Astroteilchenphysik II: Gammastrahlung
Vorlesung 7

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Supernova-Überreste

- Beobachtungsergebnisse von Supernova-Überresten
- Interpretation der Ergebnisse
- Vergleich der Vorhersagen leptonischer und hadronischer Modelle

Entdeckung und Eigenschaften von Pulsaren

- Entdeckung von Neutronensternen und Pulsaren
- Eigenschaften von Pulsaren

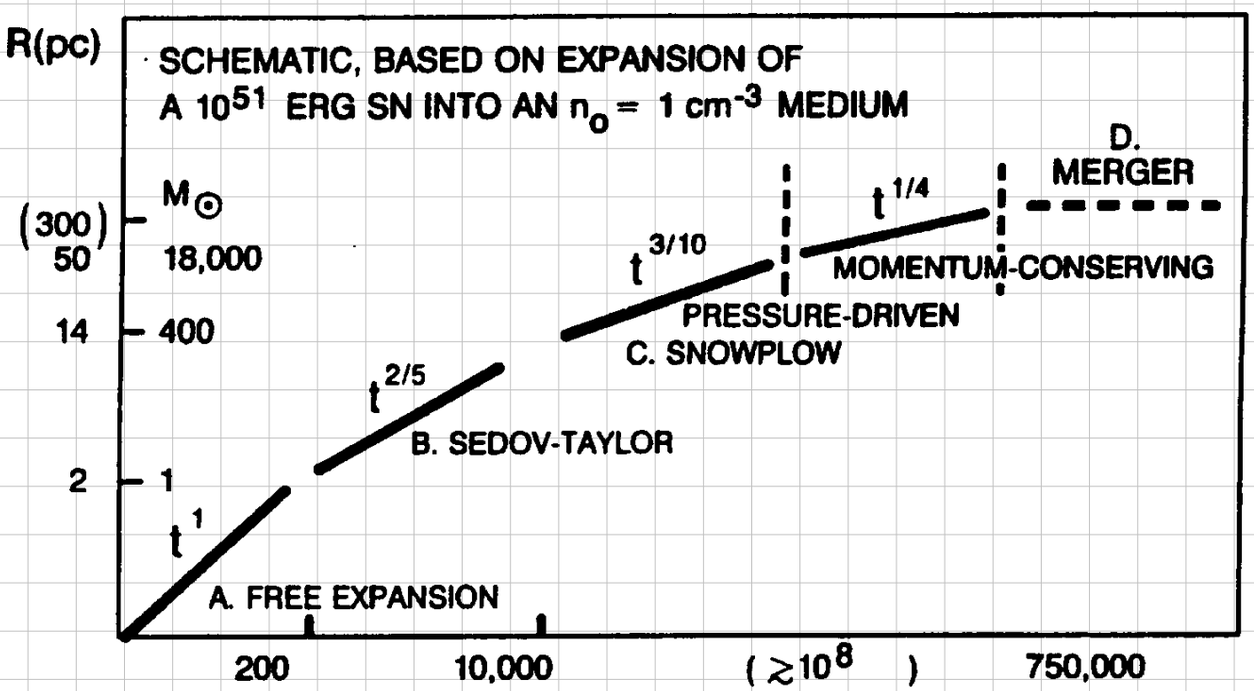
Theorie der Neutronensterne und Pulsare

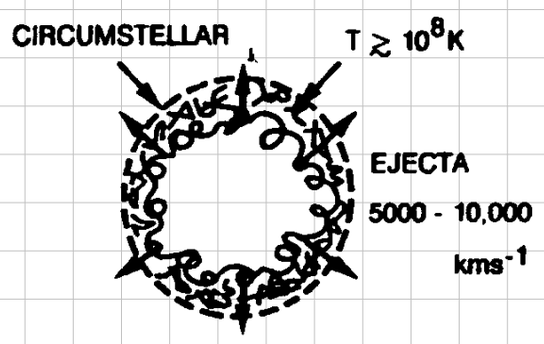
- Pulsare als Neutronensterne
- Eigenschaften von Neutronensternen (Krebs-Pulsar)
- Pulsarwind-Nebel-Systeme

Vorlesung: Termine

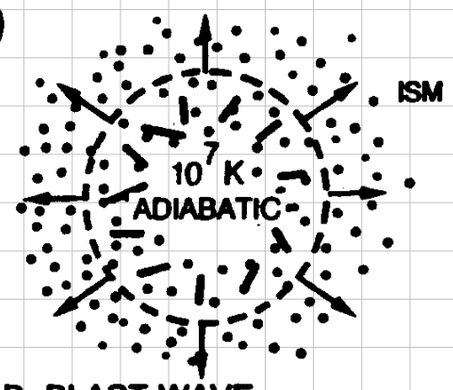
Dienstag		Donnerstag	
		23.04.2020	Vorlesung
		30.04.2020	Vorlesung
		07.05.2020	Vorlesung
12.05.2020	Übung	14.05.2020	Vorlesung
		-	Feiertag
		28.05.2020	Vorlesung
		04.06.2020	Vorlesung
09.06.2020	Übung	-	Feiertag
		18.06.2020	**Vorlesung**
23.06.2020	**Übung**	25.06.2020	Vorlesung
		02.07.2020	Vorlesung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

