Kosmologie und Astroteilchenphysik

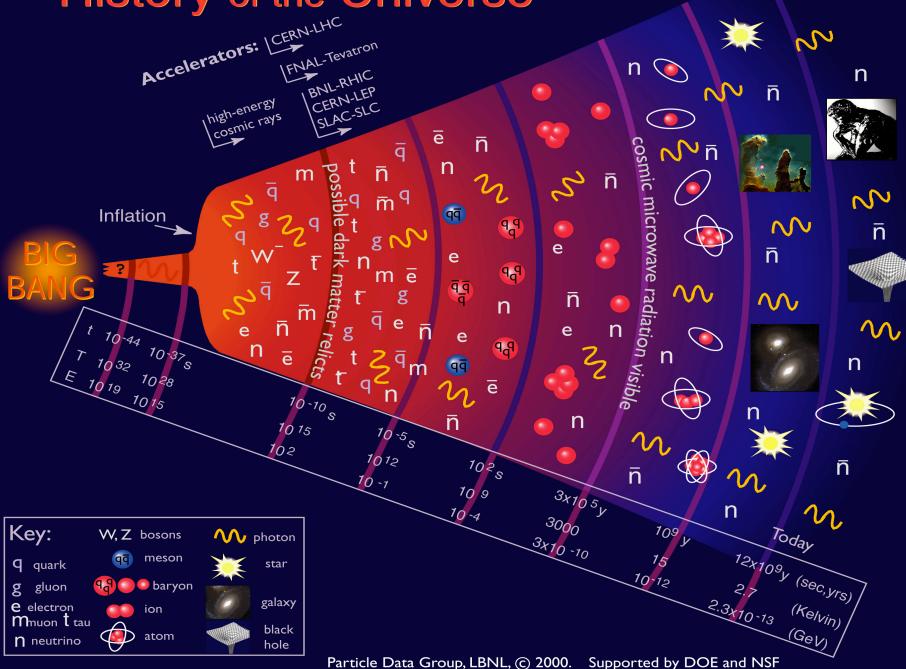
Prof. Dr. Burkhard Kämpfer, PD Dr. Daniel Bemmerer

- Einführung in die Kosmologie
- Weltmodelle und kosmologische Inflation
- Thermische Geschichte des Universums
- Urknall-Nukleosynthese
- Dunkle Energie, dunkle Materie und die beschleunigte Expansion des Universums
- Kosmische Mikrowellen-Hintergrundstrahlung
- Supernovae als kosmische Standardkerzen
- Neutronensterne
- Entstehung und Nachweis kosmischer Strahlung
- Altersbestimmung des Universums
- Neutrinos aus der Sonne und ihre Oszillationen

