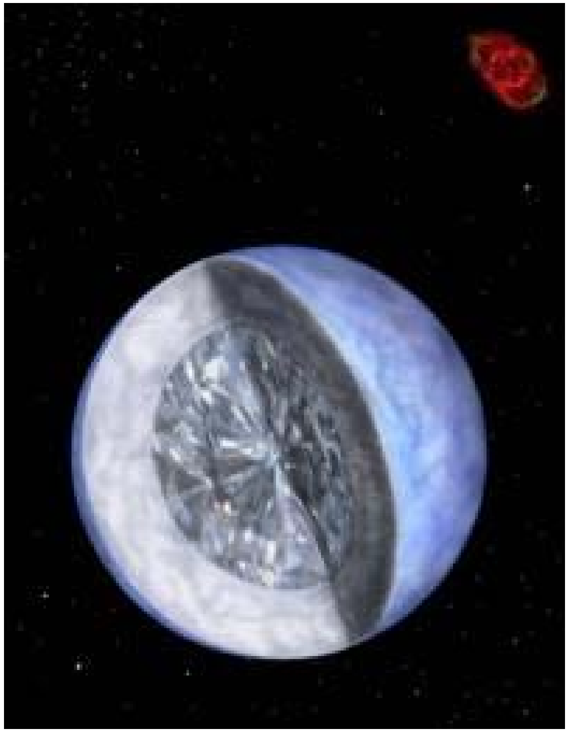
$$P_{Fermi} \gg P_{gas}$$

==> Kontraktion nach H-Ausbrennen
führt nicht zu Expansion



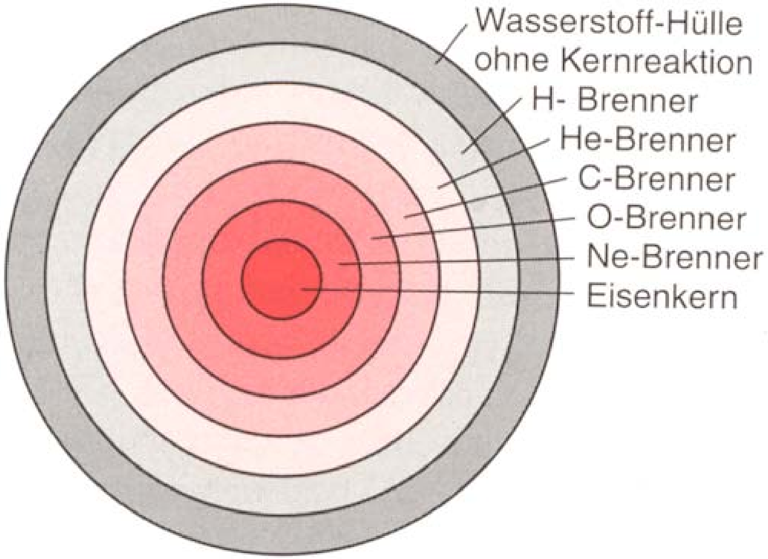
==>
explosionsartiges Zünden
bei Erreichen von (P,T)
für Triple-α-Prozess:

Helium-Flash



Der Weiße Zwerg BPM 37093 dürfte der größte Diamant der Milchstraße sein.

Supernova Typ II (Kernkollaps-SN)



Eisenkern überschreitet $\boldsymbol{M_{Ch}}$,,,
Explosion durch **schnelle Kühlung**:

- **Photodisintegration von Fe, He**
  $T>10^{10}$ K → E_γ erreicht ~2.5 MeV

$$\begin{aligned} \gamma + {}^{56}\mathrm{Fe} &\leftrightarrow 13\,{}^{4}\mathrm{He} + 4n \\ \gamma + {}^{4}\mathrm{He} &\rightarrow 2p + 2n \end{aligned}$$

- **Neutronisierung:** bei mit der Dichte steigendem Fermi-Impuls der Elektronen:

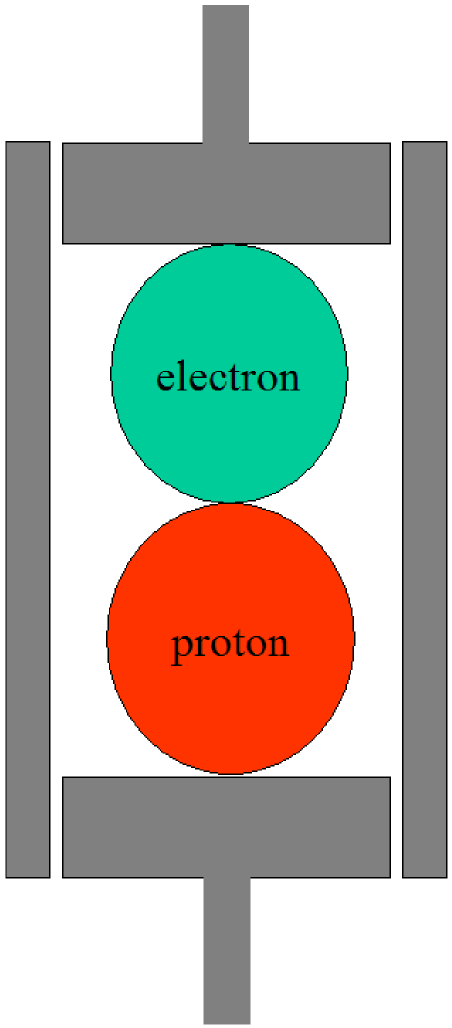
$$e^- + p \rightarrow n + \nu_e$$

$$e^- + {}^{56}\mathrm{Fe} \rightarrow {}^{56}\mathrm{Mn} + \nu_e$$

Neutrinos entweichen → „Freifallzeit“ des Kerns

$$\boxed{t_{ff} = \sqrt{\frac{3\pi}{32 G\rho}} \approx 0.1\,\mathrm{s}}$$

Neutronisierung

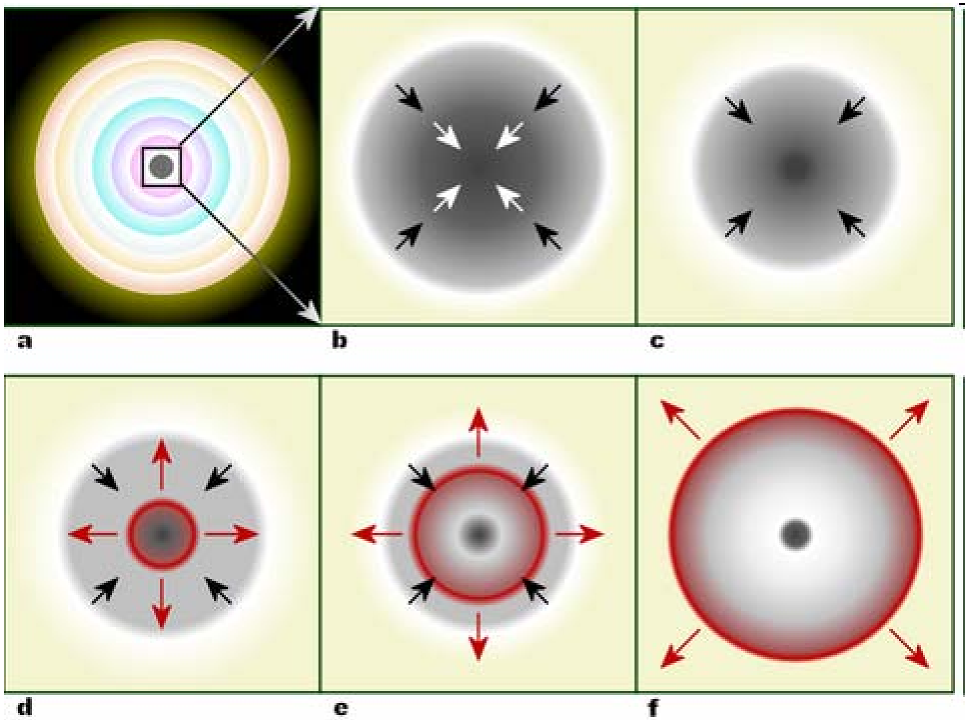


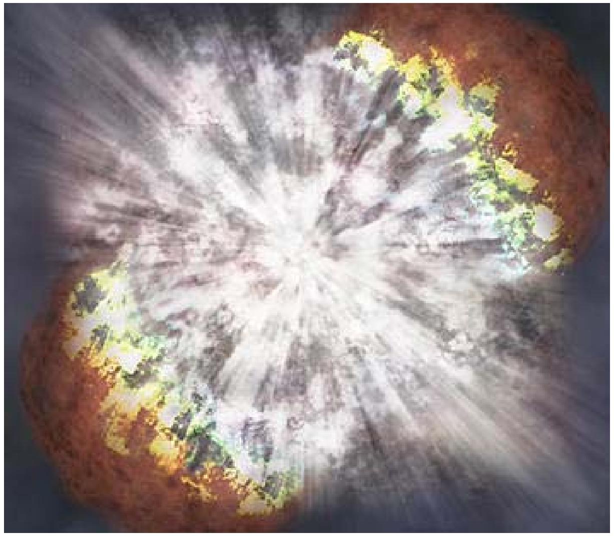
Schockwelle

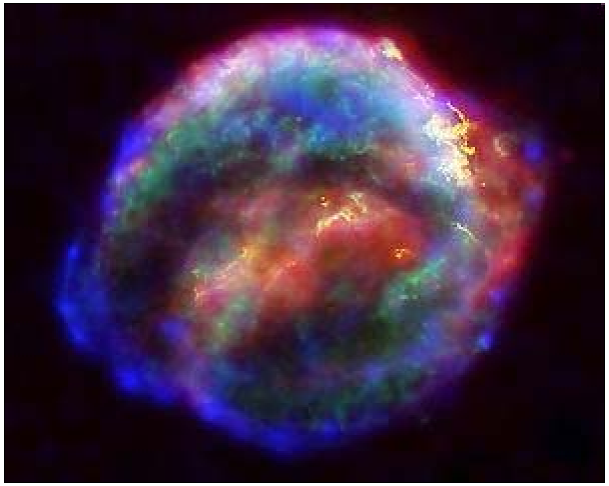
$$\rho_{Kern} = \rho_{nukl} = \frac{3m_p}{4\pi r_0^3} \approx 2 \cdot 10^{17}\,\mathrm{kg\,m^{-3}}$$