Entwicklung von SN-Überresten

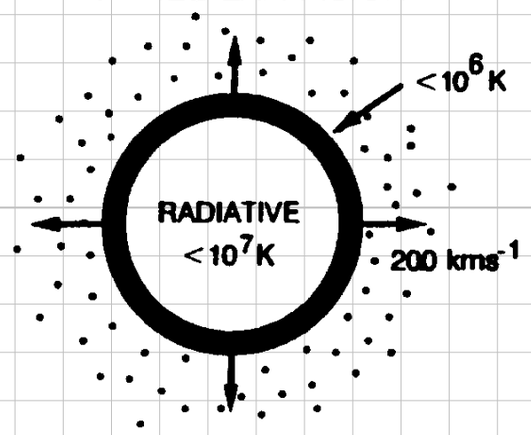




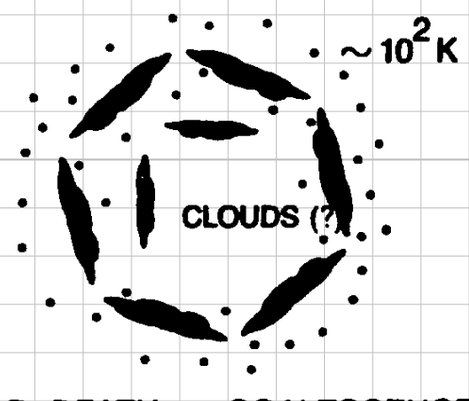
A. FREE EXPANSION



B. BLAST WAVE

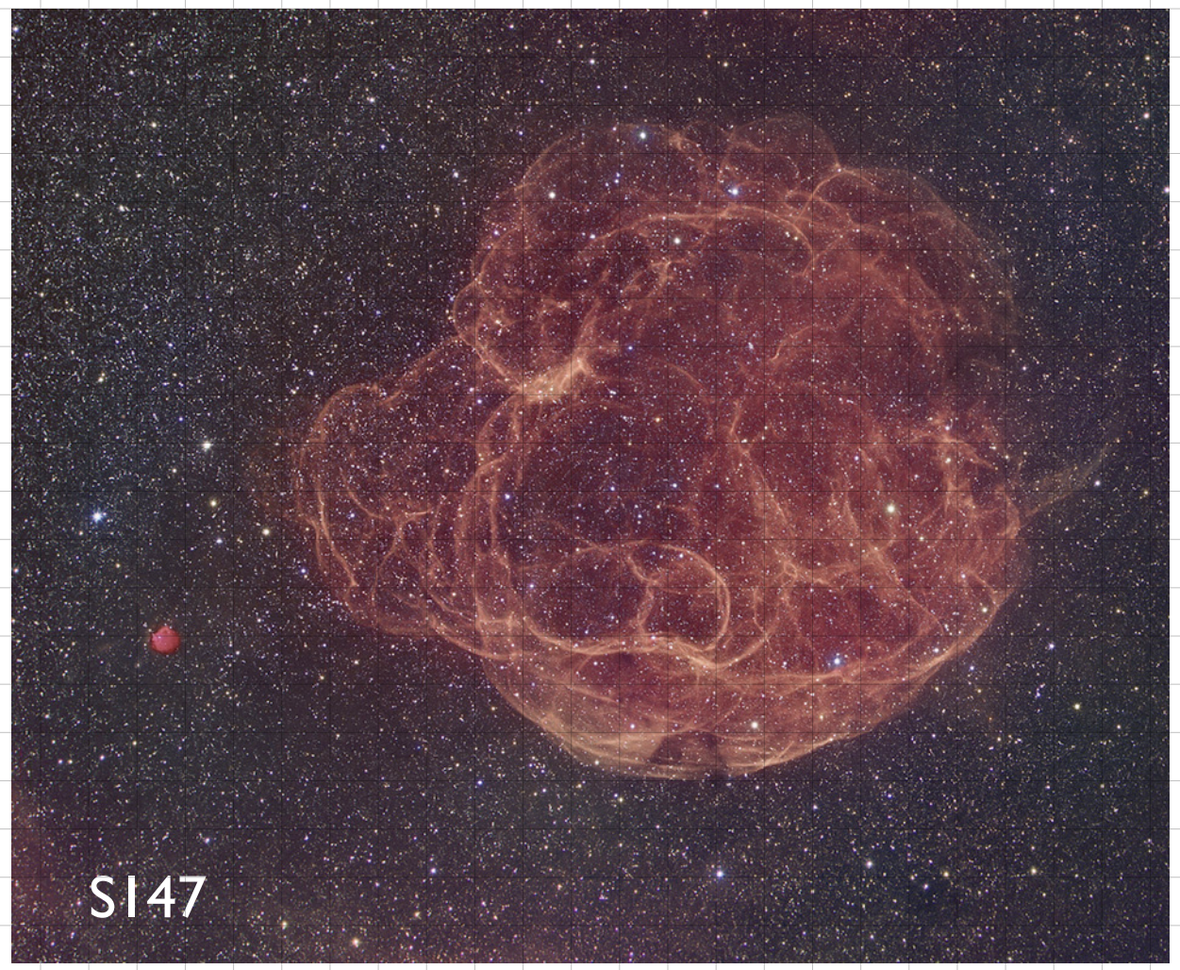


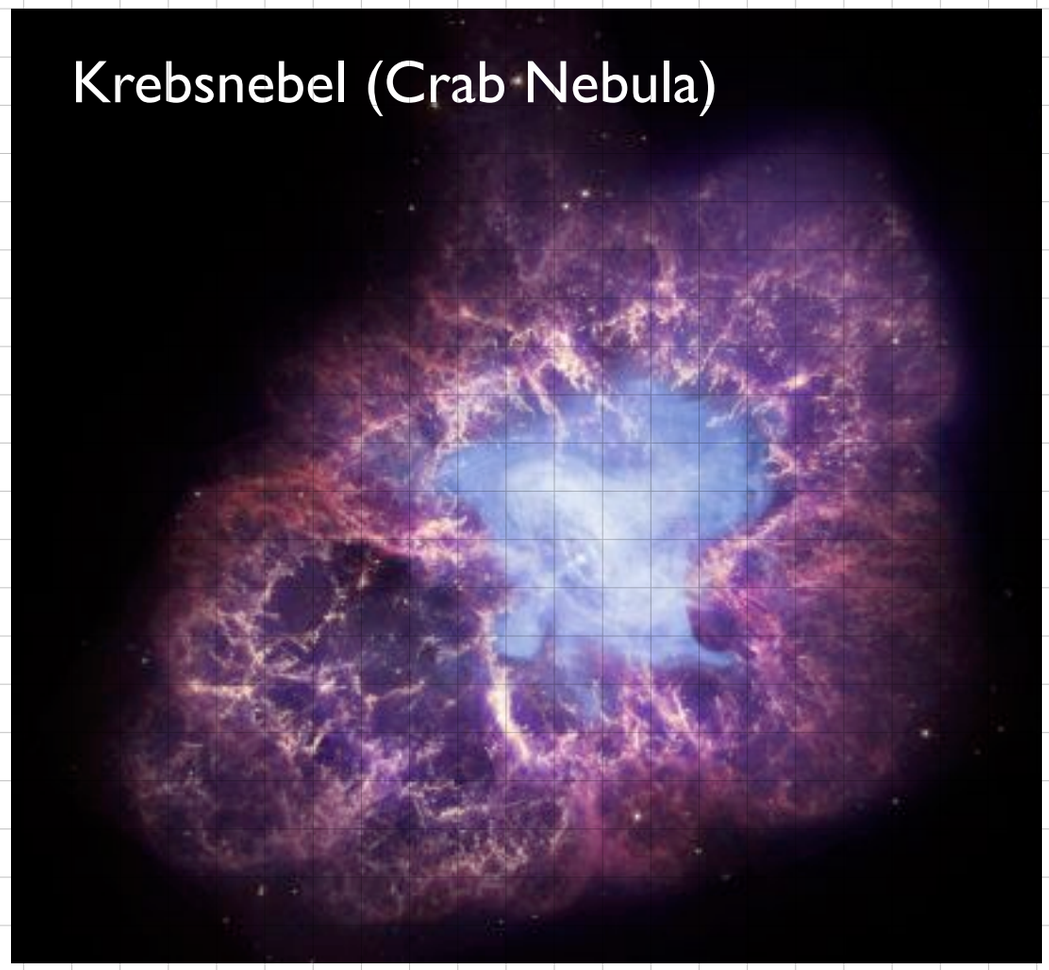
C. SNOWPLOW



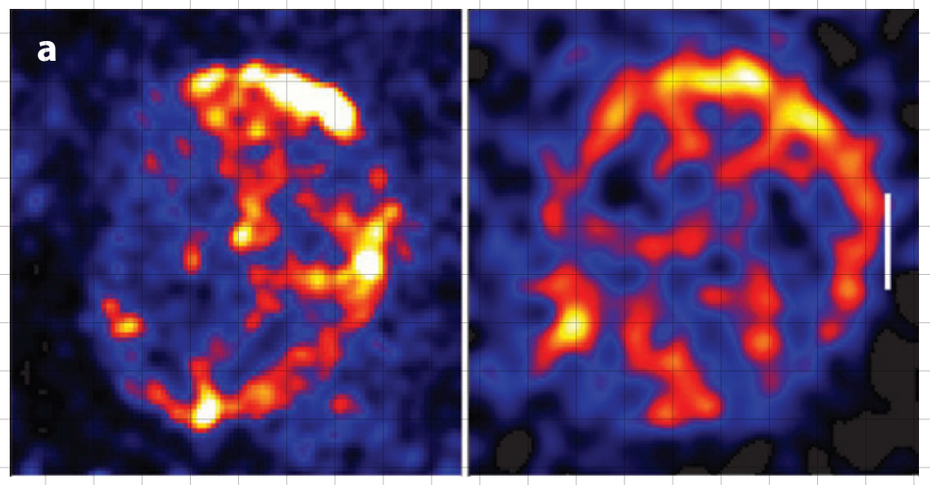
D. DEATH → COALESCENCE

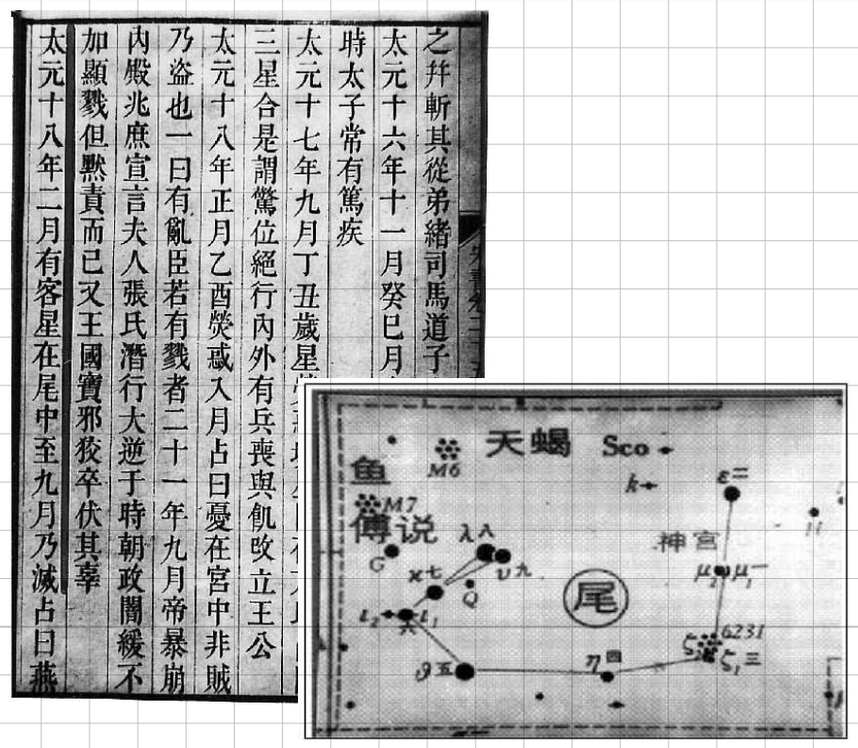
Beispiele für Supernova-Überreste