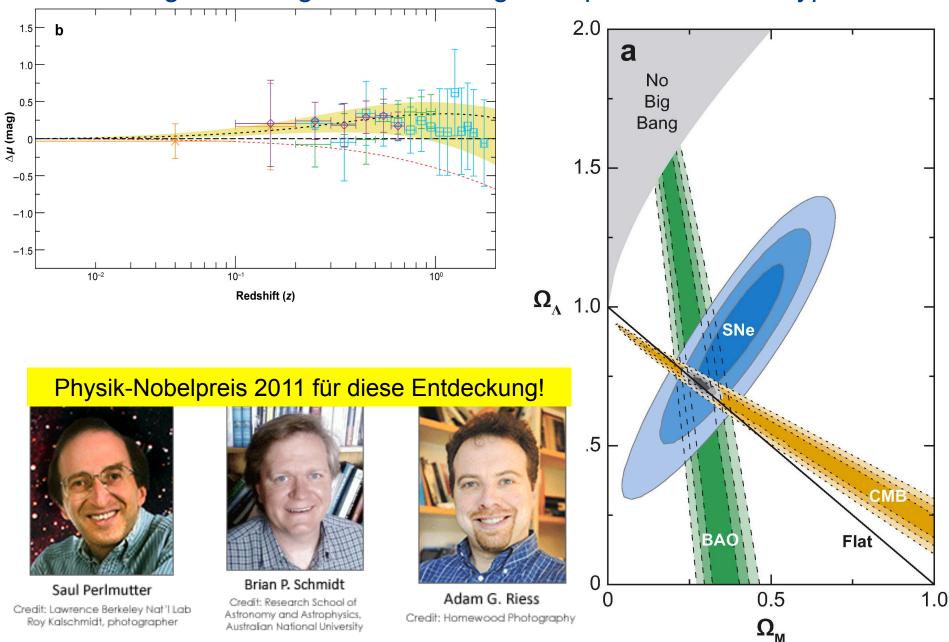
8. Vorlesung, 14.06.2017



History of the Universe



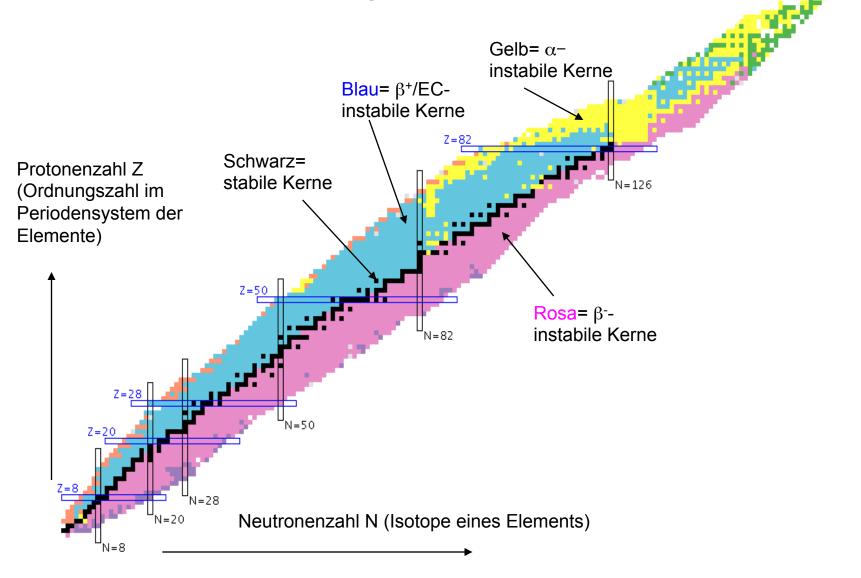
Entfernungsmessung und Kosmologie: Supernovae vom Typ la