Rücklaufende Schockwelle wenn

$$\rho_{Kern} \approx 2 \ldots 3 \cdot \rho_{nukl}$$



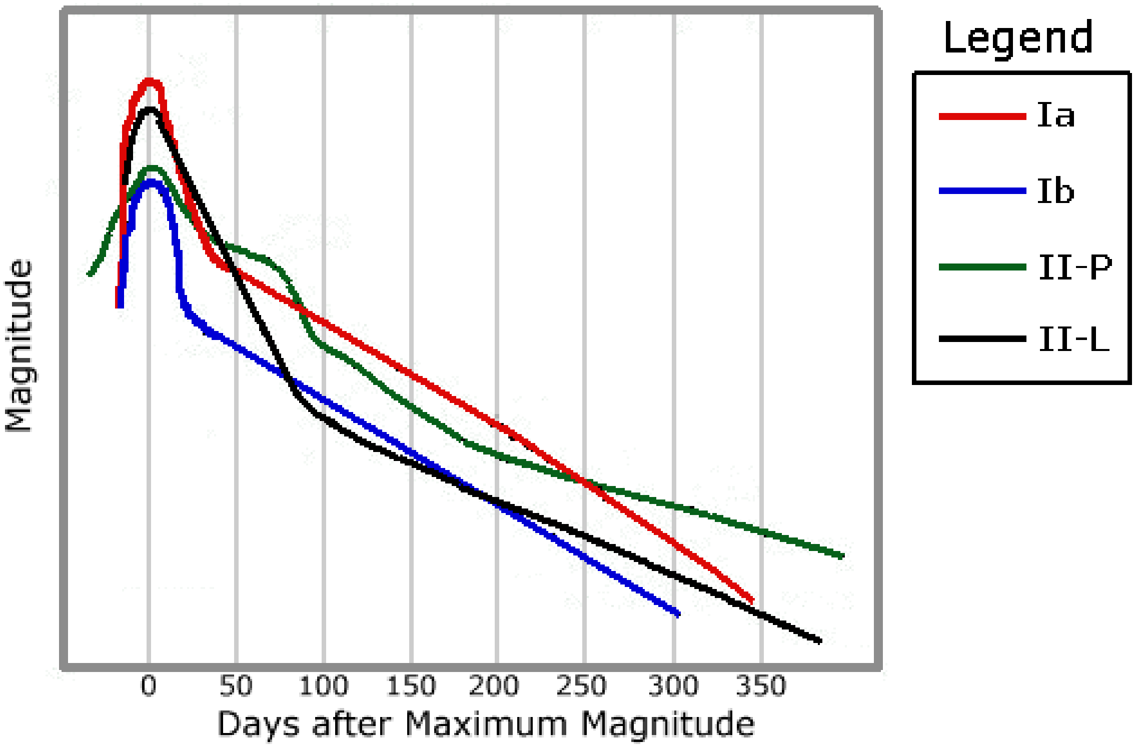




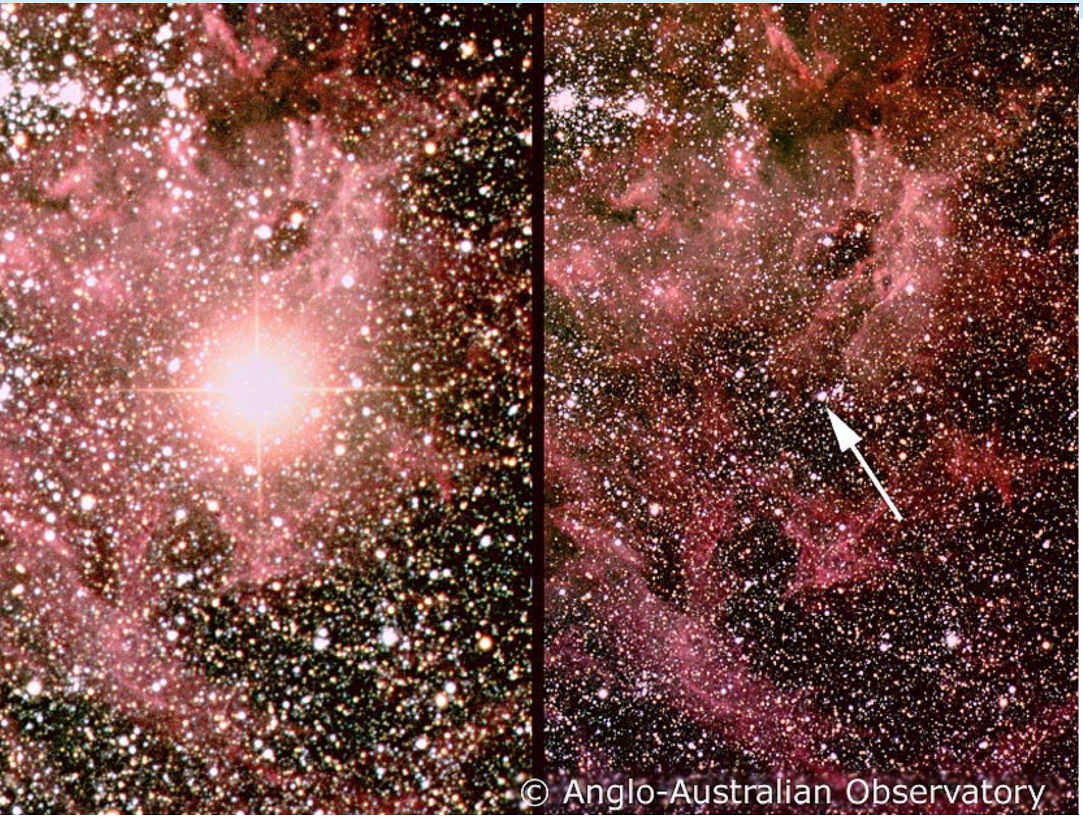
Kepler's Supernova Remnant, SN 1604.

Supernova-Explosion

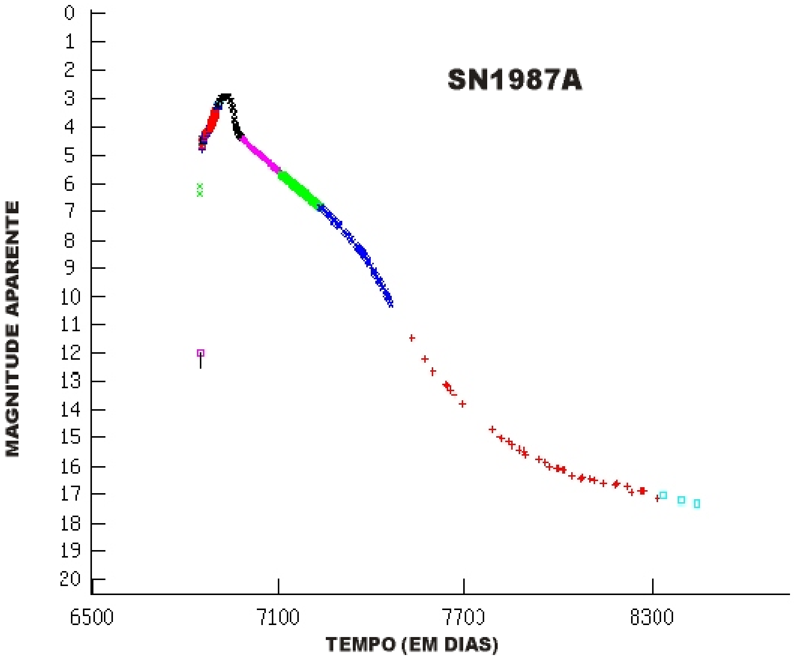
SN-Lichtkurven



SN1987A



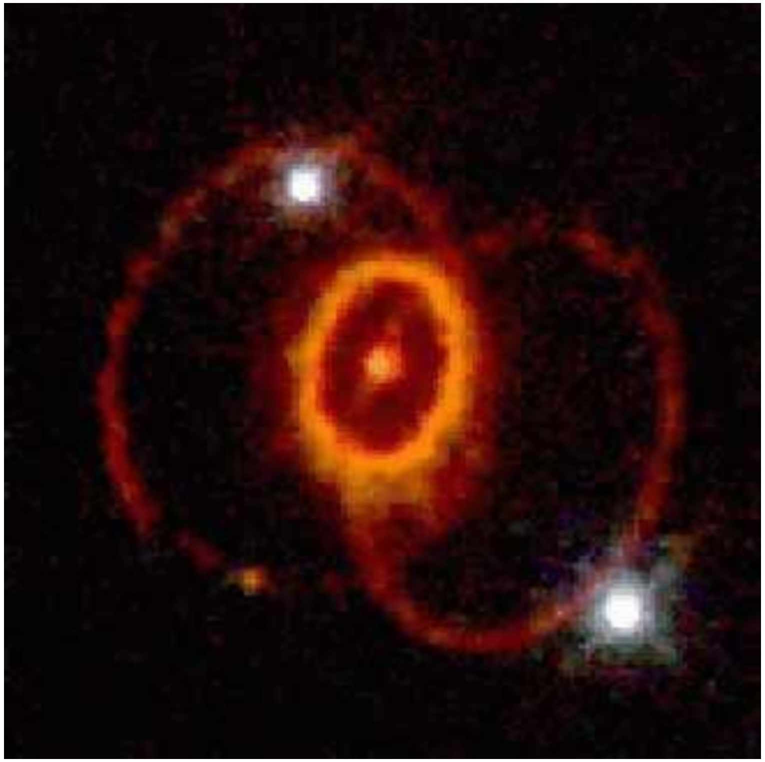
Lichtkurve



Sometime during 23 February 1987 a supernova exploded in the Large Magellanic Cloud (LMC), a nearby galaxy. However, the LMC is about 170,000 light years distant, so the supernova exploded 170,000 years ago. It was discovered the following day and brightened rapidly to become the first supernova to be easily visible to the unaided eye for almost 400 years.

This photograph shows the field around the site of the supernova in great detail, both before the supernova exploded (right) and about 10 days afterwards, when it was still brightening.