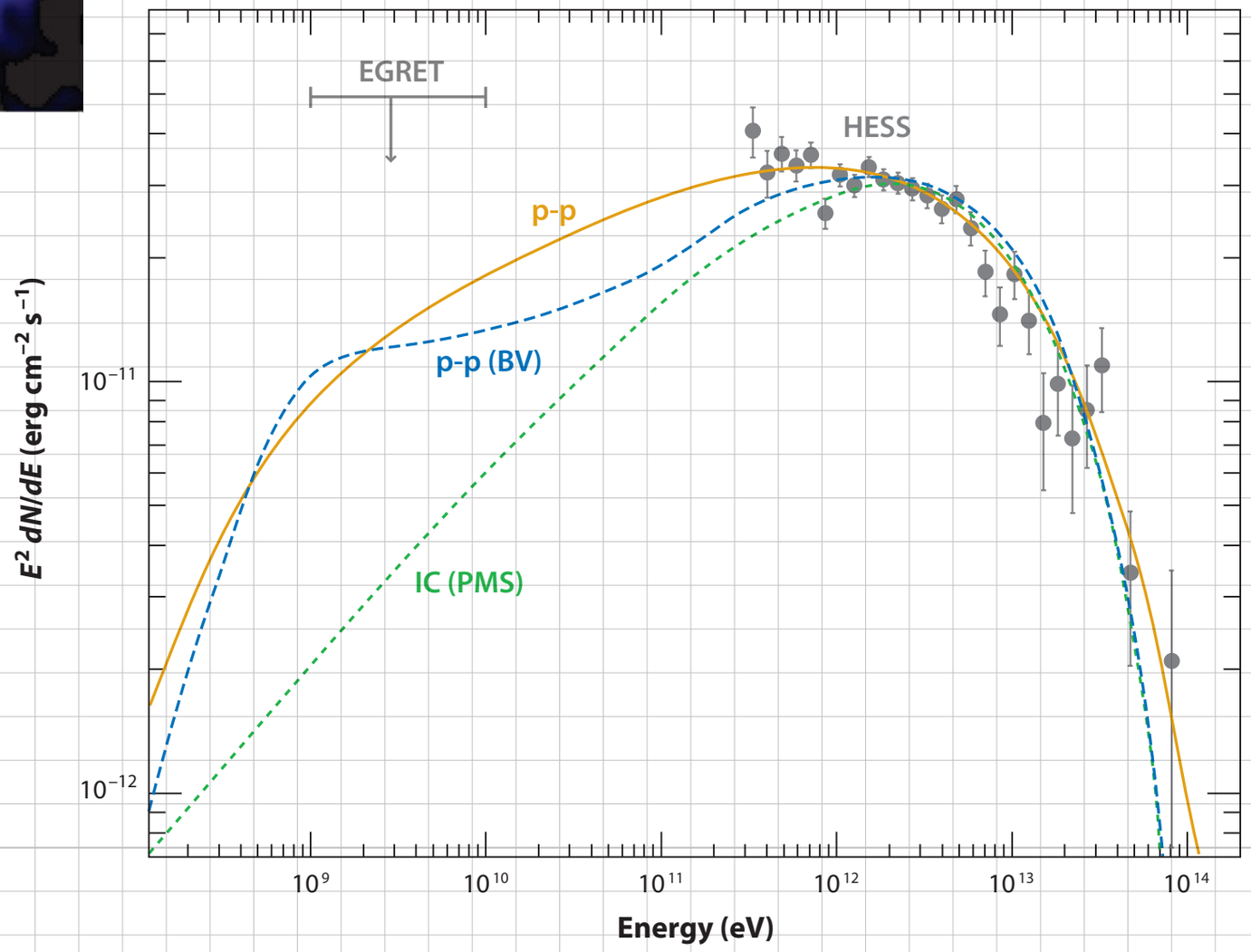




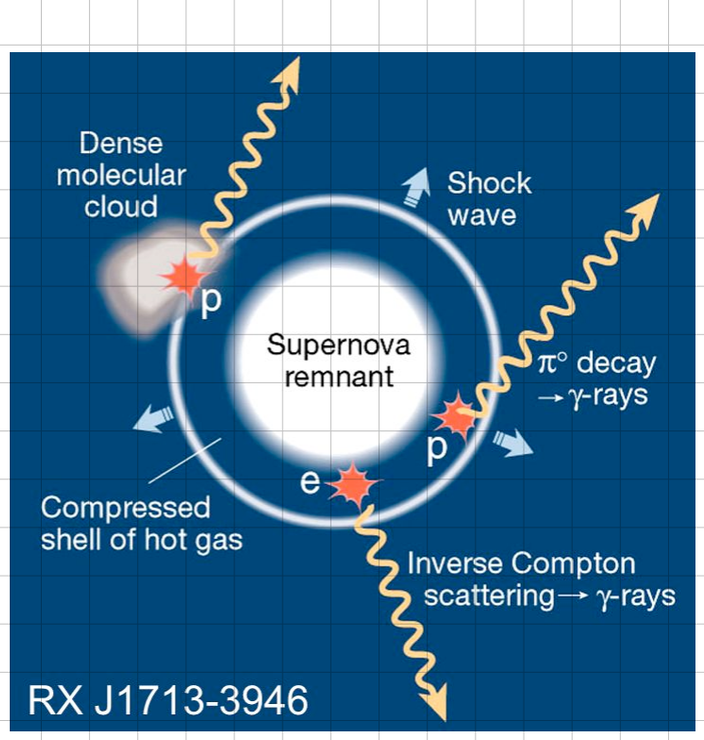
Supernova-Überrest RX J1713.7-3946

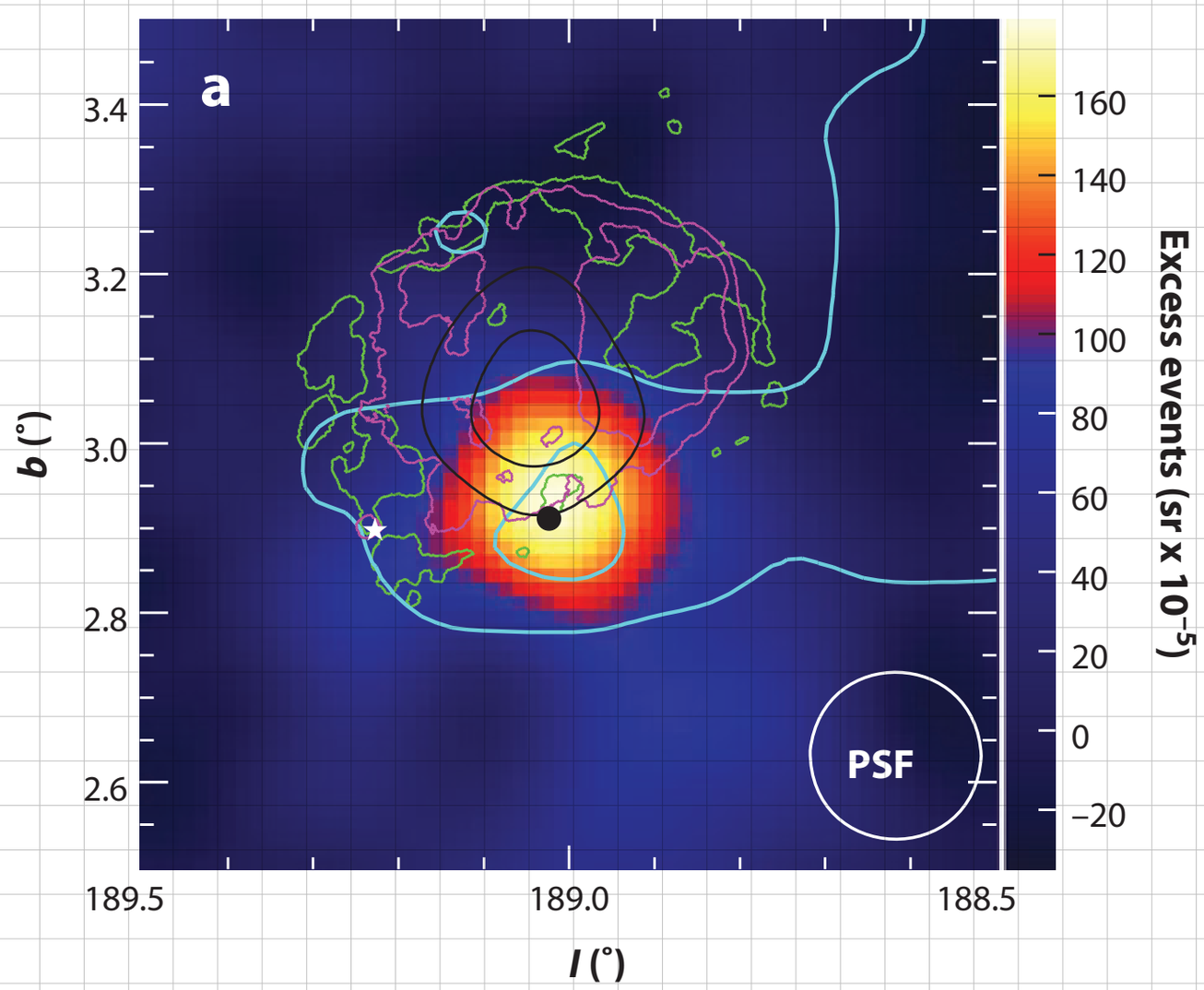




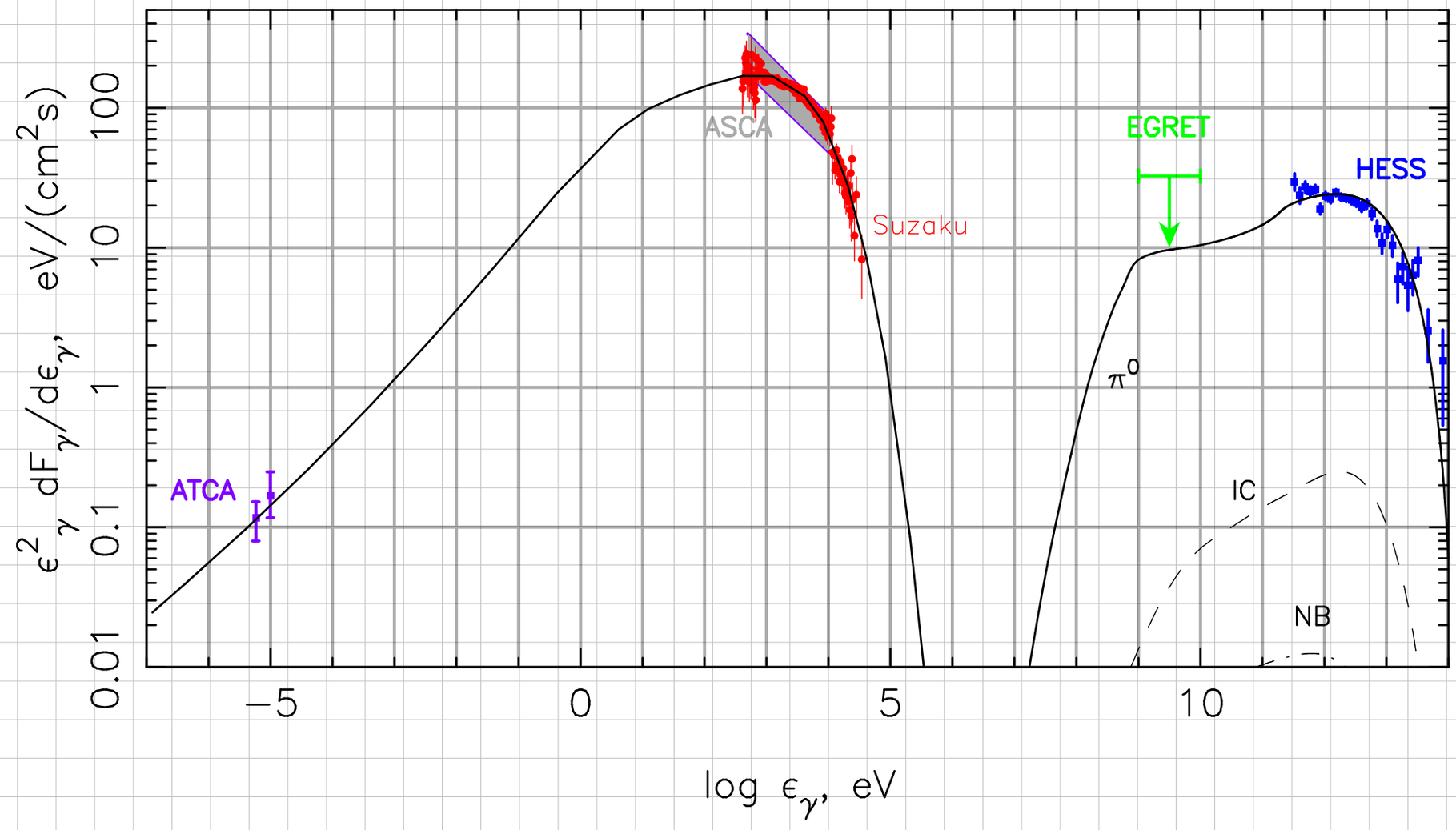


Wechselwirkung mit Molekülwolke: RX J1713.7-3946

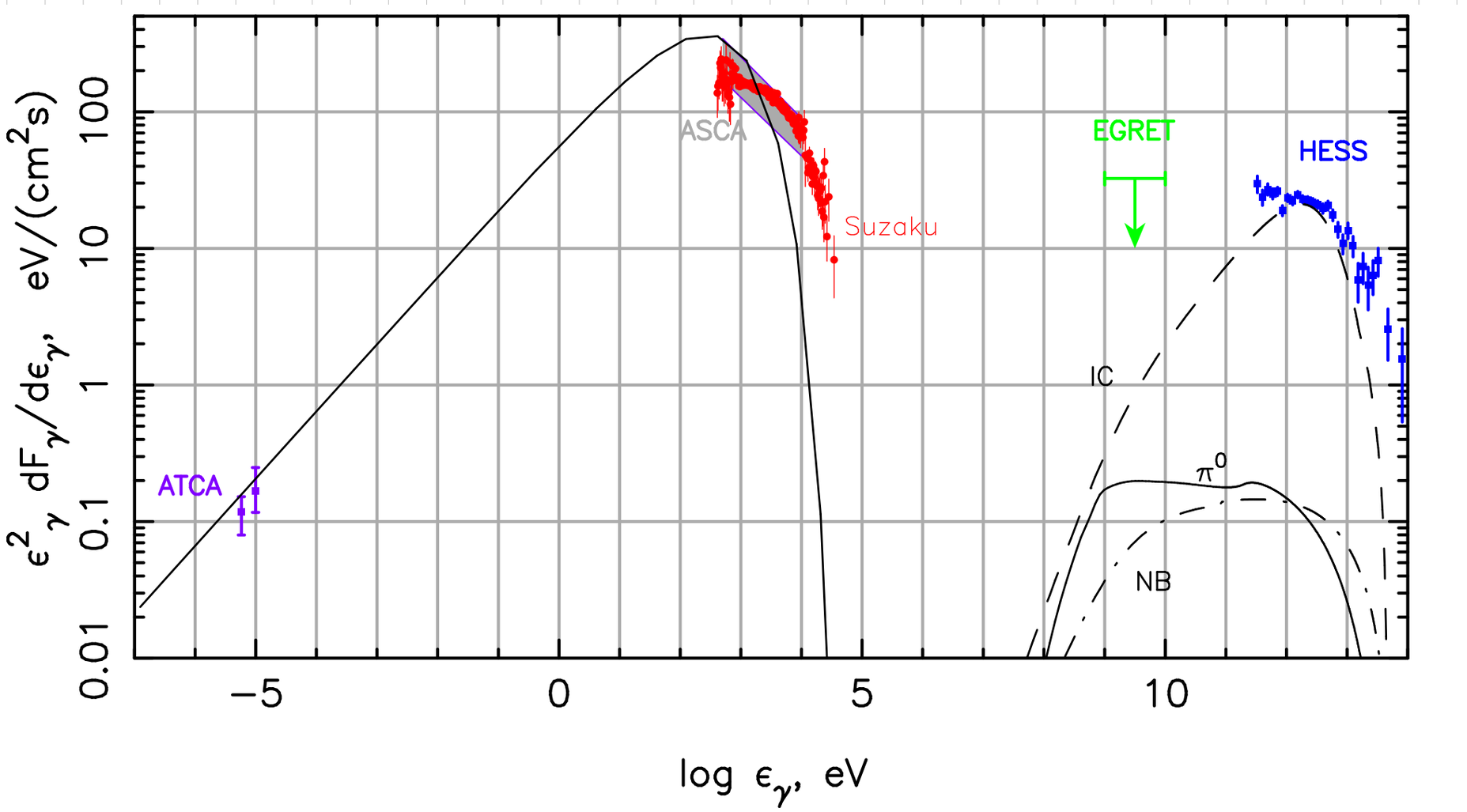




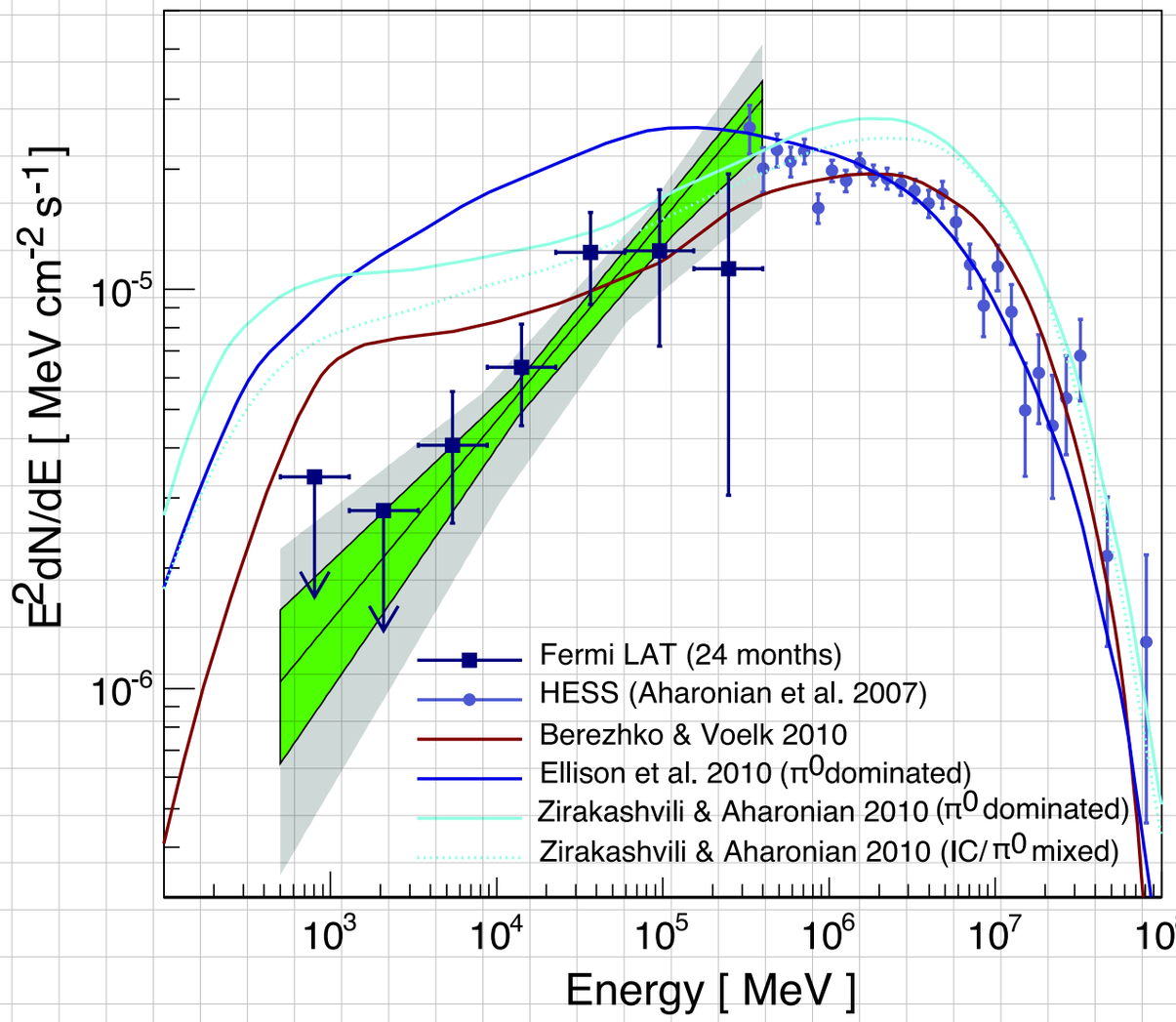
RX J1713.7-3946
Modellrechnung: hadronische Erzeugung