Australian National University

Mitglied der Helmholtz-Gemeinschaft

Nuklidkarte und Entstehung der chemischen Elemente



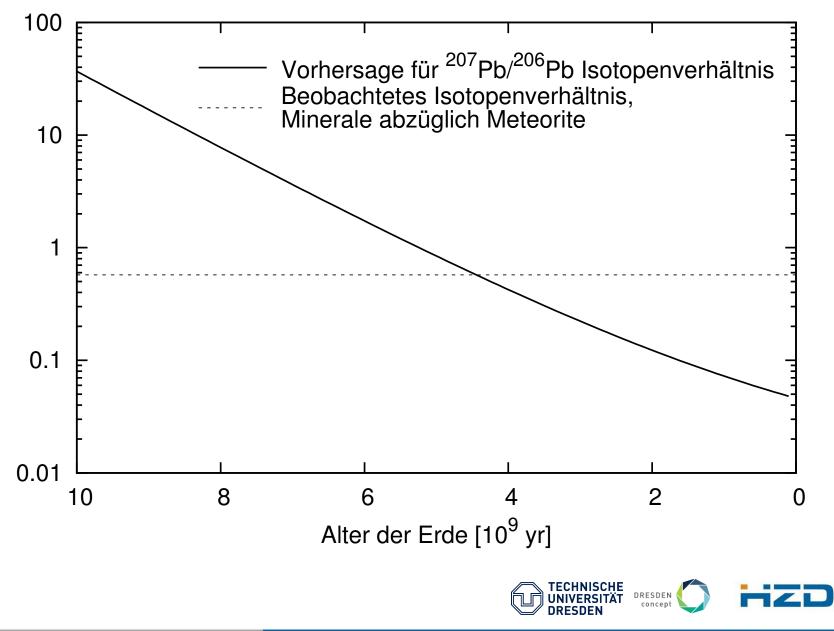


Nuklidkarte am Ende des Tals der Stabilität und Nukleokosmochronologie

| | | | | | | | | | L to Tak | α 1.112 ε? | α 7.465 | 0 | a-6.72 | 1 0.00, 0.54 | γ 235, 535 | 10 0000, 0.101. | 7 49. (756, 34) | r (48, 109_), e c, 160 | y 60, e dr 2300 | r (43, 100), e o 510, o, 17 | a 270, at 752 | 9 n 290, oy ~0.05 | No.3 |
|----------------------------------|-------------------------------|--|--|---|---|--------------------------------------|---|---|---|--|---|---|---|--|---|--|--------------------------------------|---|---|--|---|---|--------------------------|
| 1 | | | | | | | Np | Np 225 | Np 226 31 ms | Np 227 0.51 s | Np 228 61.4 s | Np 229 | Np 230 | Np 231 48.8 m | Np 232 | Np 233 36.2 m | Np 234 4.4 d | Np 235 396.1 d | Np 236 | Np 237 | Np 238 2.117 d | Np 239 2,355 d | N |
| | | | | | | 93 | | | 31 ms | 0.51 \$ | 61.49 | 4.010 | 4.0 11 | ε α.6.28 | c y 327, 820, 867 | α 5.54 | c, β ⁺ γ 1559, 1528 | E | 1642 160 888.). • 104 | sf | β ⁻ 1.2, y 984 1029, 1026, | β ⁻ 0.4, 0.7 γ 106, 278 | 1 2.2. 1 555 |
| | | | | | | | | α 8.63 | α 8.06, 8.00 | a 7.68, 7.65 | a ~7.15 psf | α 6.690 | ε α 6.66 | y 371, 348 264 | 864, 282 | γ (312, 299 547) | 1602 σ ₁ ~900 | y (26, 84), e ⁻ g r 160 + 7 | g 2700 di 3000 | a 4.790, 4.774 7.29, 87 | 924, e ⁻ , g o _f 2600 | 228, e ⁻ , g σ 32 + 19, σ _l < | 19 |
| U | U 217 | U 218 | U 219 | | T | U 222 | U 223 | U 224 | U 225 | U 226 | U 227 | U 228 | U 229 | U 230 | U 231 | U 232 68.9 a | U 233 | U 234 0.0054 | U 235 0.7204 | U 236 | U 237 6.75 d | U 238 99.2742 | Ļ |
| 238.02891 | 16 ms | 0.56 ms 0.51 ms | 0.08 ms | | | 1 µs | 18 µs | 0.9 ms | 59 ms | 0.28 s | 1.1 m α 6.86, 7.06 | 9.1 m α 6.68, 6.59 | 58 m | 20.8 d α 5.888, 5.818 Ne22, γ (72 | 4.2 d | a 5.320, 5.262 | α 4.824, 4.783 No25 | 2.455·10 [°] a | 26 m 7.038-10 | 4.494 4.445_st | β ⁻ 0.2 γ 60, 208, e ⁻ | 298 np 4.468-10 ⁴ | β ⁻¹ γ 75. |
| σ 3.4 σ ₁ 4.2 | a 8.005 | a 10.678 a 5 612 | a 9.774 | | | | a 8.78 | α 8.47 | α 7.868, 7.833. | α 7.555, 7.374. γ 182 | | γ <u>(</u> 246, 187) | 6.36367.6.334 6.297 1 123, 86, 199. | 154, 230), e" g,~25 | a 5 456, 5.471, 5.404 7 26, 84, 102 a - 250 | γ (58, 129), e σ 73, σ ₁ 74 | | a 4 775, 4 723 st Mg28, Ne, r(53, 121 e , c 98, p; 0.07 | hy (0.07) α 4 398 | 4 17 1723 Mg30, y (49 64 113_), e ⁻ c 5.1 | σ -100 σ _t < 0.35 | hy 2014 2β ⁻ , γ (50. 1829 e . σ 2.7 o ₁ 3E-6 | a 22 a, 15 |
| Pa 215 | Pa 216 | Pa 217 | Pa 218 | Pa 219 | Pa 220 | Pa 221 | Pa 222 | Pa 223 | Pa 224 | Pa 225 | Pa 226 | Pa 227 | Pa 228 | Pa 229 | Pa 230 | Pa 231 | Pa 232 | Pa 233 | Pa 234 | Pa 235 | Pa 236 | Pa 237 | P |
| 14 ms | 105 ms | 1.1 ms 3.8 ms | 113 µs | 53 ns | 0.78 µs | 5.9 µs | 4.3 ms | 6.5 ms | 0.79 s | 1.8 s | 1.8 m | 38.3 m | 22 h | 1.50 d ε, α 5.580 5.670, 5.615 | 17.4 d | 3.276·10 ⁴ a | 1.31 d | 27.0 d | 1.17 m 6.70 h 1 2.3. p 0.5 | | 9.1 m β ⁻ 2.0, 3.1 γ 642, 687 | 8.7 m 6 ⁻ 1.4, 2.3 | β [−] 1. |