SN1987A, 7 Jahre später

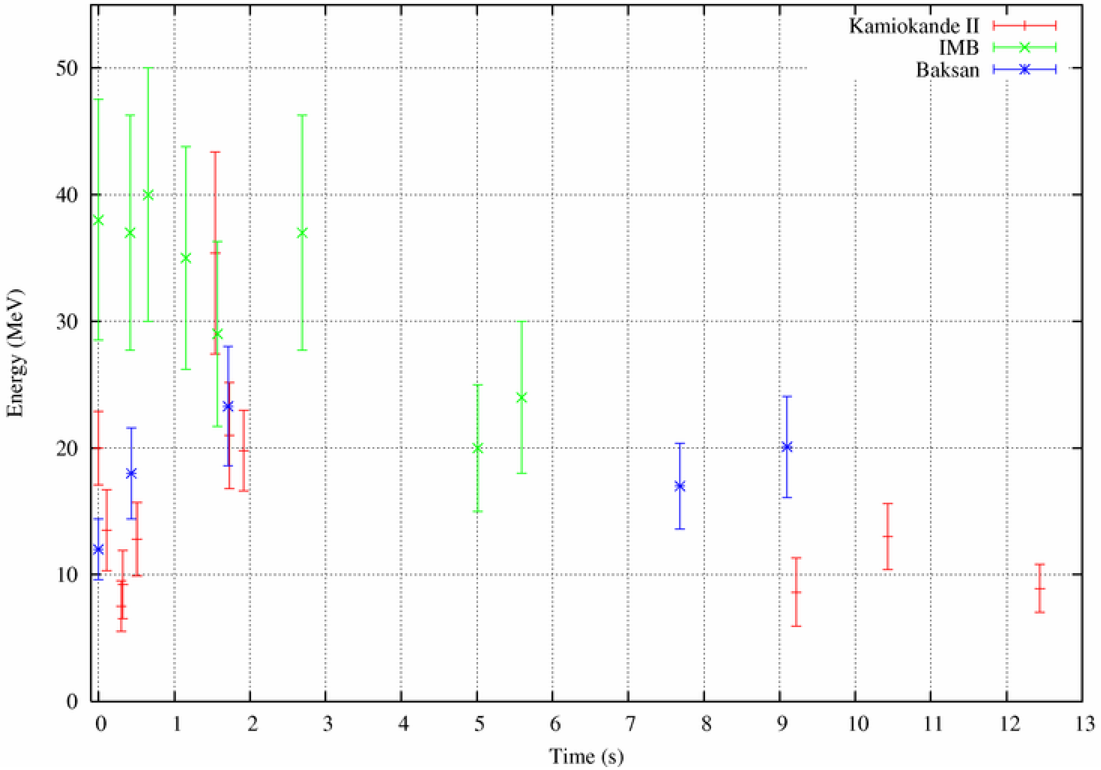


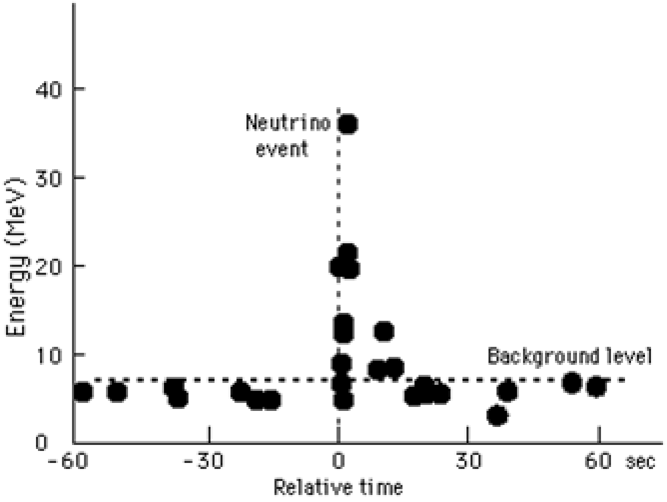
May 19, 1994
STScI-1994-22

The Hubble telescope has obtained the best images yet of a mysterious mirror-imaged pair of rings of glowing gas encircling the site of the stellar explosion called supernova 1987A.

One possibility for these "hula hoops" of gas is that the two rings might be caused by a high-energy beam of radiation that is sweeping across the gas, like a searchlight sweeping across clouds. Though all of the rings appear inclined to our view (so that they appear to intersect), they are probably in three different planes. The small, bright ring lies in a plane containing the supernova; one larger ring lies in front of and the other behind the smallest one.

SN1987A-Neutrinos





Neutrino signal in the three detectors on line at the moment of SN1987A explosion. The first neutrinos were detected at 7:35:35, 7:35:41 and 7:36:12 in Kamiokande II, IMB and Baksan, respectively. However, the clocks were not synchronized and had large uncertainties in their absolute measure of time. As a result, since the three signals probably happened within a fraction of a second, the first neutrinos in each detector are assumed to be simultaneous.

Neutrino-Emission

$$\Delta E_{grav} \approx \frac{3}{5}\frac{GM^2}{R_{nukl}} = \frac{3}{5}\frac{GA^2 m_p^2}{r_0\, A^{1/3}} = \frac{3}{5}\frac{GA^{5/3} m_p^2}{r_0} = 3\cdot 10^{46}\,\mathrm{J} = 1.8\cdot 10^{56}\,\mathrm{MeV}$$

etwa $100\,\mathrm{MeV}$ pro Nukleon

$$\boxed{\gamma \;\leftrightarrow\; e^+ + e^- \;\leftrightarrow\; \nu_i + \bar{\nu}_i, \quad i = e,\, \mu,\, \tau}$$

$$\sigma(\nu_e + n \rightarrow p + e^-) = \frac{G_F^2(\hbar c)^2}{\pi}(1 + 3g_A^2)\, E_\nu^2 \approx 10^{-43}\left(\frac{E_\nu}{\mathrm{MeV}}\right)^2 \mathrm{cm}^2$$