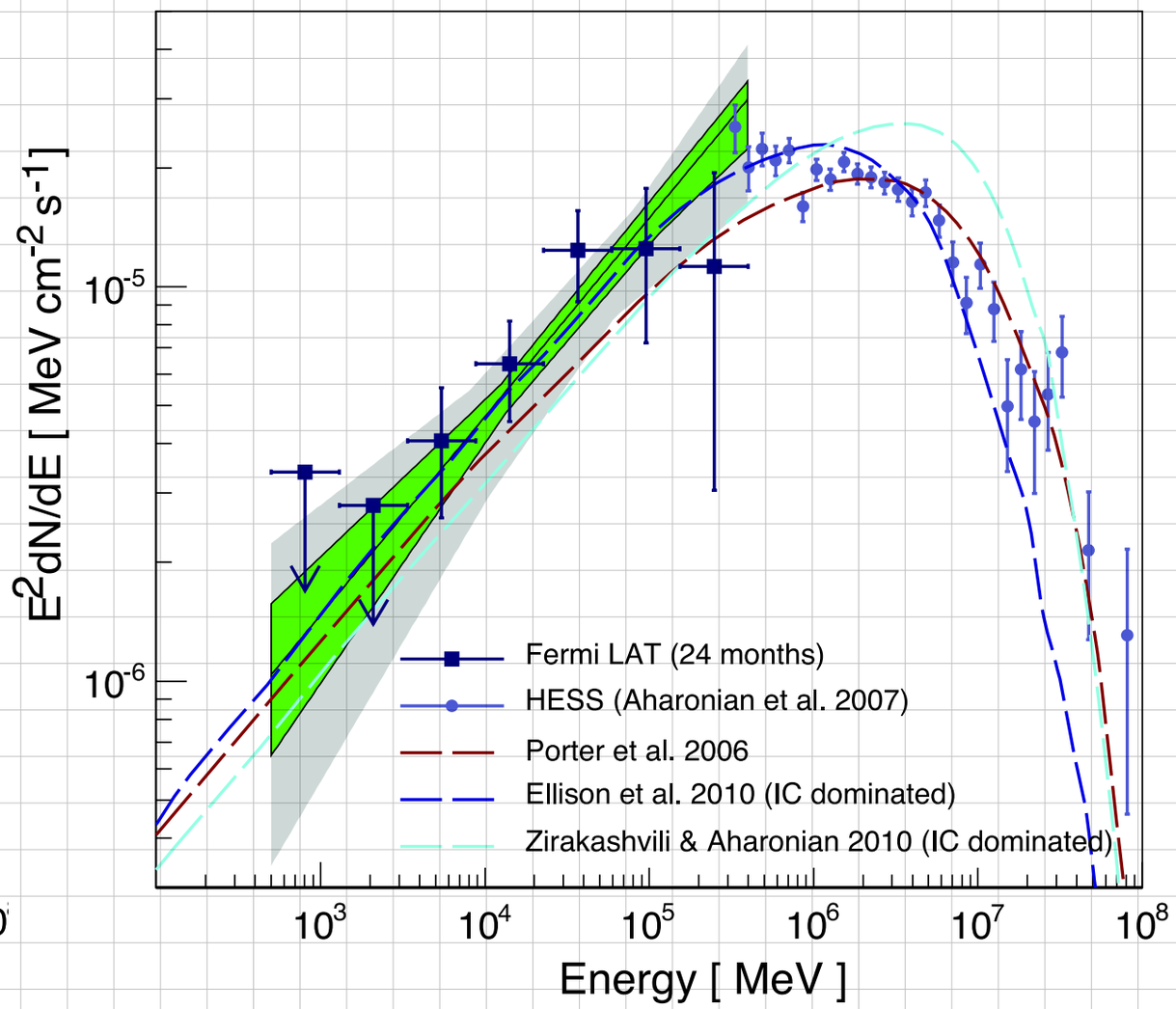


RX J1713.7-3946
Modellrechnung: leptonische Erzeugung



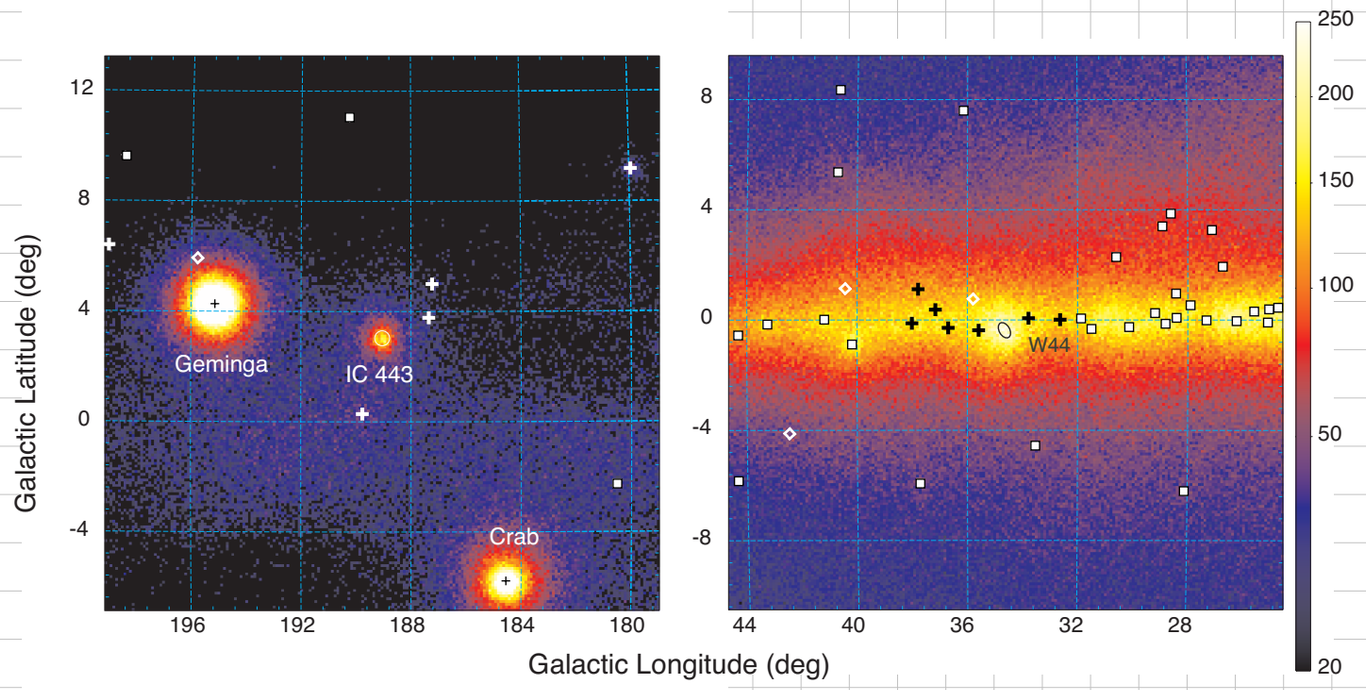
FERMI-LAT-Messung

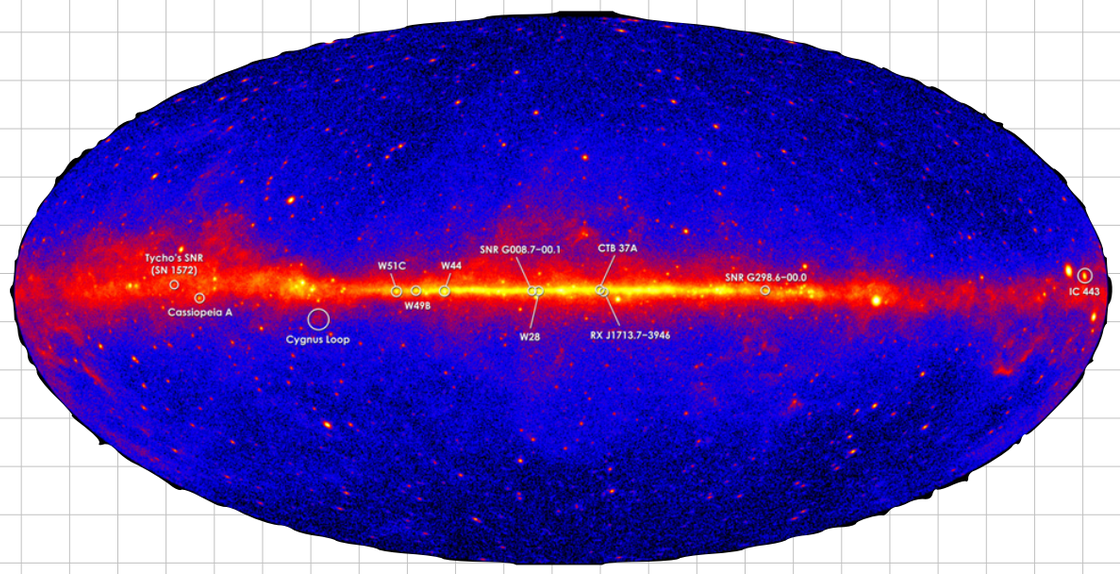




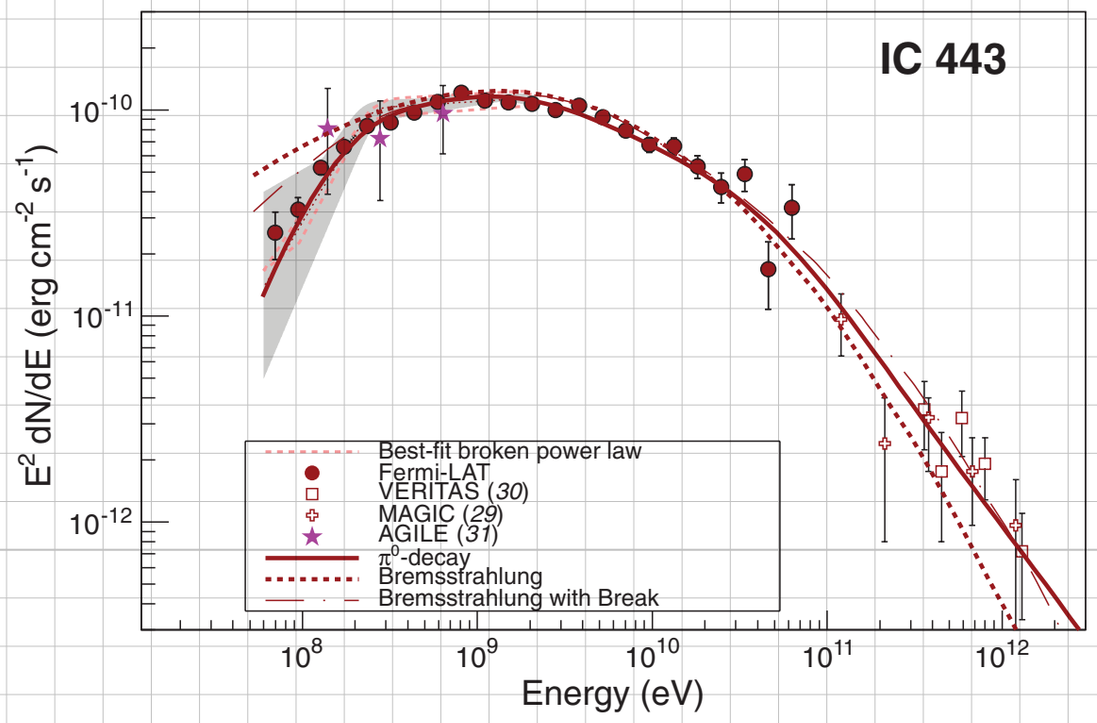
arXiv:1103.5727v1

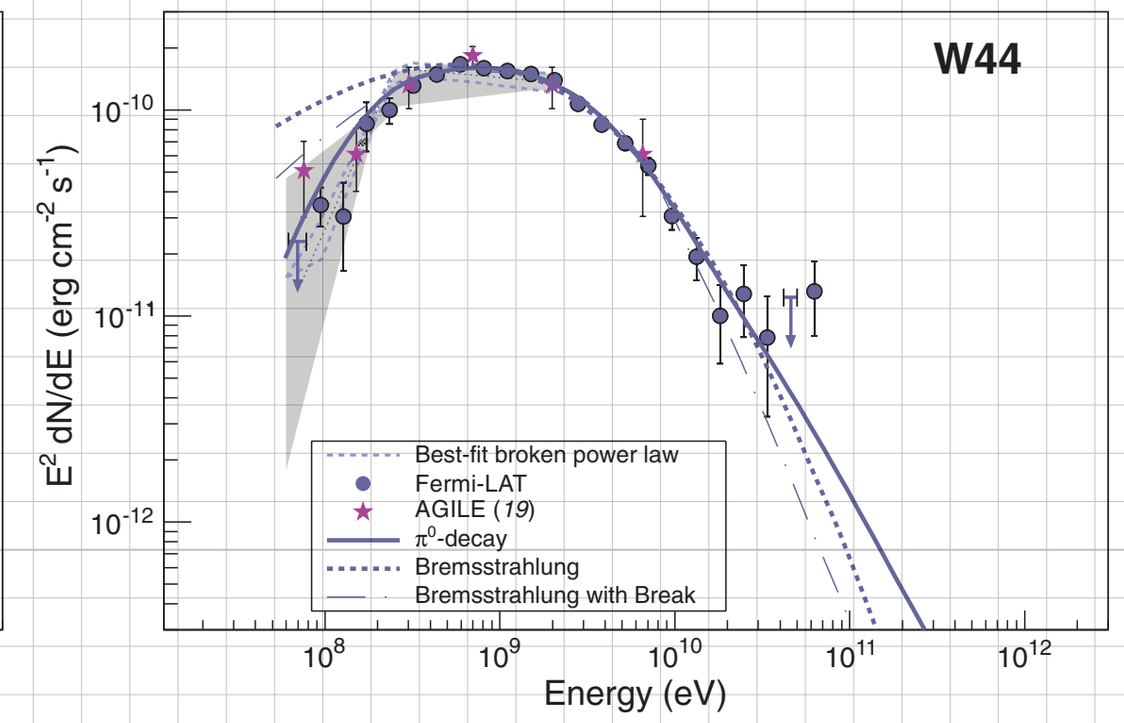
Fermi-Beobachtungen von IC 443 und W44



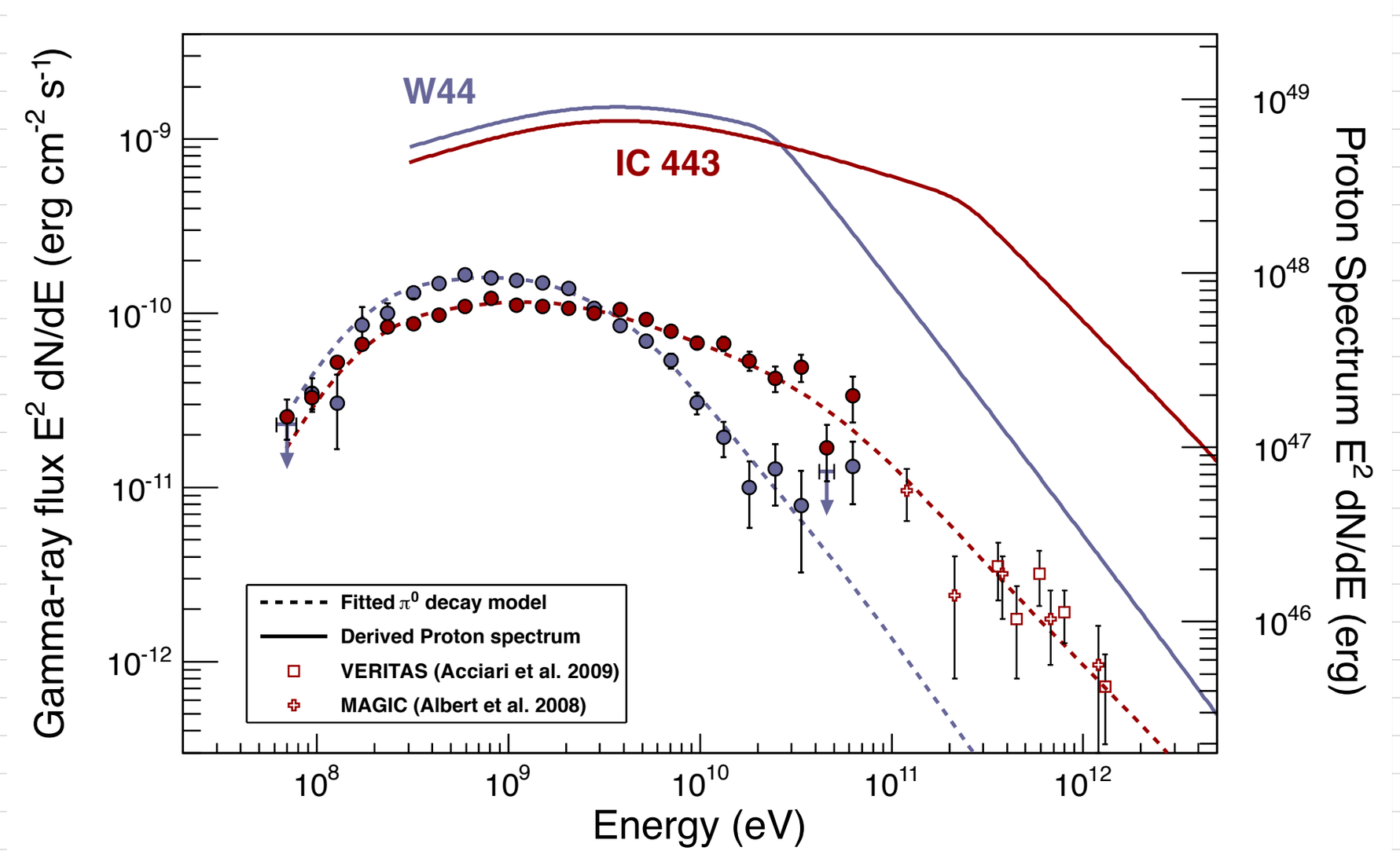


Gamma rays released from supernovae are highlighted on this map (2014).