| | α 7.948, 7.815 y 134 | 8.306. 17 α 8.337 7.613,450 821. 7.873 7.873 7.873 | α 9.616, 9.544 γ 92 | α 9.90 | α 9.65 | α 9.08 | α 8.21, 8.54 8.33 | a 8.01, 8.20 | α 7.488, 7.405. γ 195, 153 | a 7.25. 7.20 | α 6.86, 6.82 ε | a 6 456, 6.416. | 6 0.078, 0.105, 5.791 5,118 911, 463, 969, 965. | 8 y (119, 40 | a 5.345, 5.326 7 952, 919, 455, 899 444. | 5.028 Ne24, F237 T 27, 300, 303 | 969, 894, 150 9 9 480, e, 1500 | 7 312 300, 341 | h ⁻ 2.3. γ(1001 707_) hγ(74_) σ ⁻ d ₄ < 500 h ⁻ 0.5 1.2. γ 131,88 853 σ α,4834 | y 128 - 859 | 1763, g βsi? | y 854, 865, 529 | a 448, |
| α 8.09 Th 214 | Th 215 | Th 216 | Th 217 | Th 218 | Th 219 | Th 220 | Th 221 | Th 222 | Th 223 | Th 224 | Th 225 | Th 226 | Th 227 | Th 228 | Th 229 | Th 230 | Th 231 | Th 232 | Th 233 | Th 234 | Th 235 | Th 236 | Т |
| 0.10 s | 1.2 s | 135 µs 28.0 ms | 237 µs | 0.1 µs | 1.05 µs | 9.7 µs | 1.68 ms | 2.24 ms | 0.66 s | 1.05 s | 8.72 m a 6.482 6.445 | 31 m α 6.336, 6.230. | 18.72 d α 6.038, 5.978 | 1.913 a α 5.423, 5.340 | 7932 a | 7.54·10' a | 25.5 h | 100 1.405·10 ¹⁵ a | 22.3 m β ⁻ 1.2 | 24.10 d β ⁻ 0.2 | 7.1 m | 37.5 m | |
| | α 7.392, 7.523 7.335 | h 1478 α 9.930 α 7.923 9.312 7 304 γ 629 γ 629 | a 9.261, 8.455 | | | a 8.79 | a 8.15, 8.47 | α 7.980, 7.599 | α 7.324, 7.285. γ 140, 152 114 | α 7.17, 7.00 γ 177 | 6.504, ε γ 321, 246, 359 306 | γ 111, (242 131) | 5.757 γ 236, 50, 256. e ⁻ , σ ₁ 200 | γ 84, (216), e O20 σ 120, σ _f < 0.3 | 4 815 | α 4.687, 4.621 γ(68, 144_), e ⁻ Na24 α 23.4, α ₁ < 5E-4 | β ⁻ 0.3, 0.4 γ 26, 84 | a 4.013, 3.950 st, y (64), e ⁻ g 7.37, a, 3E-6 | 9 87, 29, 459 9 σ 1500, σι 15 | γ 63, 92, 93. e , m σ 1.8, σ ₁ < 0.01 | γ 417, 727 696 | γ 111, (647 196) | 6- |
| α 7.68 Ac 213 | γ 134, 195 Ac 214 | Ac 215 | γ 822, 546 Ac 216 | α 9.67 Ac 217 | α 9.34 Ac 218 | Ac 219 | Ac 220 | Ac 221 | Ac 222 | Ac 223 | Ac 224 | Ac 225 | Ac 226 | Ac 227 | Ac 228 | Ac 229 | Ac 230 | Ac 231 | Ac 232 | Ac 233 | Ac 234 | | Ac |
| 0.80 s | 8.2 \$ | 0.17 s | 0.44 ms | 0.74 µs 69 ns | 1.1 µs | 11.8 µs | 26.4 ms | 52 ms | 63 s 5.0 s | 2.10 m a 6.647, 6.662 | 2.78 h | 10.0 d u 5.830, 5.793 | 29 h β ⁻ 0.9, 1.1 | 21.773 a | 6.13 h β ⁻ 1.2, 2.1 | 62.7 m | 122 s β ⁻ 2.7 | 7.5 m | 119 s β ⁻ γ 665, 1899 | 145 s | 44 s | | |
| 7.00 | a 7.216. 7.081 | α 7.600, 7.211 ε γ (396) | a 9.029, 9.105. | h 680 488, 382 g 10.54 | a 9.205 | a 8.664 | α 7.86, 7.71 7.79 γ 134ε? | α 7.65, 7.44 7.38 | a 6.81 6.75, 6.89 7.00, m a 7.009 h7 6.963 | 6.564, ε, C14 γ (99, 191, 84) | α 6.142, 6.060 6.214 γ 216, 132 | 5.732, C14 y 100, (150, 188 63), e | c, α 5:34 7 230, 158, 254 | β 0.04 u 4 953, 4.941 γ (100, 84), e σ 850 σ, < 3.5E-4 | α 4.27? γ 911, 969, 338 | β ⁻ 1.1 γ 165, 569, 262 146, 135 | y 455, 508 1244 | p 7 282, 307, 221 186, 369 | | β ⁻ 7 523, 540 | p y 1847, 1912 689, 1954 | | 8- |
| α 7.36 Ra 212 | Ra 213 | Ra 214 | 7 83, 854, 771 Ra 215 | a 10.54. a 9.65 Ra 216 | 8 Ra 217 | Ra 218 | Ra 219 | Ra 220 | Ra 221 | Ra 222 | Ra 223 | Ra 224 | Ra 225 | Ra 226 | Ra 227 | Ra 228 | Ra 229 | Ra 230 | Ra 231 | Ra 232 | Ra 233 | Ra 234 | - |