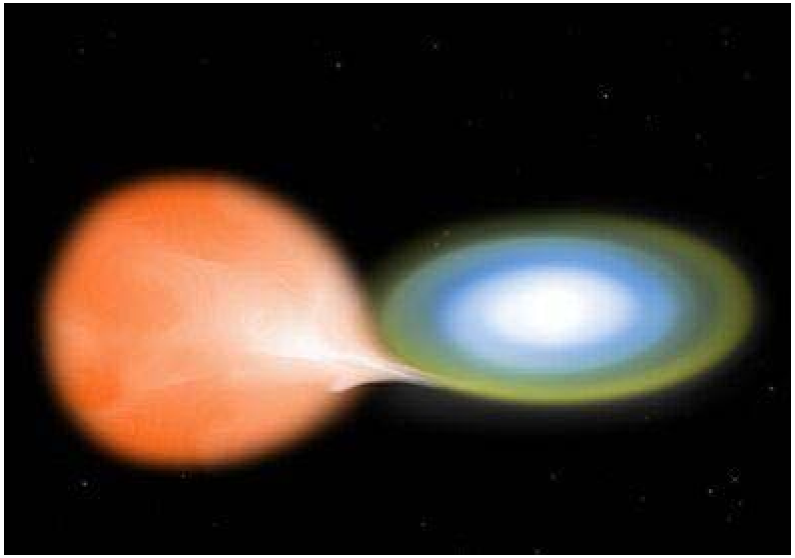
$$E_\nu = 20\,\mathrm{MeV}$$

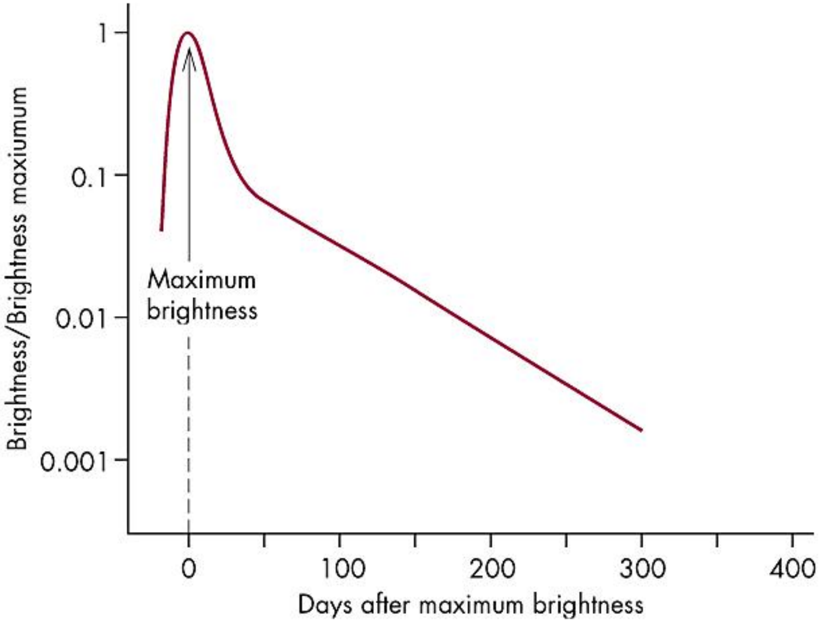
$$\rho = 10^{15}\,\mathrm{kg\,m^{-3}}$$

$$\boxed{\lambda = \frac{1}{\sigma n} = \frac{1}{\sigma N_A \rho} = \frac{900}{(E_\nu/\mathrm{MeV})^2}\,\mathrm{m} \approx 2\,\mathrm{m}}$$

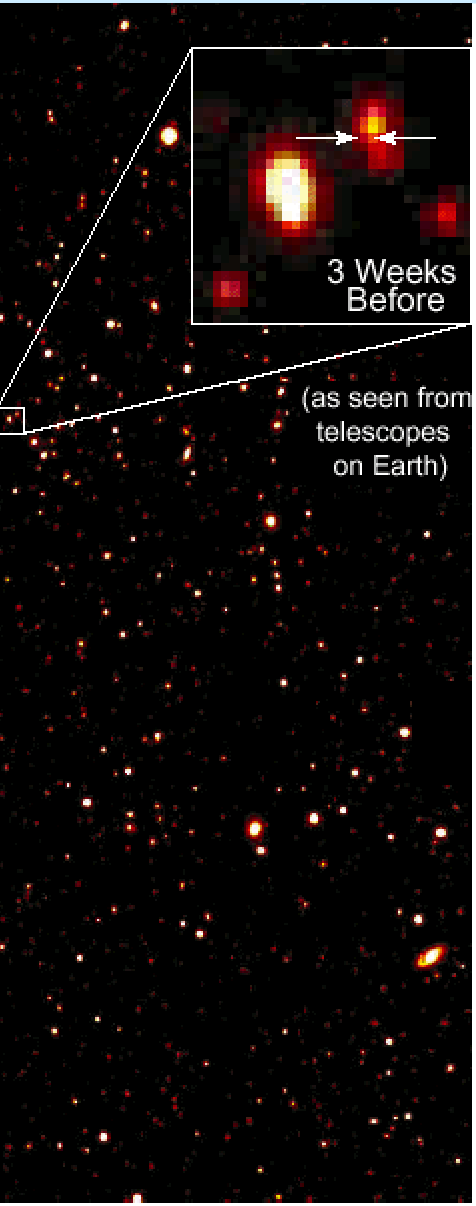
Supernova Typ Ia

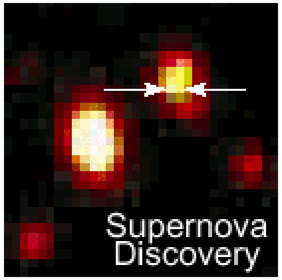
A type Ia Supernova is an events that happens in a binary system. It happens to Red Giant/ White Dwarf pairs of stars. The Red Giants will start to lose its outer layers, like when an isolated dies, but the difference is that the White Dwarf will pull the ejected mass onto itself. When the mass of the White dwarf exceeds the Chandrasekhar limit the Star will restart nuclear fusion and collapse in on itself. It will keep gaining mass and collapsing until the star has too much energy and it will explode in a type Ia supernova.