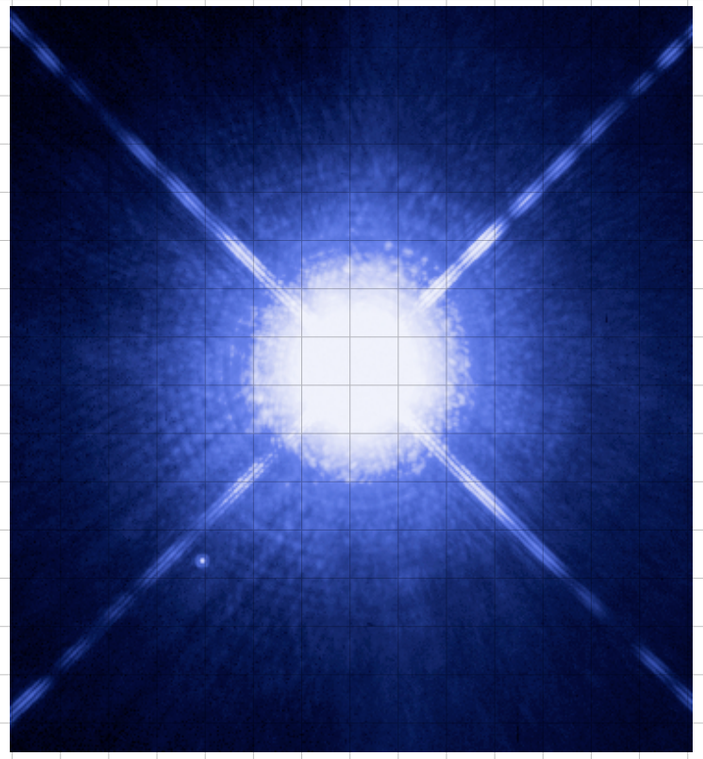


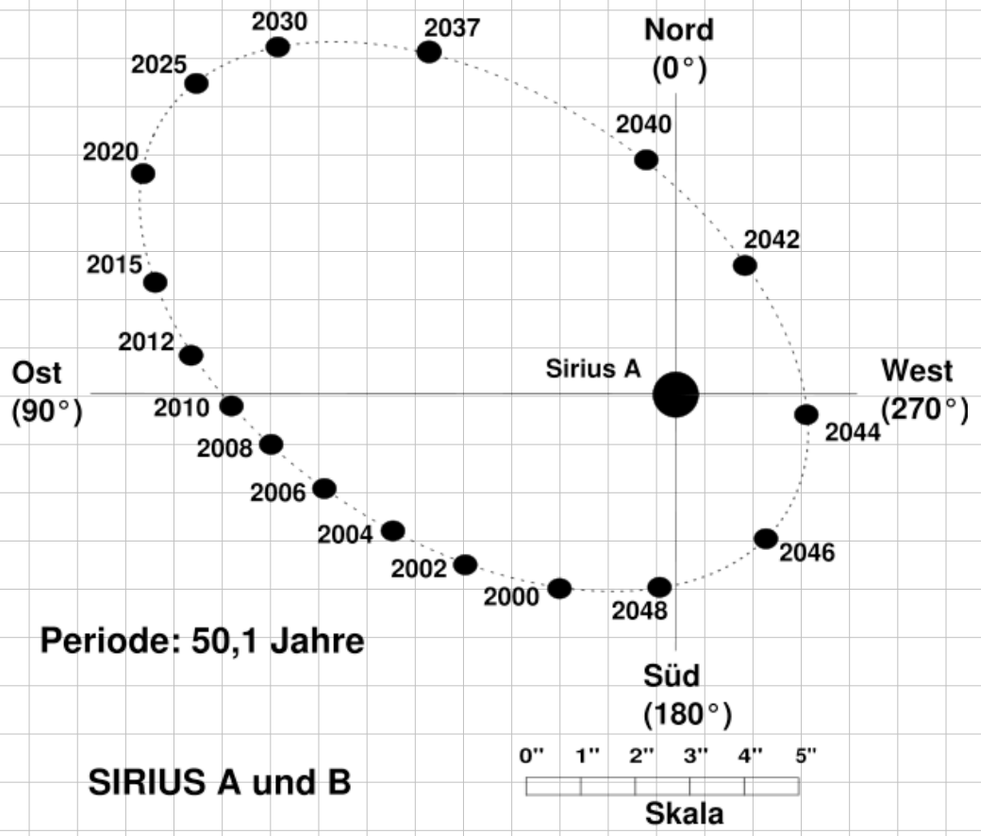


Abgeleitete Protonflüsse



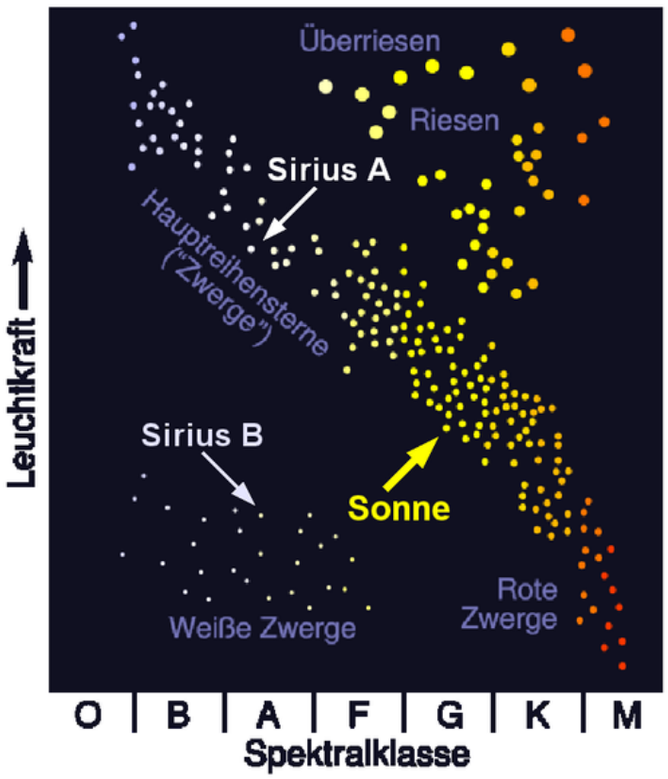
Kompakte Sterne: Sirius B

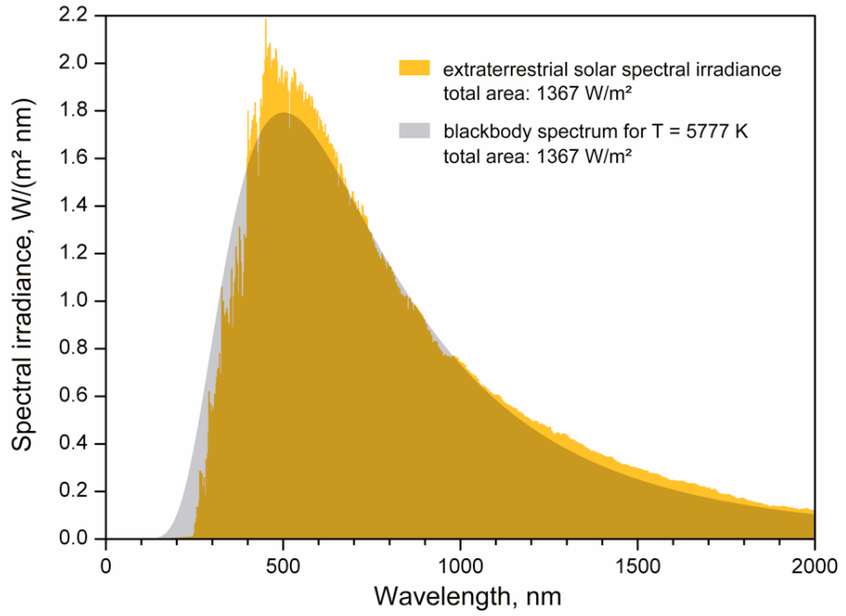




Periode: 50,1 Jahre

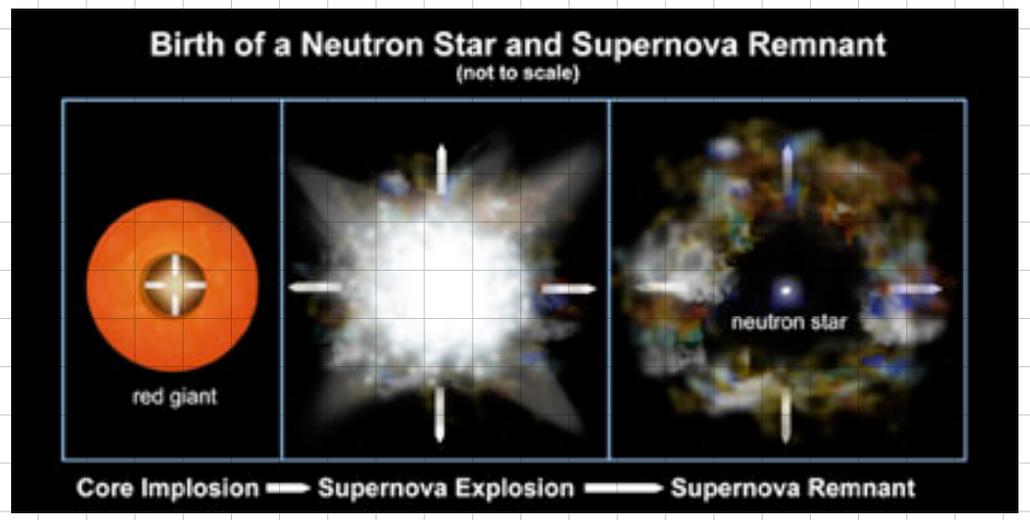
SIRIUS A und B

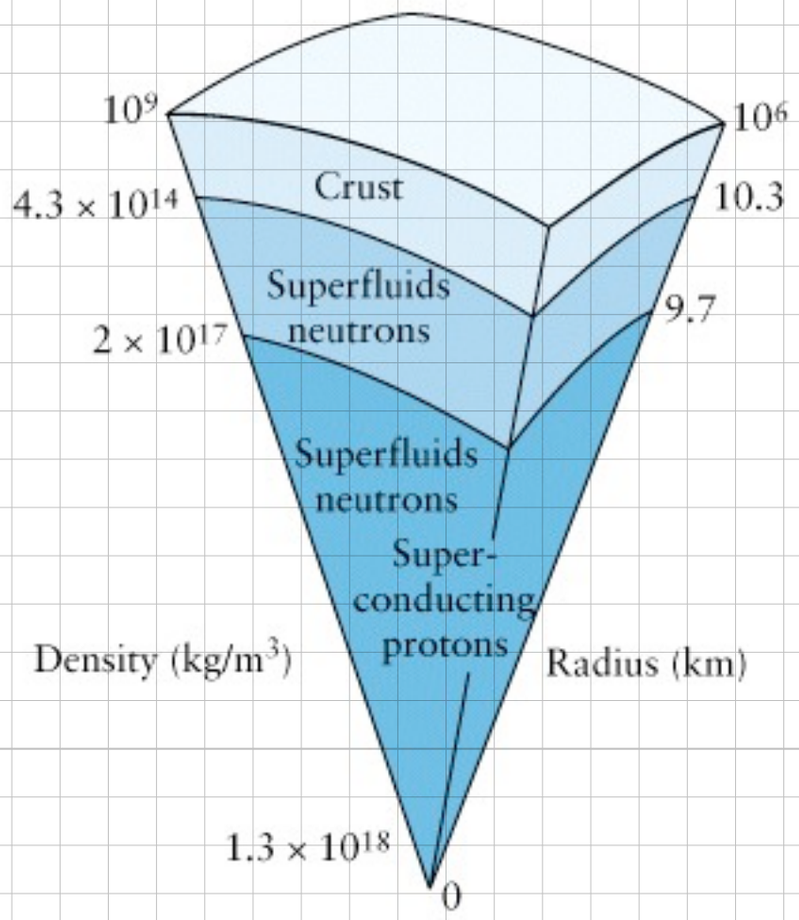



extraterrestrial solar spectral irradiance
total area: 1367 W/m²
blackbody spectrum for T = 5777 K
total area: 1367 W/m²
Spectral irradiance, W/(m² nm)
Wavelength, nm
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
0
500
1000
1500
2000