| 13.0 9 | 2.1 ms 2.74 m | 2.46 s α 7.137, 6.505 | 1.67 ms | 2.0 ns 0.18 µs | | 25.6 µs | 10 ms | 18 ms | 28 s a 6.613, 6.761 | 38 s a 6.559, 6.237 | 11.43 d | 3.66 d a 5.6854 | 14.8 d | 1600 a α 4.7843 | 42.2 m | 5.75 a β 0.04 | 4.0 m | 93 m β 0.8 | 104.1 s | 4.2 m | 30 s | 30 s | |
| a 6.899 c? | 1063 6.731 181 | а 9 | α 8.700, 7.879 | hy 688, 476 344 α 9.551 | a 8.99 | α 8.39 | α 7.679, 7.989 γ 316, 214 592 | α 7.45 γ 465 | 6.668 γ 149, 93, 174 C14 | γ 324, (329 473) C14 | γ 269, 154, 324 C14 σ 130 | 5.4486 γ 241, C14 σ 12.0 | β ⁻ 0.3, 0.4 γ 40 | 4.601 γ 186, C14 σ 12.8, σ ₁ <5E-5 | β 1.3 γ 27, 300, 303 | $\gamma (14, 16)$ e $\sigma 36, \sigma_1 < 2$ | β ⁻ 1.8 | γ 72, 63, 203 470 | β γ 410, 54, 469 205, 456, 513 | β γ 471, 98, 479 105, 373 | 6- | 6- | |
| 7/635) Fr 211 | Fr 212 | γ (642) Fr 213 | γ 834, 540 Fr 214 | Fr 215 | Fr 216 | 9 Fr 217 | Fr 218 | Fr 219 | Fr 220 | Fr 221 | Fr 222 | Fr 223 | Fr 224 | Fr 225 | Fr 226 | Fr 227 | Fr 228 | Fr 229 | Fr 230 | Fr 231 | Fr 232 | Fr 233 | |
| 3.10 m | 20.0 m | 34.6 s | 3.35 ms 5.0 ms | 0.09 µs | 850 ns 71 ns 0.7 µs | 16 µs | 22 ms 1.0 ms | 21 ms | 27.4 s α 6.68, 6.63 | 4.77 m α 6.341, 6.126 | 14.2 m β 1.8 | 21.8 m | 3.3 m | 4.0 m | 48 s | 2.47 m | 39 s | 50:2 s | 19.1 s | 17.5 s | 5 \$ | >160 ns | |
| y 540, 918 | 6 262, 6.384 6 408, 6.340. | a 6.775 | u 8.477 u 8.426 8.547 8.356 | α 9.36 | a 8.933 9 004 7 160 7 160 a 9.000 45, e ⁻ 45, e ⁻ | a 8.315 | 7.680 7.656 a 7.867 m.g 7.576 hr 9 | α 7.312 γ (352, 517) | 6.57 β γ 45, 106, 161 | β ⁻ γ 218, (101 411), C14 | γ 206, 211 242 α? | β ⁻ 1.1 α 5.34 γ 50, 80, 235 | β ⁻ 2.6, 2.8 γ 216, 132, 837 1341 | β 1.6 γ 182, 32, 225 200 | β 3.2, 3.5 γ 254, 186 1323 | β 1.8, 2.4 γ 90, 586 | γ 474, 410, 141 835 | ρ γ 310, 336, 143 350 | р у 711, 129, 728 877 | p 7 433, 454, 96 525 | β ⁻ γ 125 | 6-7 | |
| 281 Rn 210 | Rn 211 | ء Rn 212 | Rn 213 | Rn 214 | Rn 215 | Rn 216 | Rn 217 | Rn 218 | Rn 219 | Rn 220 | Rn 221 | Rn 222 | Rn 223 | Rn 224 | Rn 225 | Rn 226 | Rn 227 | Rn 228 | Rn 229 | Rn 230 | Rn 231 | | · · · |
| 2.4 h α 6.040 | 14.6 þ | 24 m | 19.5 ms | 6.5 ms 0.7 ms 0.27 µm | s 2.3 µs | 45 µs | 0.54 ms | 35 ms | 3.96 s | 55.6 s | 25 m β ⁻ 0.8, 1.1 | 3.825 d | 23.2 m | 1.78 h | 4.5 m | 7.4 m | 22.5 s | 65 s | 12 s | >160 ns | >160 ns | 146 | |
| y 458, (571, 649 | α 5,783, 5.851 γ 674, 1363 | α 6.264 | a 8.088, 7.252 | 17 182 448 302 a 10.53 a 10.46 a 9 00 | α 8.67 | a 8.05 | α 7.740 | α 7.133 | α 6.819, 6.553 6.425 γ 271, 402 | α 6.268 γ (550) σ < 0.2 | a 6.037, 5.788 5.778 186, 150 | α 5.48948 γ (510) α 0.74 | β ⁻ γ 593, 417, 638 | β ⁻ y 261, 266 | β γ 29 - 207 | A- | β γ 162, 739, 686 805 | β γ 125, 63, 156 112 | 8- | 8-7 | β-? | | |
| 73) At 209 | 678g At 210 | γ At 211 | γ 540 At 212 | At 213 | At 214 | 9 At 215 | At 216 | γ (609) At 217 | At 218 | At 219 | At 220 | At 221 | At 222 | At 223 | At 224 | At 225 | At 226 | At 227 | At 228 | At 229 | | | 1 |