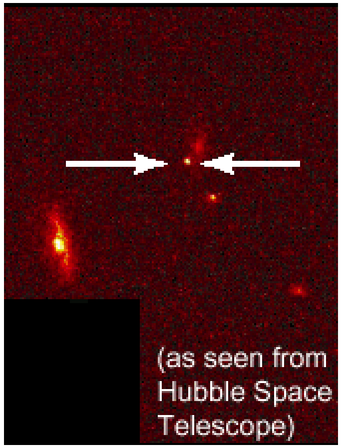


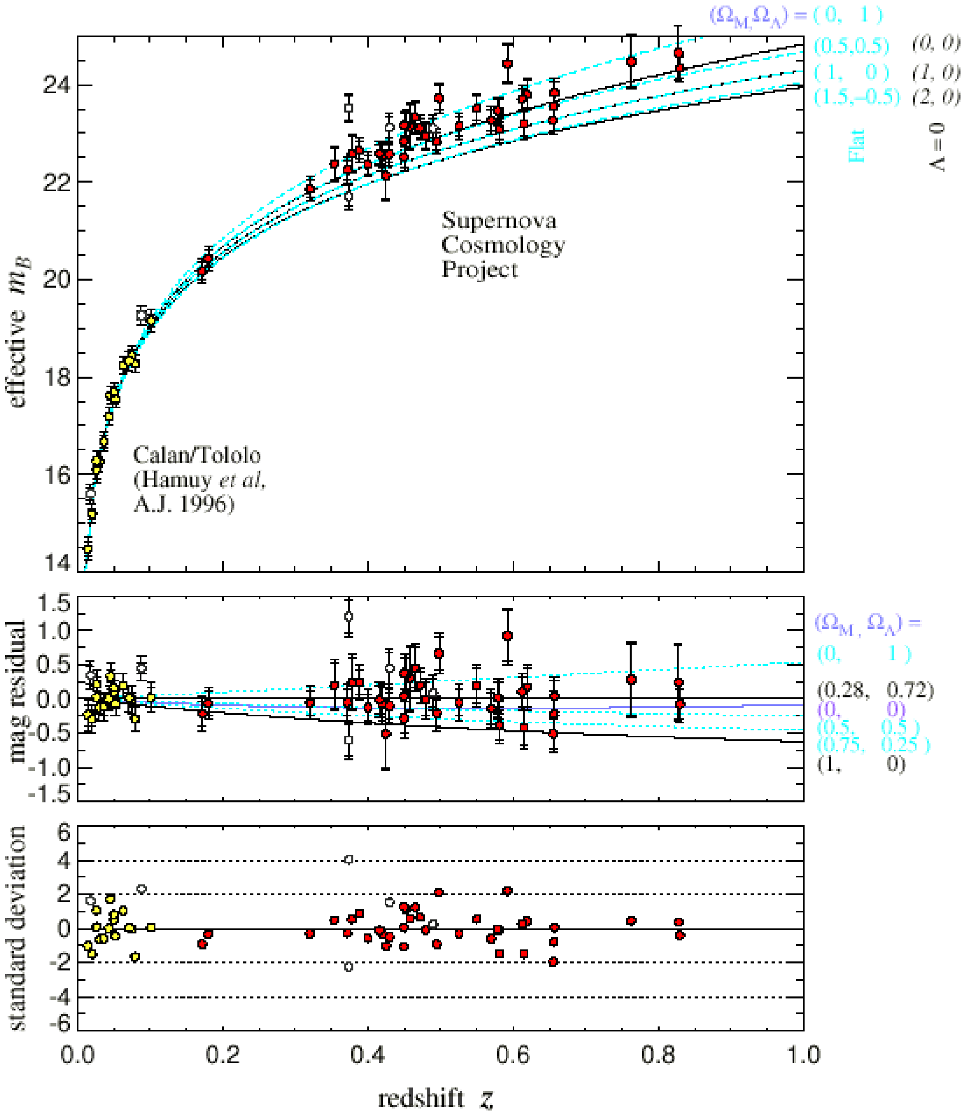


Supernova-Ia-Beobachtung

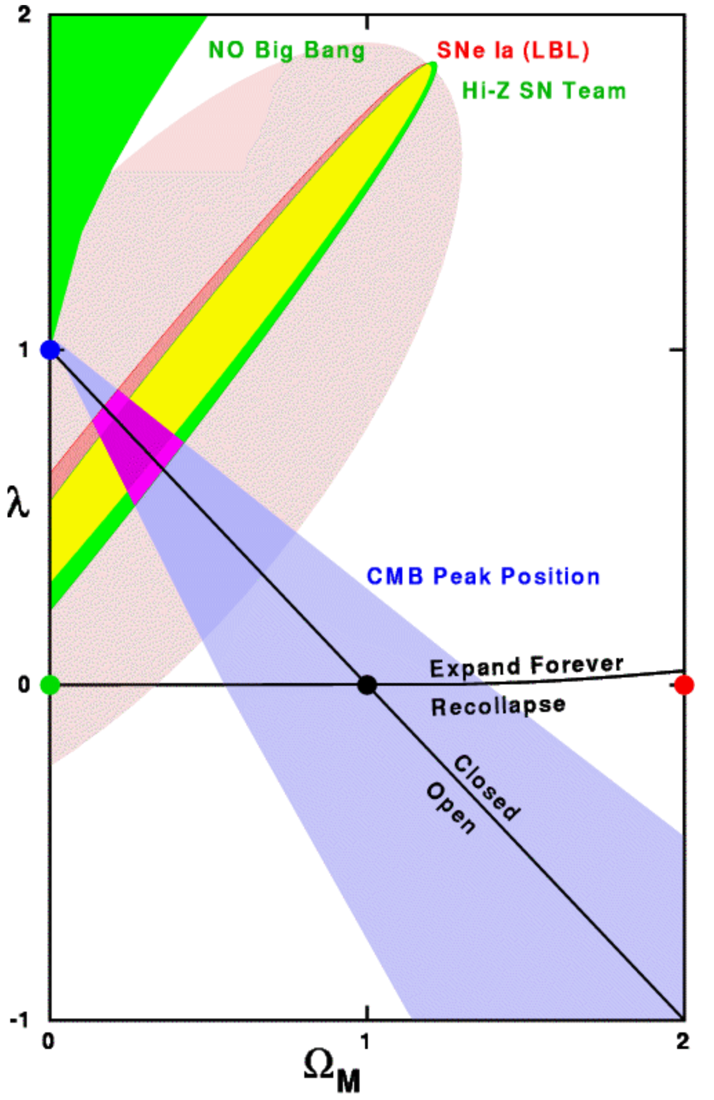








Kosmologische Konstante



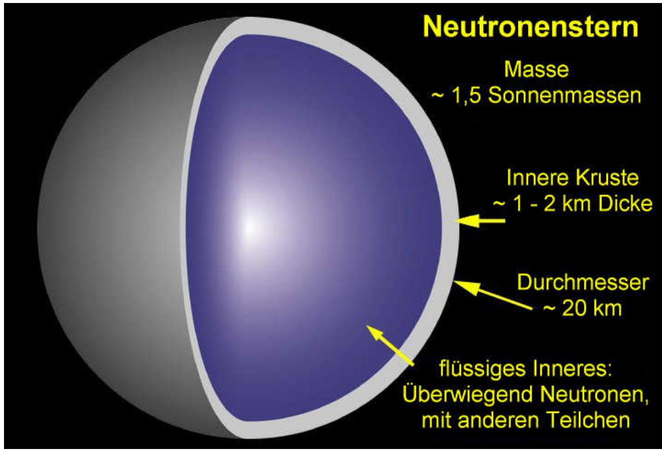
Neutronensterne

$$\boxed{\frac{p_F^e}{p_F^n} = \frac{48}{300} = \left(\frac{n_e}{n_n}\right)^{1/3} \quad \Longrightarrow \quad n_e \approx 0.004 \cdot n_n}$$

$$\rho = 2 \cdot 10^{17}\,\mathrm{kg\,m^{-3}} \qquad n_n = 1.2 \cdot 10^{44}\,\mathrm{m^{-3}}$$

$$\text{für } M = 1.4\,M_\odot \qquad A = M/m_n = 1.9 \cdot 10^{57}$$

$$\boxed{R \leq r_0 A^{1/3} \approx 10 \;\ldots\; 15\,\mathrm{km}} \quad (R_{Sonne} = 7 \cdot 10^5\ \mathrm{km})$$