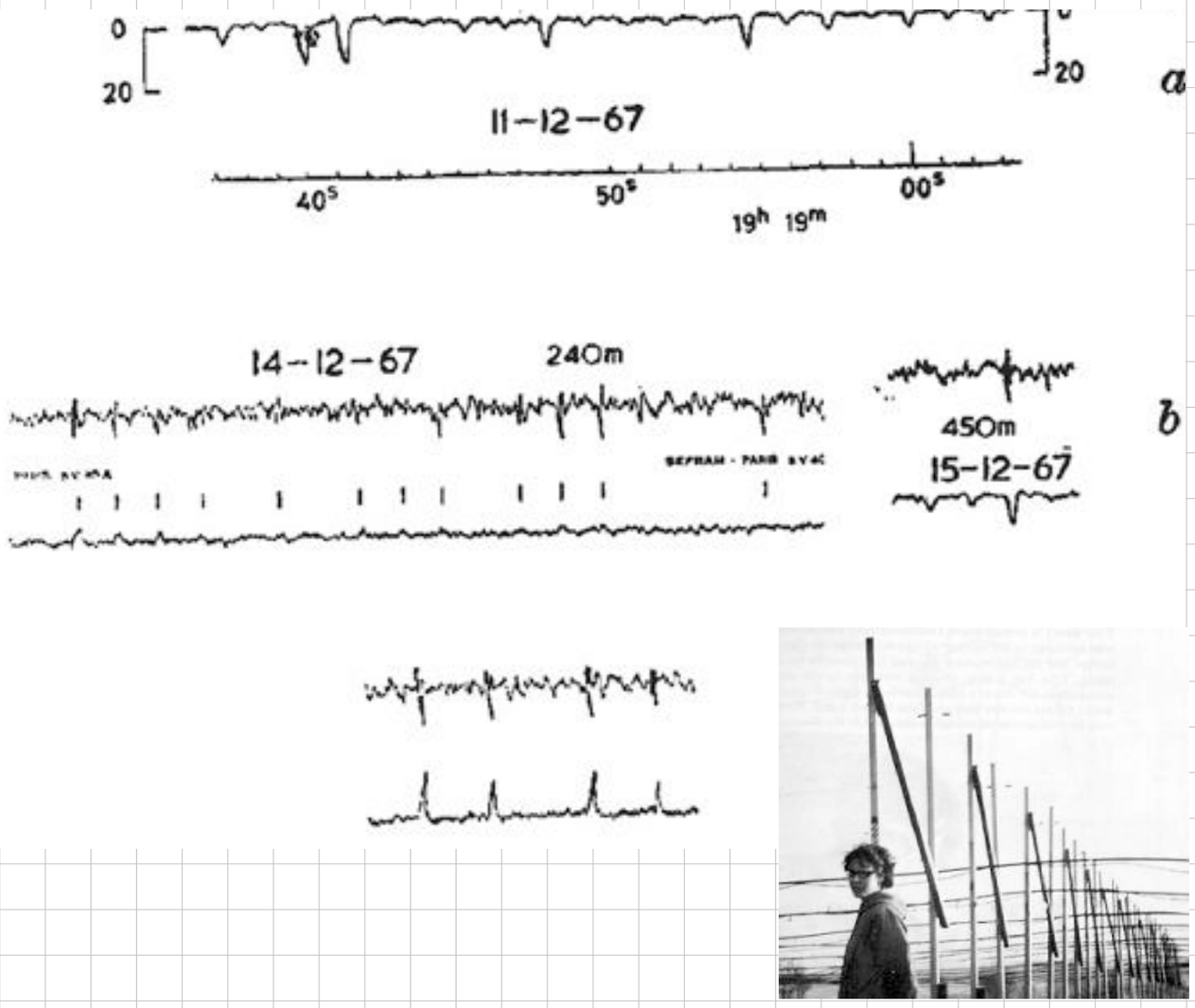
Quantenmechanischer Entartungsdruck

Entstehung von Neutronensternen

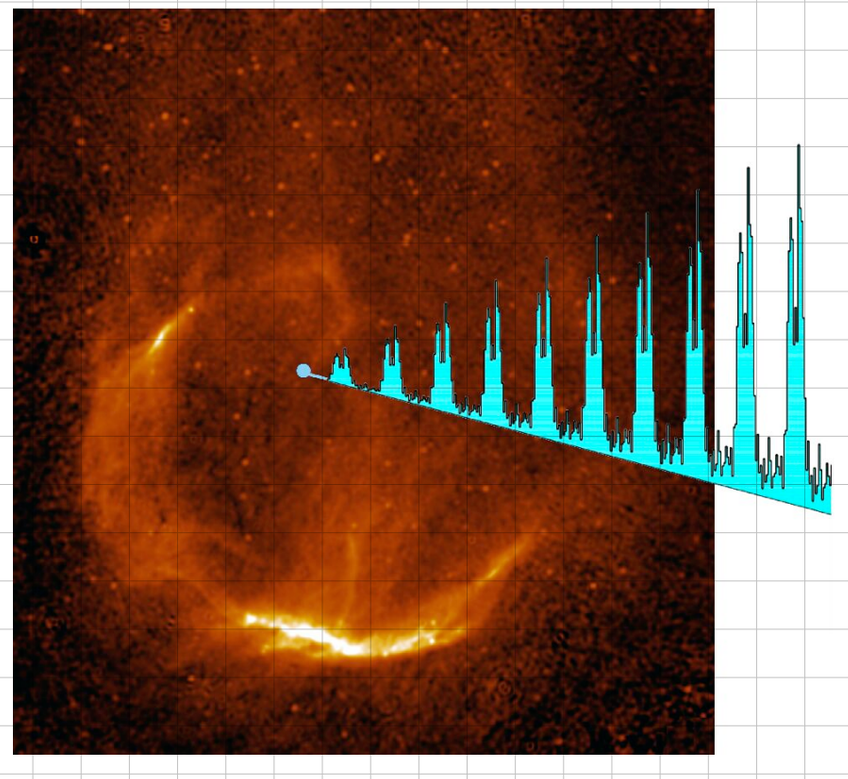


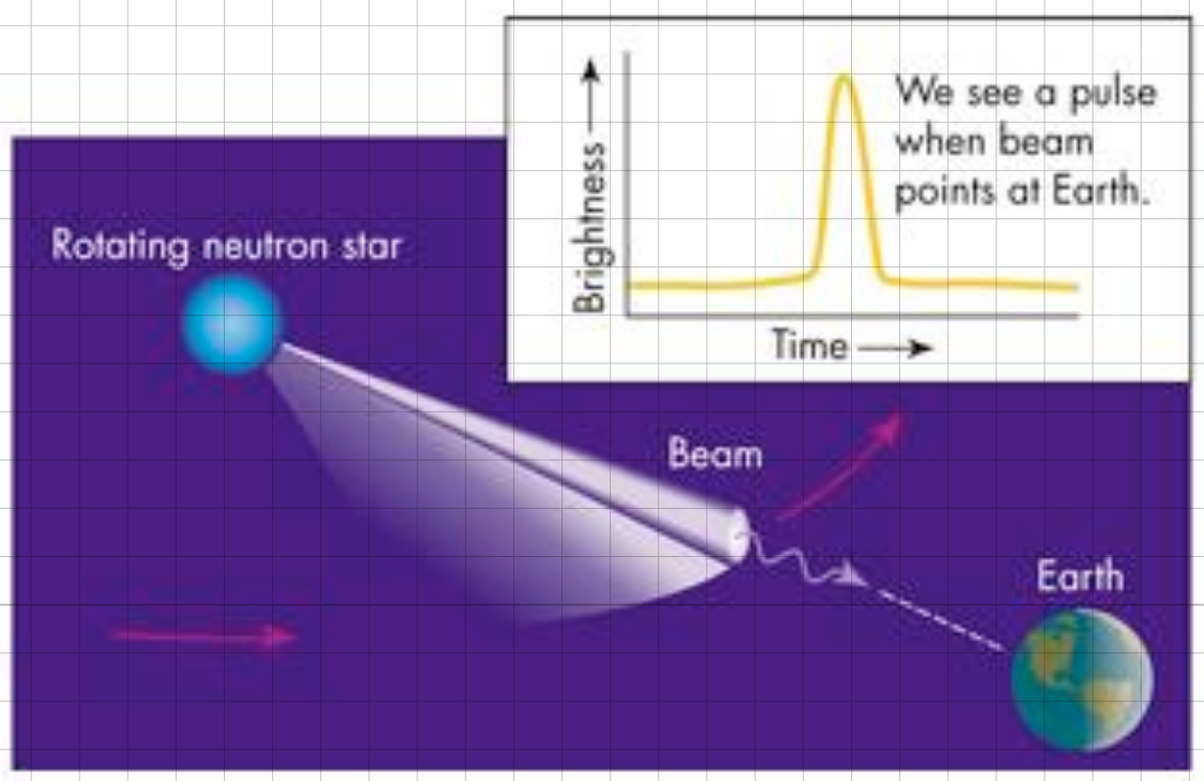


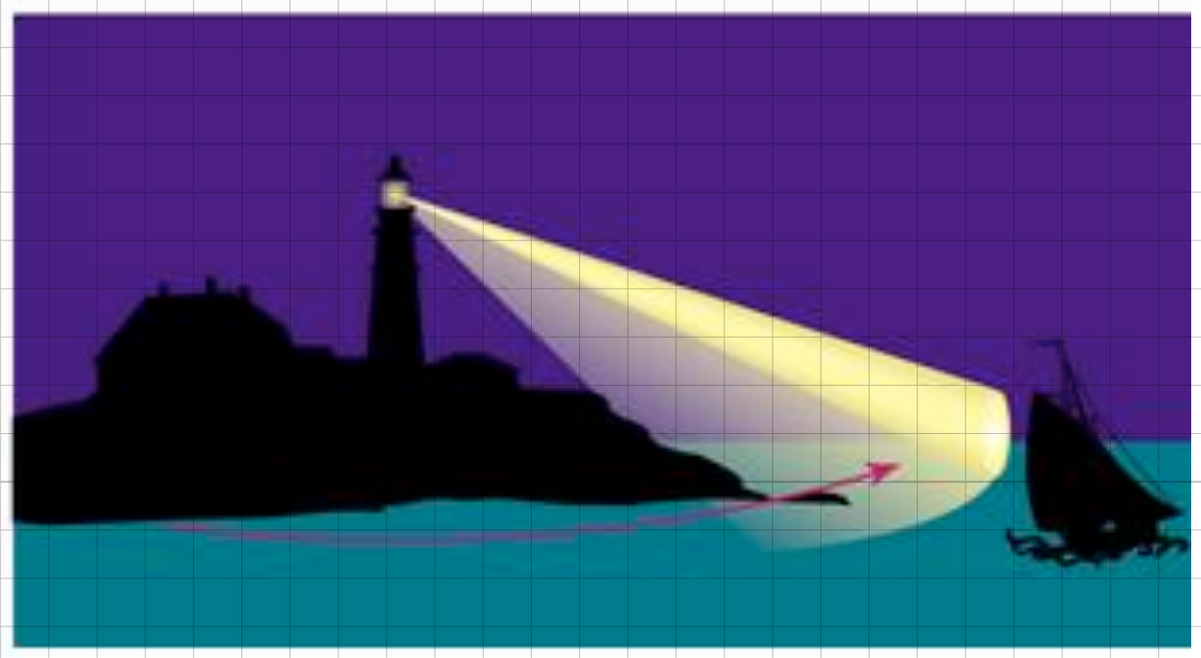
Entdeckung des ersten Pulsars



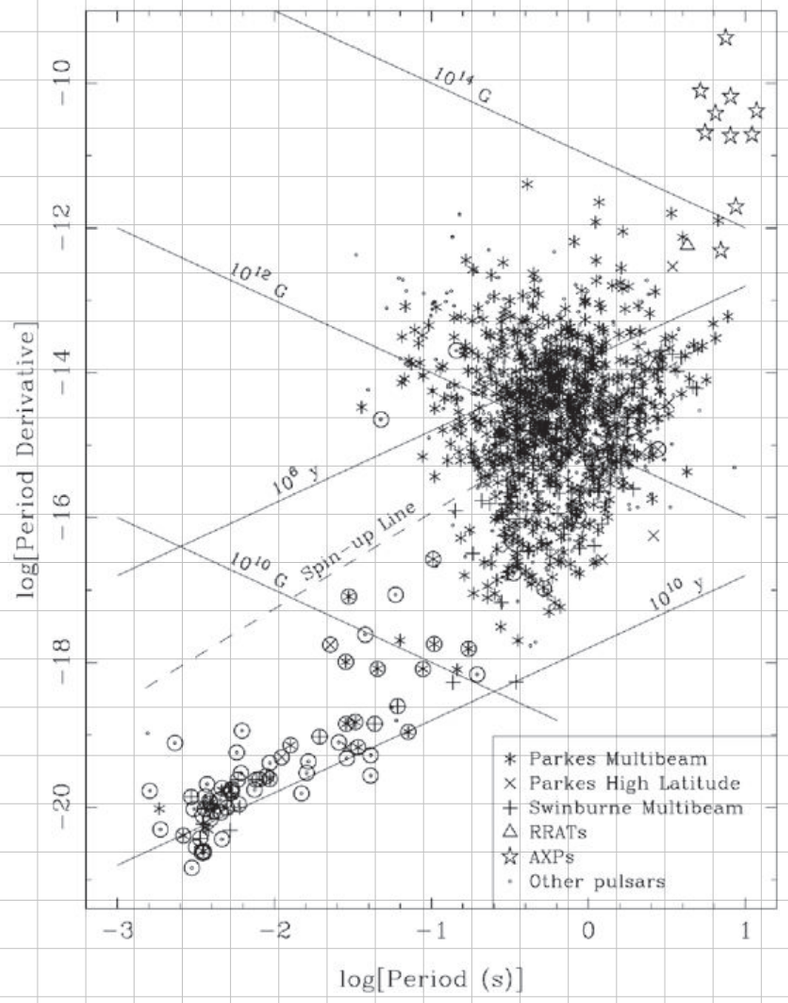
0
20
20
11-12-67
40s
50s
00s
19h 19m
a
14-12-67
240m
450m
15-12-67
b
c

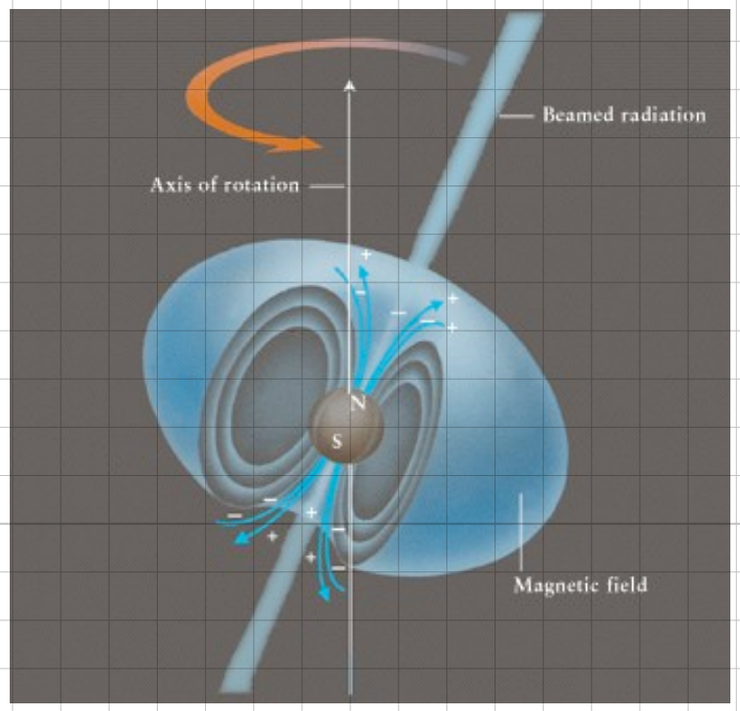



Brightness
Time
We see a pulse when beam points at Earth.
Rotating neutron star
Beam
Earth