| 5.4 h | 8.3 h | 7.22 þ | 119 ms 314 ms | 0.11 µs | 0.76 µs 0.27 µs 0.56 µs | 0.1 mş | ? 0.3 ms | 32.3 ms a 7.069 | ~2 s | 0.9 s | β ⁻ 3.71 m | 2.3 m | 54 s | 50 s | 76 s | >160 ns | >160 ns | >160 ns | >160 ns | >160 ns | | | |
| α 5.847 γ 545, 782 | 5.442, 5.361 7 1181, 245 | α 5.867 γ (687) | a 7.84 a 7.68 7.90 7.62 7 63 7 63 | | a 8.782 m a 8.877 g | α 8.026 | 7.691 α.7.488 g m ₁ γ (115) γ 103 418) | β γ (259, 334 | α 6.694, 6.653 β | a 6.27 | α 5.945 γ 241, 293 | - | a- | n- | 8- | β ⁻ ? | 8-7 | 677 | 8"? | B ⁻ ? | | | |
| ⁷⁹⁰ Po 208 | 1483 Po 209 | 9 Po 210 | Po 211 | α 9.08 Po 212 | Po 213 | γ (405) Po 214 | Po 215 | ⁵⁹⁵⁾ | Po 217 | Po 218 | Po 219 | Po 220 | Po 221 | Po 222 | Po 223 | Po 224 | Po 225 | Po 226 | Po 227 | | | | |
| 2.898 a α 5.1152 | 102 a α 4.881 | 138.38 d | 25.2 s 516 ms | 45.1 s 17.1 ms 0.3 µs | 4.2 µs | 164 µs | 1.78 ms | 0.15 s | 1.53 s | 3.05 m | >300 ns | >300 ns | 112 s | 145 s | >160 ns | >160 ns | >160 ns | >160 ns | >160 ns | 144 | | | |
| с ү (292, 571) | ε γ (895, 261 | α 5.30438 γ (803) σ < 0.0005 + < 0.030 σ _{4,0} 0.002 | 8.883 7 570 u 7.450 1084 7 (898 | 11 65 17 728 7 2615 408 583 223 | α 8.376 | α 7.6869 | α 7.3862 β γ (439) | α 6.7783 γ (805) | α 6.543 | α 6.0024 β | β-? | 8-7 | o- | a- | 6 -7 | B-7 | β-7 | β"? | β-7 | | | | 1 |
| 9 Bi 207 | 263) Bi 208 | Bi 209 | Bi 210 | Bi 211 | s _{γ (779)} Bi 212 | γ (800, 298) Bi 213 | γ (439) Bi 214 | Bi 215 | Bi 216 | Bi 217 | Bi 218 | Bi 219 | Bi 220 | Bi 221 | Bi 222 | Bi 223 | Bi 224 | Pr 1 | IN I | / | | | 1 |
| 31.55 a | 3.68·10 ^s a | 100 1.9 ·10 ¹¹ a | 3.0-10 ⁸ a | 2.17 m α 6.6229 | 9 m 25 m 640 m | 45.59 m 8 ⁻ 1.4 | 19.9 m | 38.9 8 7.7 m | 3.6 m 2.17 m | 98.5 s | 33 s | >160 ns | >160 ns | >160 ns | >160 ns | >160 ns | >160 ns | 142 | | | | | 24 |
| ε, β ⁺ γ 570, 1064 | 0045 | a 3.077 e 0.011 + 0.023 e < 38-7 | a 4.948 p ⁺ 1.2 4.908 a 4.649 7.266 4.688 304 7 (305 | 6.2788, β [™] γ 351 | 0- 1011 6-10.54 | α 5.869 γ 440, (293 1100) | β 1.5, 3.3 α 5.450, 5.513 γ 609, 1764, 1120 ρα 9.079 | 187 | p- 7 550, 419 550, 419 380, 223 | β ⁻ γ 265, 254, 890 | β ⁻ 3.5, 3.7 γ 510, 386, 426 263 | 8-7 | p-7 | B ⁻ 7 | β ⁻ ? | 0-7 | β ⁻ ? | | | | | 1. A | |
| 1770 Pb 206 | γ 2615 Pb 207 | Pb 208 | Pb 209 | α - g, β - g Pb 210 | Pb 211 | Pb 212 | Pb 213 | Pb 214 | Pb 215 | Pb 216 | Pb 217 | Pb 218 | Pb 219 | Pb 220 | p - | | | - / | | | | | |
| 24.1 | | | 3.253 h | 22.3 a β ⁻ 0.02, 0.06 | 36.1 m | 10.64 h | 10.2 m | 26.8 m | >160 ns | >160 ns | >160 ns | >160 ns | >160 ns | >160 ns | | 140 | | | | | | | 1.4 |
| | | | β= 0.6 | γ 47, e . g α 3.72 | β ⁻ 1.4 γ 405, 832 | β 0.3, 0.6 γ 239, 300 | - | β 0.7, 1.0 γ 352, 295 242 | 072 | 8-7 | β-? | B_5 | β ? | β ⁻ ? | | | | | | | | | e - 18 |
| a 0.027 TI 205 | a 0.61 | 0 _{ma} + 8E-6 | ΤΙ 208 | σ < 0.5 TI 209 | 427 TI 210 | g TI 211 | β TI 212 | TI 213 | TI 214 | TI 215 | TI 216 | TI 217 | P I | P 1 | | | | | | | | | |
| | | | | | | | | | | | | and a first state of the | | | | | | | | | | | 1.11 |