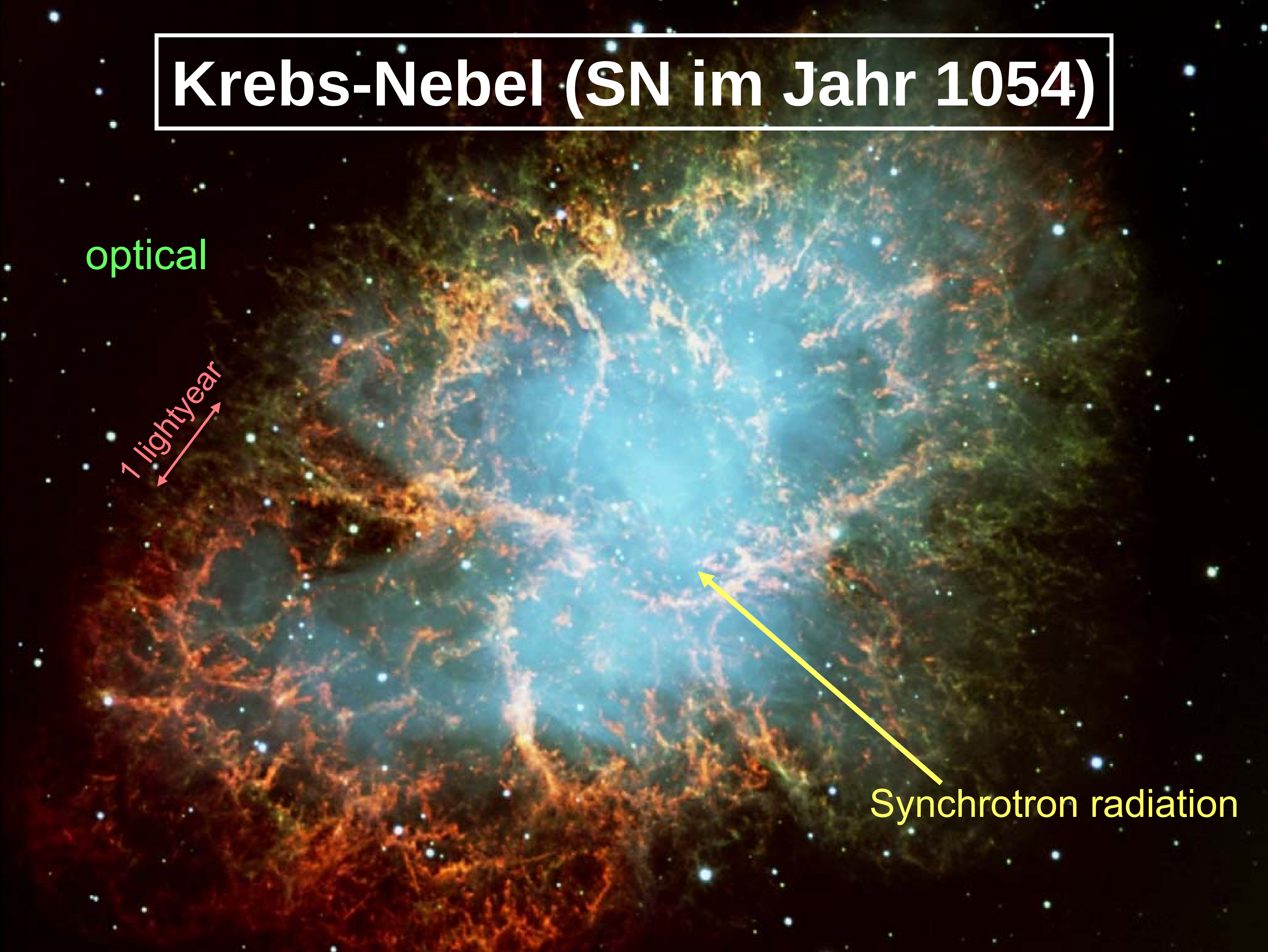


$$I_1\omega_1 = I_2\omega_2; \quad \frac{I_1}{I_2} = \frac{R_1^2}{R_2^2} \quad \Longrightarrow \quad \omega_2 = \frac{R_1^2}{R_2^2}\omega_1$$

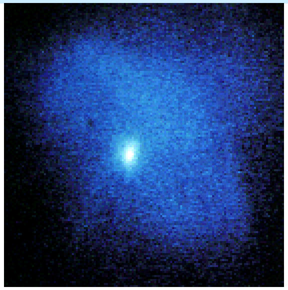
$$B_1 R_1^2 = B_2 R_2^2 \quad \Longrightarrow \quad B_2 = B_1 \left(\frac{R_1}{R_2}\right)^2 \approx B_1 \cdot 10^{11}$$

für $B_1 = 10^{-2}\,\mathrm{T}$ ein Feld von $B_2 = 10^9\,\mathrm{T}$

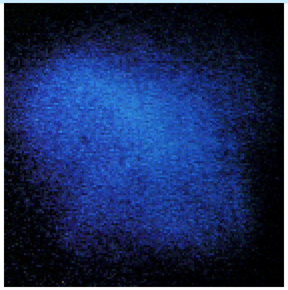
Krebs-Nebel (SN im Jahr 1054)