Interpretation von Pulsaren als Neutronensterne





Drehimpulserhaltung

Erhaltung des mag. Flusses

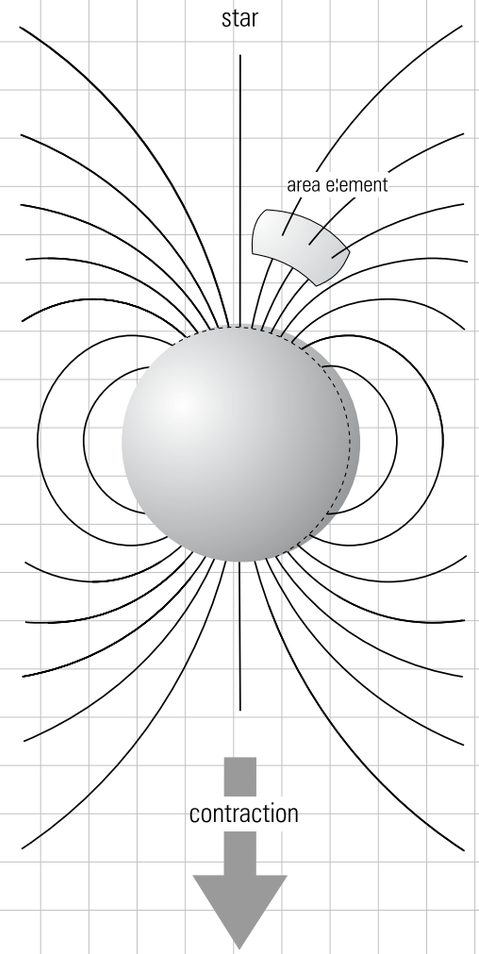
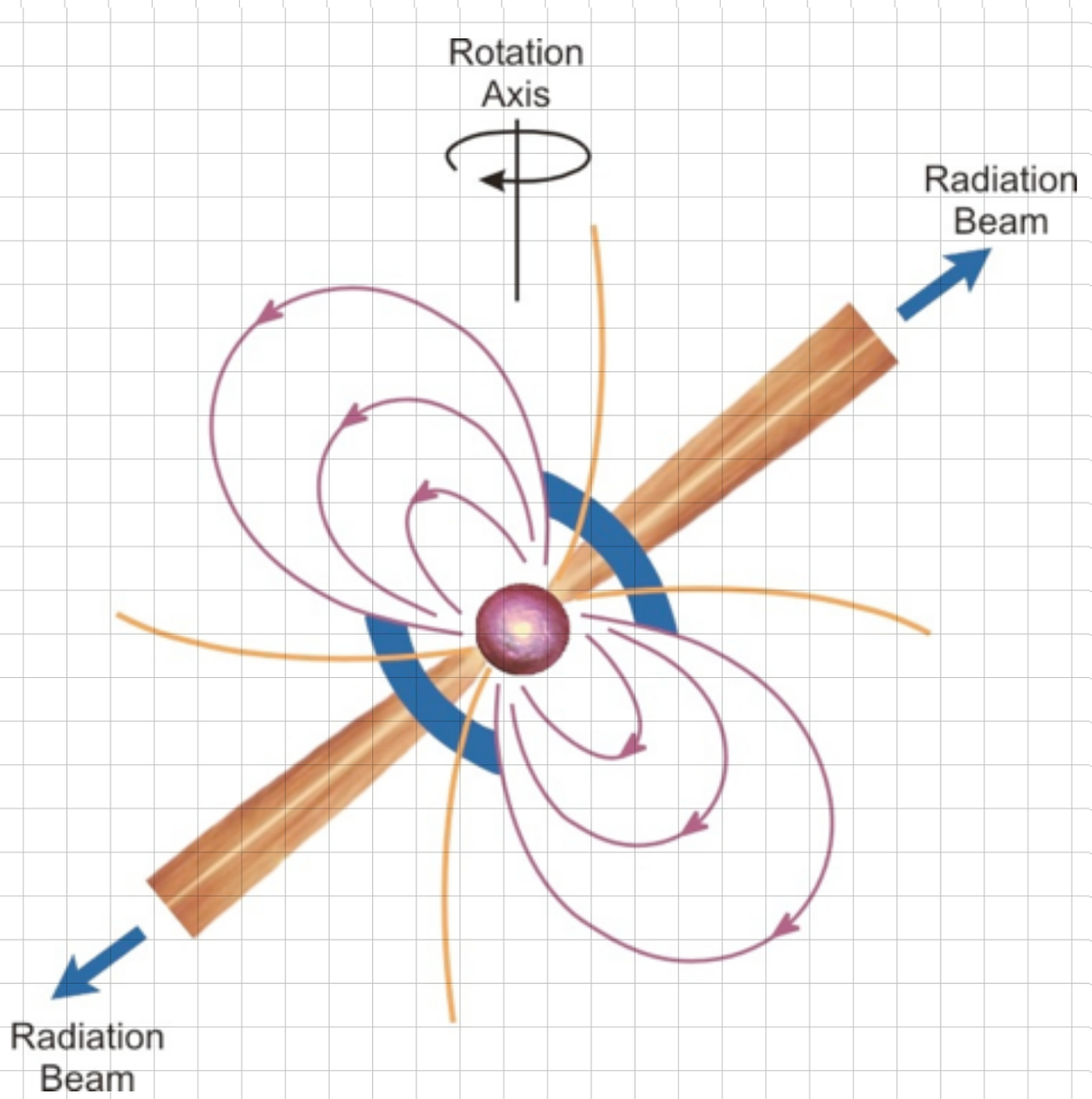
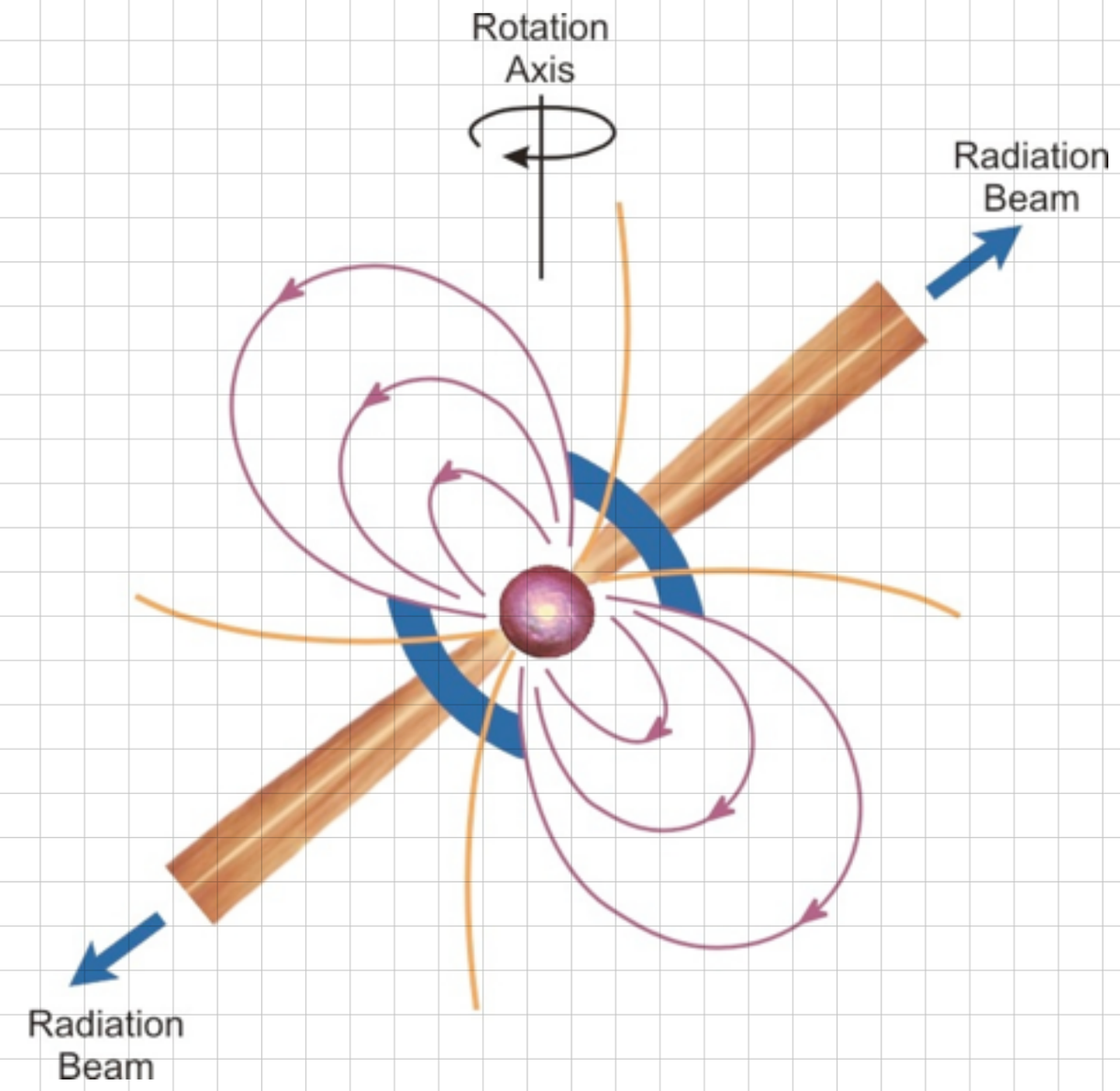


Fig. 5.6
Increase of the magnetic field during the gravitational collapse of a star

Abgestrahlte Energie



Magnetosphäre von Neutronensternen



Induktionsgesetz

$$\mathrm{rot}\,\vec{E} + \frac{\partial B}{\partial t} = 0$$

Ansatz: Elektromagn. Dipolstrahlung
(Jackson, Elektrodynamik)

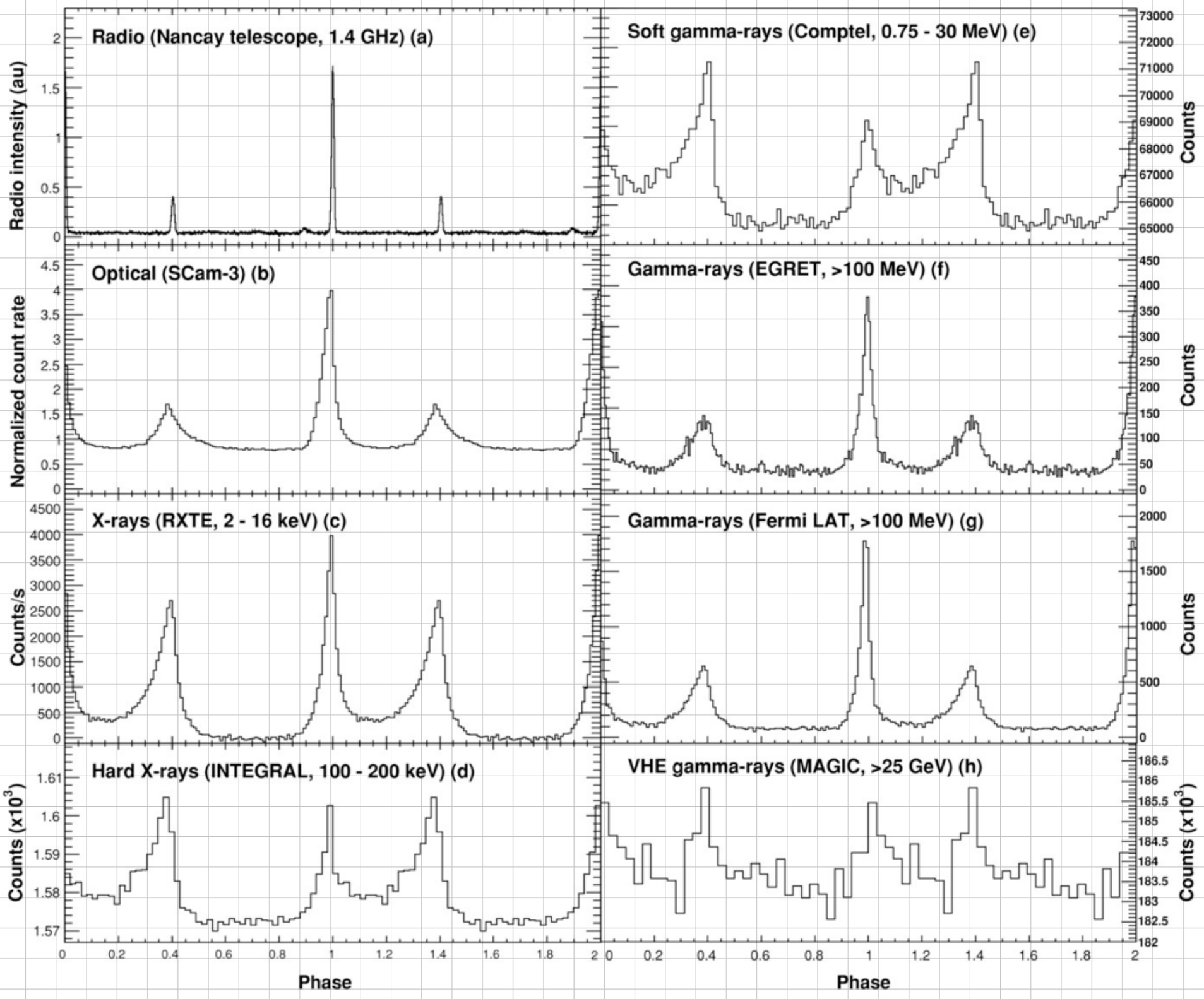
$$\frac{\partial E_{\mathrm{em}}}{\partial t} = \frac{16\pi^4}{6}\frac{B^2 R^6}{c^3 P^4}\sin^2\theta$$

$$\frac{\partial E_{\mathrm{rot}}}{\partial t} = \frac{\partial E_{\mathrm{em}}}{\partial t}$$

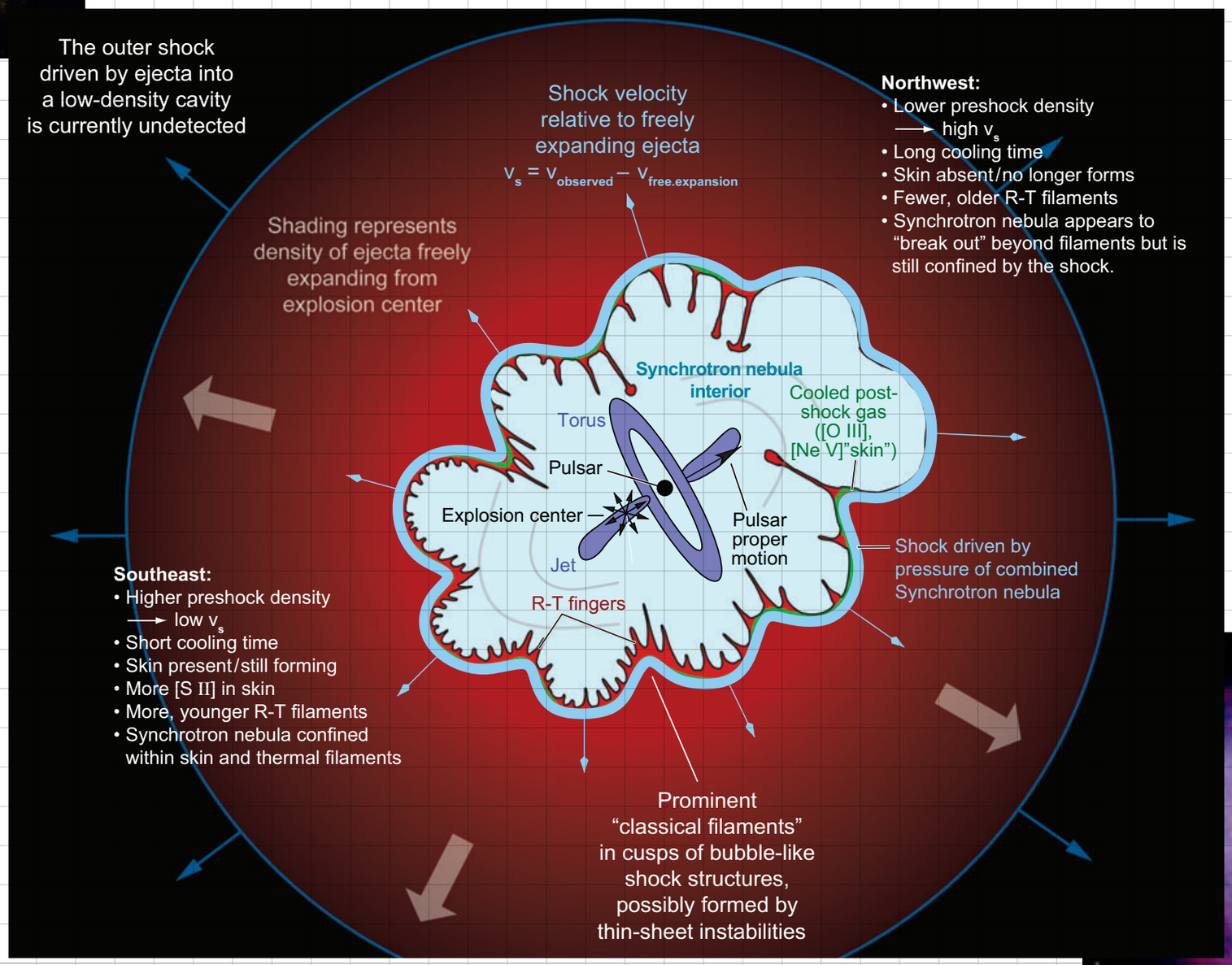
$$B = \frac{1}{2\pi}\frac{1}{R^3\sin^2\theta}\sqrt{6c^3 J P \dot{P}}$$

mit $\theta = 90° \Rightarrow B \approx 8 \times 10^{12}\mathrm{G}$ für Krebs-Pulsar