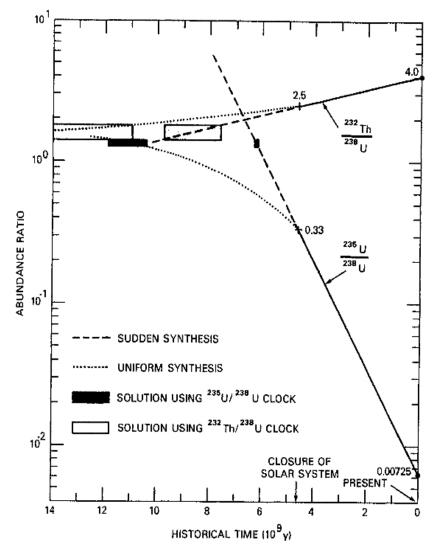
Blei-Isotopenverhältnisse



Mitglied der Helmholtz-Gemeinschaft

Uran-Thorium-Uhr

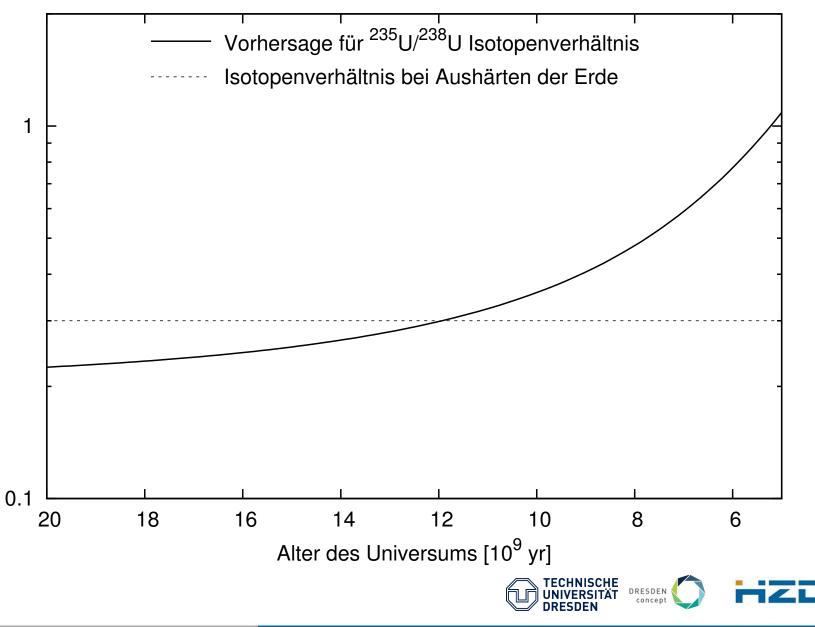
| 9, 1528 00 | 1 5 025 5 007 7 (26 84), e ⁻ 9 1 160 + 7 | c, f ⁻ 0.5. (642 (642), e 160 (642), e 104., e ⁻ g g ₁ 2700 d ₁ 3000 | sf a. 4.790, 4.774 7.29, 87 | β ⁻ 1.2, γ 984 1029, 1026, 924, θ ⁻ , g σ _l 2600 | β ⁻ 0.4, 0.7 γ 106, 278 228, e ⁻ , g σ 32 + 19, σ _l < 1 | 7 555 697 |
|---|---|--|--|--|---|--|
| 233 92·10 [°] a 24, 4.783 97), e ⁻ | a 4.775, 4.723 af | U 235 0.7204 26 m ⁻¹ 7.038-10- 17 (0.07) No. 7 188-10- | 4,445_sf | U 237 6.75 d β 0.2 γ 60, 208, e σ -100 | U 238 99.2742 288 m 17224 287 (50.) 189 - c 27 | U 23 23.5 β 1.2, 1.3 γ 75, 44 σ 22 |
| o _t 530 a 232 .31 d | Mg28, Ne, y(53, 121_) • e 98, e 0.07 Pa 233 27.0 d | Pa 234 | Pa 235 | σ _i < 0.35 Pa 236 9.1 m | Pa 237 8.7 m | σ _f 15 Pa 2: 2.3 n |
| 1.3 194, 150 | p ⁺ 0.3, 0.6 7 312, 300, 341 | 1 2.3. y (1001 1 2 y (1001 1 2 1 2 y (1001 1 2 y (| β ⁻ 1.4 γ 128 - 659 m | β ⁻ 2.0, 3,1 γ 642, 687 1763, g βsi? | β 1.4, 2.3 γ 854, 865, 529 541 | β 1.7, 2.6 γ 1015, 63 448, 680 9 |
| 1 231 5.5 h | Th 232 100 1.405·10 [®] a | Th 233 22.3 m β ⁻ 1.2 | Th 234 24.10 d β ⁻ 0.2 | Th 235 7.1 m | Th 236 37.5 m | Тh 23 5.0 п |
| 3, 0.4 84 | a 4.013, 3.950 st, y (64), e a 7.37, or 32-6 | γ 87, 29, 459 e σ 1500, σ _i 15 | γ 63, 92, 93 e , m g 1.8, $\sigma_f < 0.01$ | β ⁻ 1.4 γ 417, 727 696 | β 1.0 γ 111, (647 196) | β- |
| 230 22 s | Ac 231 7.5 m | Ac 232 119 s β ⁻ | Ac 233 145 s | Ac 234 44 s | | Ac 23 72 s |
| 508 | β 7 282, 307, 221 186, 369 | γ 665, 1899 1959, 1948 612 | β 7 523, 540 | β ⁻ γ 1847, 1912 689, 1954 | | β- |
| 229 | Ra 230 | Ra 231 | Ra 232 | Ra 233 | Ra 234 | |



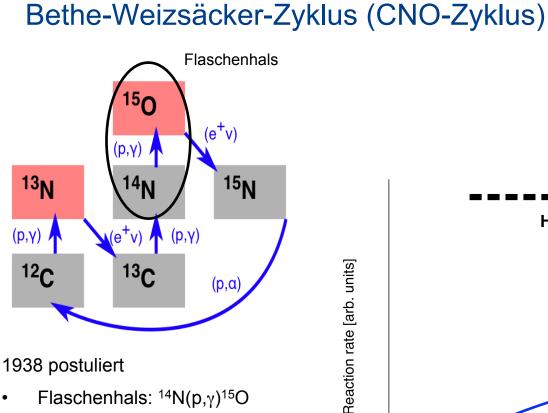
Rolfs/Rodney, Cauldrons in the Cosmos, 1988