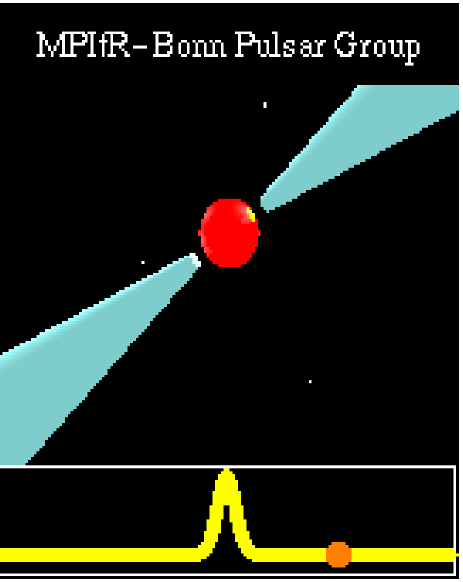
Pulsar im Krebsnebel

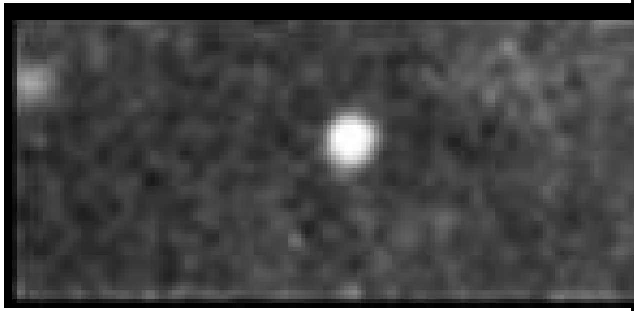


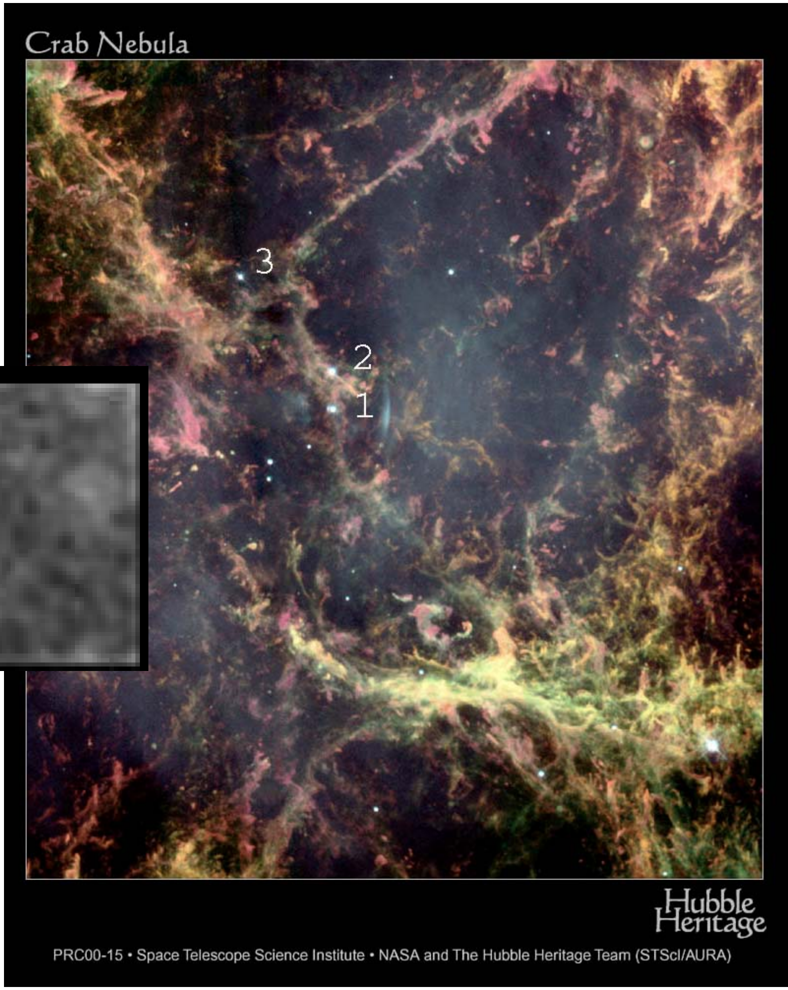
Crab Pulsar "On"



Crab Pulsar "Off"





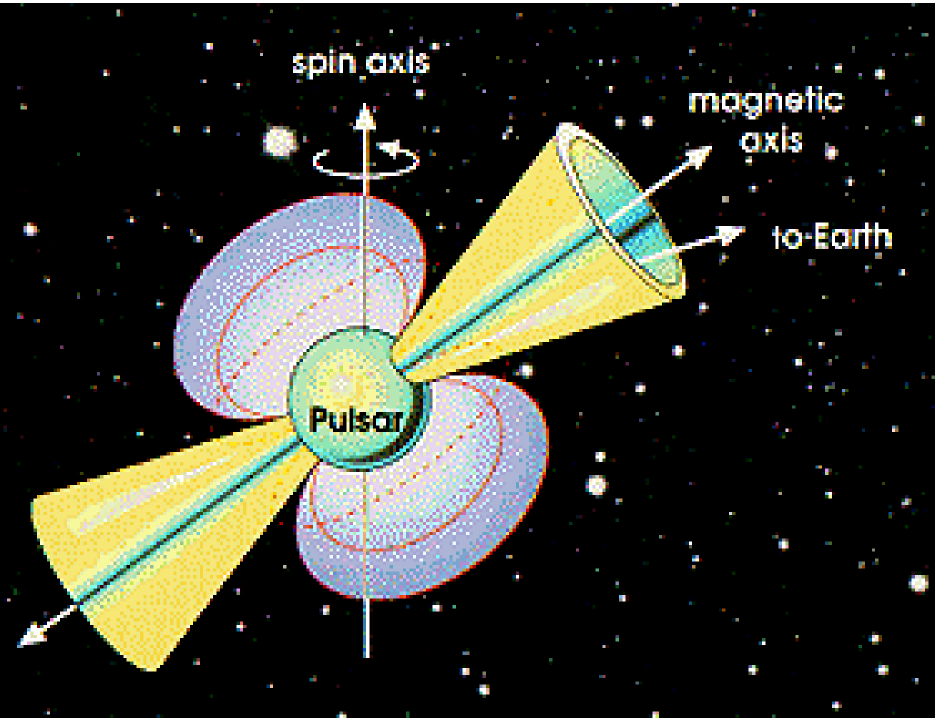


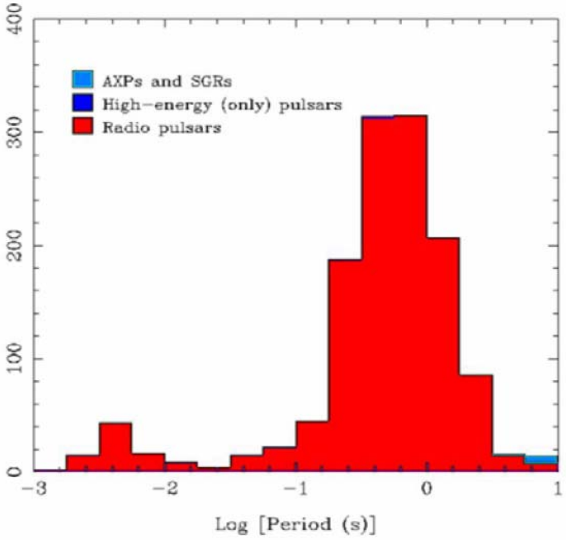
PRC00-15 • Space Telescope Science Institute • NASA and The Hubble Heritage Team (STScI/AURA)

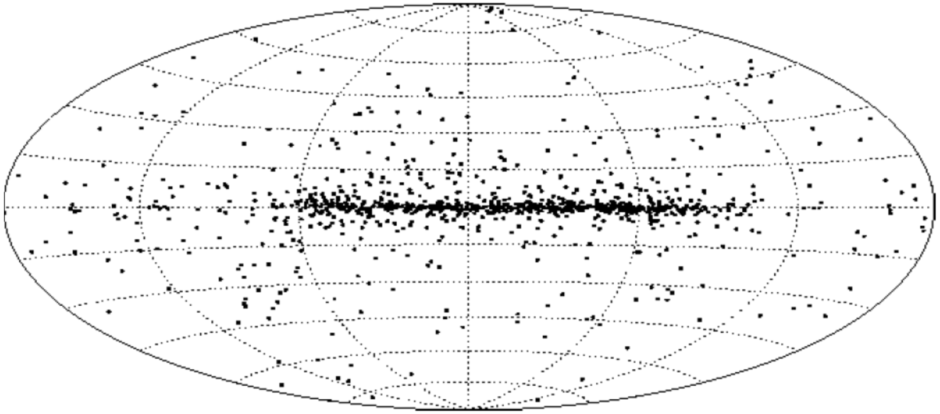
$$\omega = 190/\mathrm{s}$$

$$\dot{\omega} = -2.4 \cdot 10^{-9}\,\mathrm{s}^{-2}$$

Pulsare







$$\boxed{\frac{dE}{dt} = \frac{\mu_0}{6\pi c^3}\, p_m^2\, \omega^4 \sin^2\theta = \frac{d}{dt}\left(\frac{1}{2} I \omega^2\right) = I\omega\dot{\omega}}$$

$$\dot{\omega} \sim \omega^3$$

Schwarze Löcher

M_{max}(Neutronenstern)

$$M_{max} \approx \frac{3\sqrt{2}}{8\pi}\left(\frac{hc}{G}\right)^{3/2}\left(\frac{Z}{A\,m_p}\right)^2 \approx 5\cdot M_\odot \quad \text{(ohne Drehimpuls)}$$

Schwarzschild-Radius:

$$r_s = \frac{2GM}{c^2}$$