Krebsnebel: Zeitabhängigkeit des Signals



Krebsnebel


The outer shock driven by ejecta into a low-density cavity is currently undetected
Shock velocity relative to freely expanding ejecta
$v_s = v_{observed} - v_{free.expansion}$
Shading represents density of ejecta freely expanding from explosion center
Northwest:
• Lower preshock density → high v_s
• Long cooling time
• Skin absent/no longer forms
• Fewer, older R-T filaments
• Synchrotron nebula appears to "break out" beyond filaments but is still confined by the shock.
Synchrotron nebula interior
Cooled post-shock gas ([O III], [Ne V]"skin")
Torus
Pulsar
Explosion center
Pulsar proper motion
Shock driven by pressure of combined Synchrotron nebula
Jet
R-T fingers
Southeast:
• Higher preshock density → low v_s
• Short cooling time
• Skin present/still forming
• More [S II] in skin
• More, younger R-T filaments
• Synchrotron nebula confined within skin and thermal filaments
Prominent "classical filaments" in cusps of bubble-like shock structures, possibly formed by thin-sheet instabilities

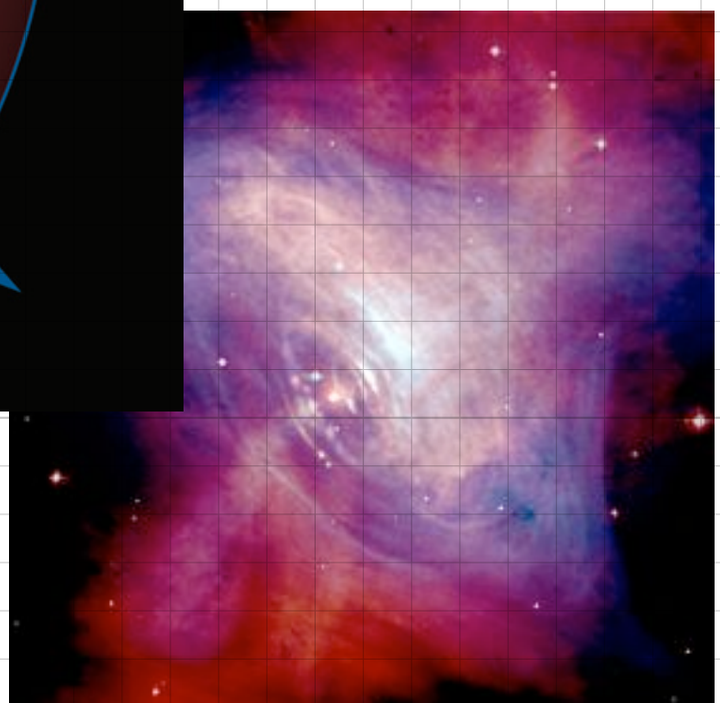
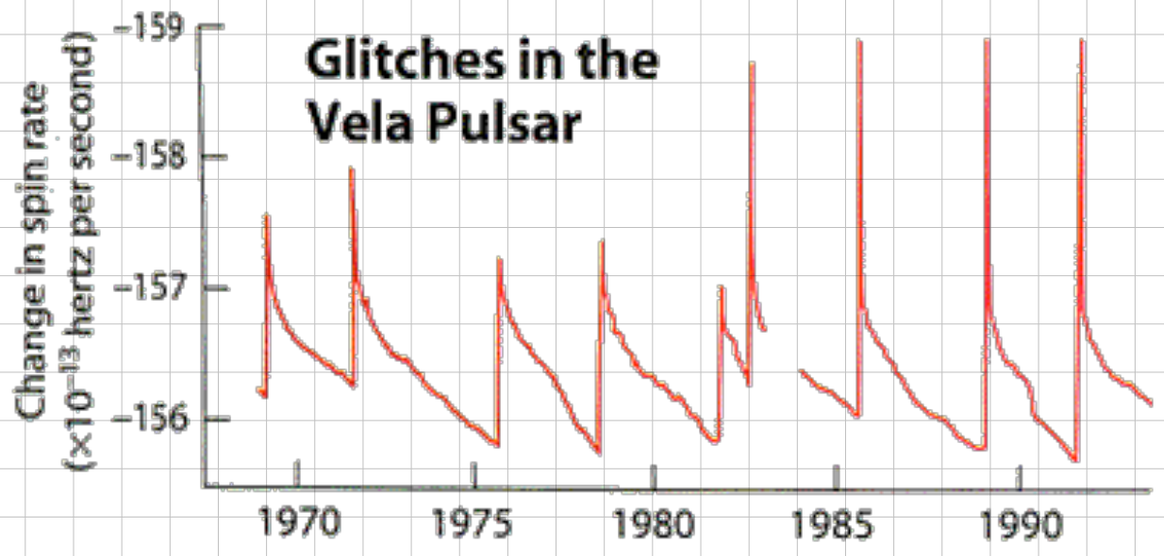


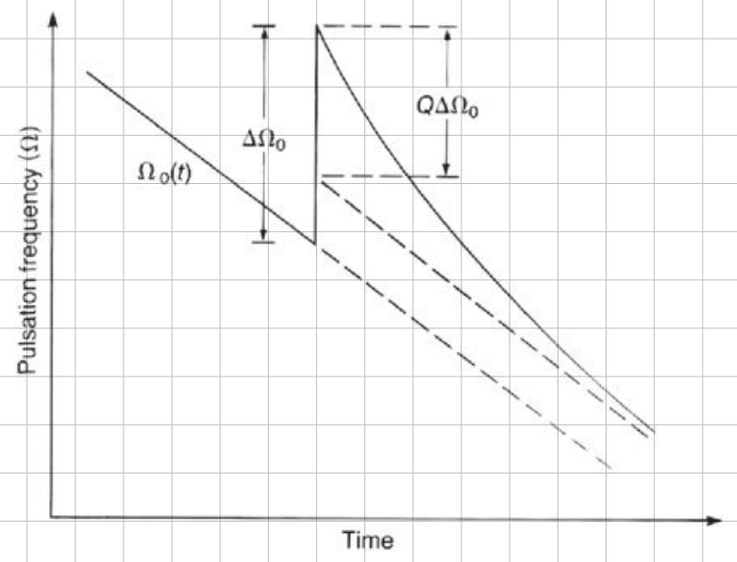
TABLE V. Physical parameters of the standard model.

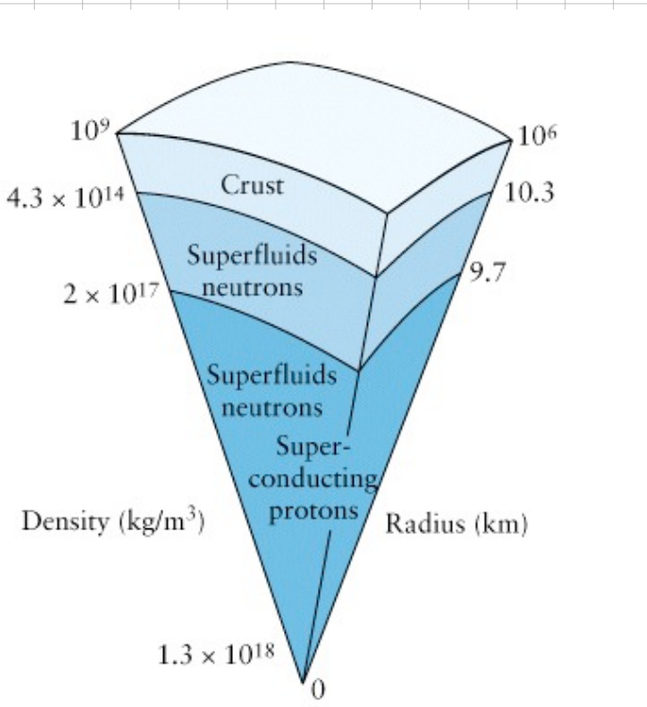
Quantity (at surface)	Estimator	Crab	Typical
Magnetic field (B)	——[a]	4×10^{12} G[c]	10^{12} G[c]
Rotation Rate (Ω)	——[a]	200 rad/sec[c]	6 rad/sec
Radius (a)	——[a]	10^6 cm	10^6 cm
Mass (M)	——[a]	1.4 M	1.4 M
Moment of Inertia	——[a]	10^{45} gcm^2	10^{45} g cm^2
$E_{\|\|}$ (vacuum)	ΩaB	8×10^{12} V/cm	6×10^6 V/cm
Polar cap area	$\pi\Omega a^3/c$	2×10^{10} cm^2	6×10^8 cm^2
Polar cap radius	$(\Omega a^3/c)^{1/2}$	8×10^4 cm	1.4×10^4 cm
grav./elect. force	$mg/eE_{\|\|}$[b]	1.5×10^{-9}	2×10^{-7}
Pole to equator potential	$\Omega a^2B/2$	4×10^{18} V	3×10^{16} V
Potential across polar cap	$\Omega^2a^3B/2c$	3×10^{16} V	6×10^{12} V
Electron Cyclotron frequency (ω_c)	eB/m_e	7×10^{19} rad/sec	1.8×10^{19} rad/sec
Proton Cyclotron frequency	eB/m_H	4×10^{16} rad/sec	1.0×10^{16} rad/sec
Iron Cyclotron frequency	eB/m_{Fe}	8×10^{14} rad/sec	2×10^{14} rad/sec
electron concentration (n_e)	$2\epsilon_0\Omega B/e$	9×10^{12}/cc	7×10^{10}/cc
Electron plasma frequency[d]	$(e^2n_e/\epsilon_0m_e)^{1/2}$	1.7×10^{11} rad/sec	1.5×10^{10} rad/sec
Alfvén velocity[e,b]	$(2\omega_{ci}/\Omega)^{1/2}c$	4×10^7c (Fe)	10^7c (Fe)
Particle flux[f]	$4\pi\epsilon_0\Omega^2Ba^3/e$	1.1×10^{34}/sec	2.5×10^{30}/sec
Slowing down rate ($\Omega/\dot{\Omega}$)	$3I\mu_0c^3/8\pi B^2a^6\Omega^2$	1340 yr	2×10^7 yr
Particle flux[f]	$4\pi\epsilon_0\Omega^2Ba^3/e$	1.1×10^{34}/sec	2.5×10^{30}/sec
Slowing down rate ($\Omega/\dot{\Omega}$)	$3I\mu_0c^3/8\pi B^2a^6\Omega^2$	1340 yr	2×10^7 yr

[a]Input assumption or observation.
[b]For singly ionized iron ions (case where gravitation would be most important).
[c]Rounded values.
[d]An equivalent expression is $\omega_p^2=2\Omega\omega_c$, hence $\omega_p<<\omega_c$. B (or n_e) should be decreased by about $(c/a\Omega)^3=3.4\times10^6$ to give the value at the light cylinder.
[e]Here one uses the ion cyclotron frequency.
[f]A simple equivalent is $L/I^2=15W/A^2$, where L is the total power output and I is the current (Michel, 1978a), hence e times the particle flux.

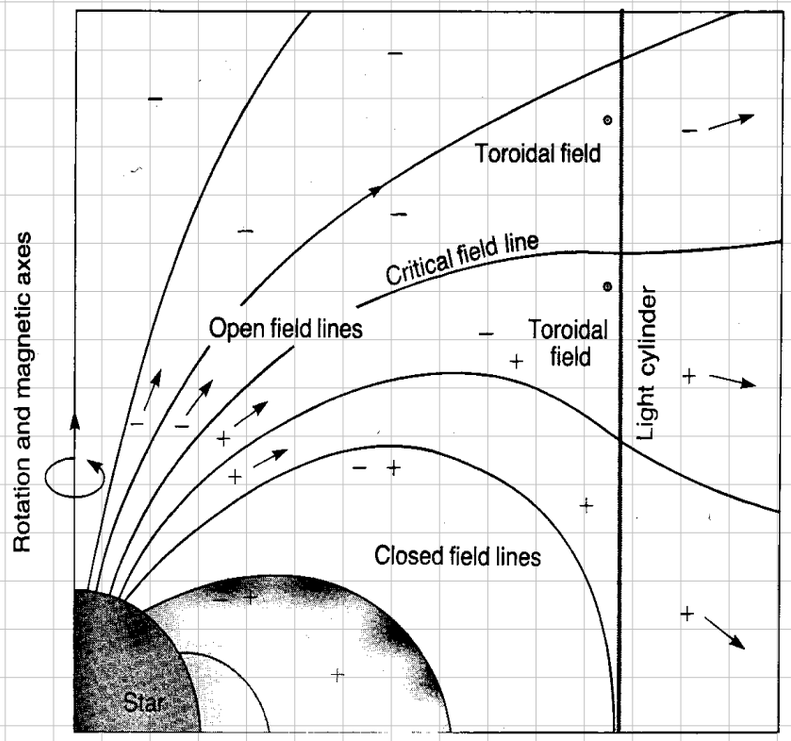
Sprünge in der Umlaufzeit (Glitches)

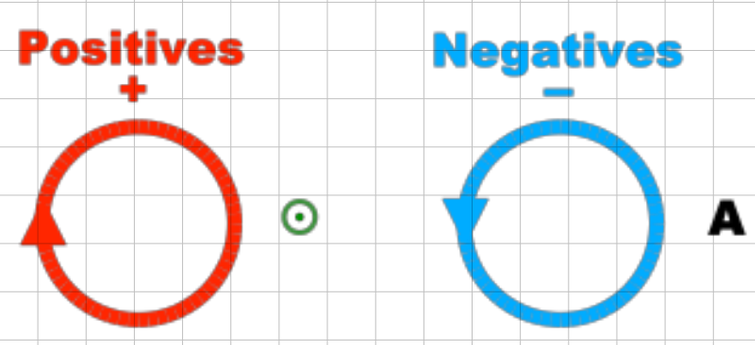


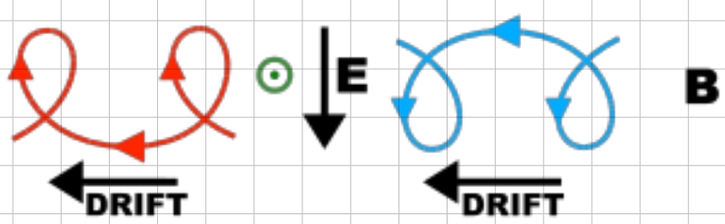




Magnetosphäre von Neutronensternen




Positives
+
Negatives
–
A


E
B
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