Uran-Isotopenverhältnisse



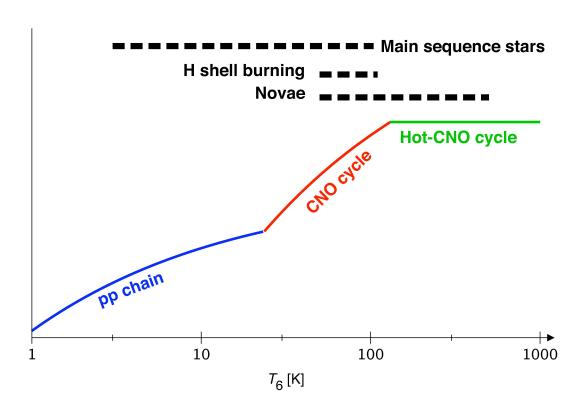
Mitglied der Helmholtz-Gemeinschaft



Wasserstoffbrennen:

- Flaschenhals: ¹⁴N(p,γ)¹⁵O ٠
- 0.8% der Energieproduktion der • Sonne
- Bestimmung des Alters von ٠ Kugelsternhaufen

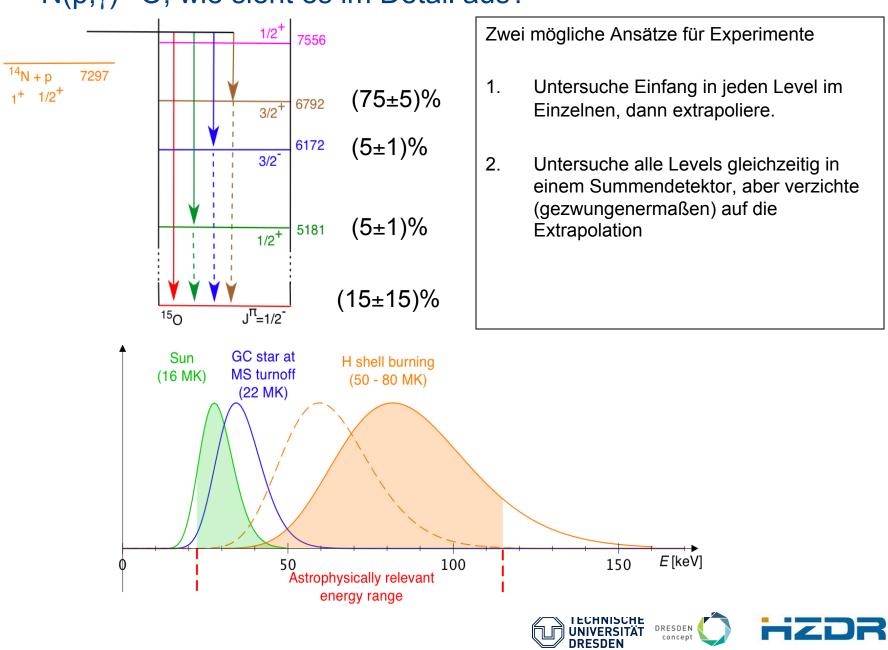






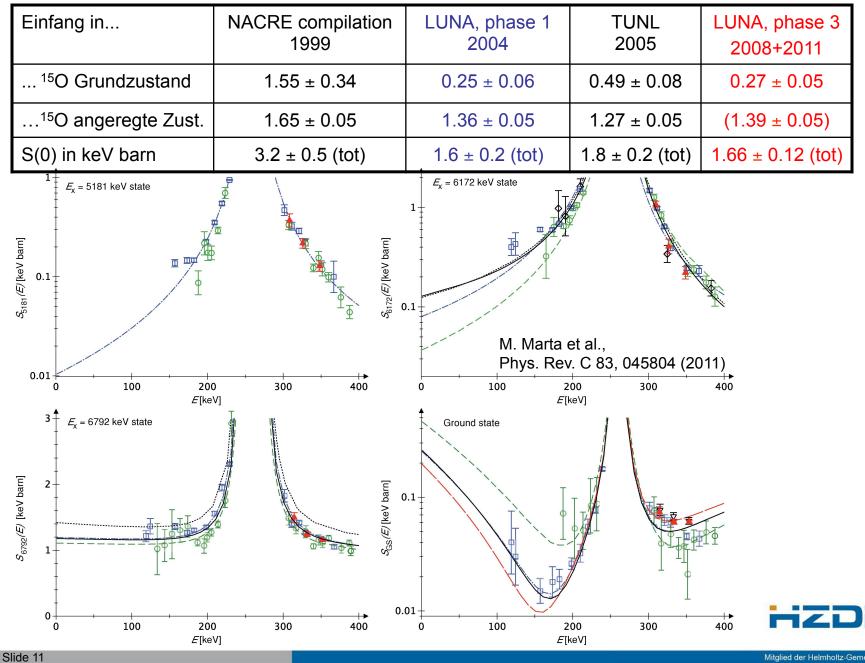
Mitglied der Helmholtz-Gemeinschaft

¹⁴N(p,γ)¹⁵O, wie sieht es im Detail aus?



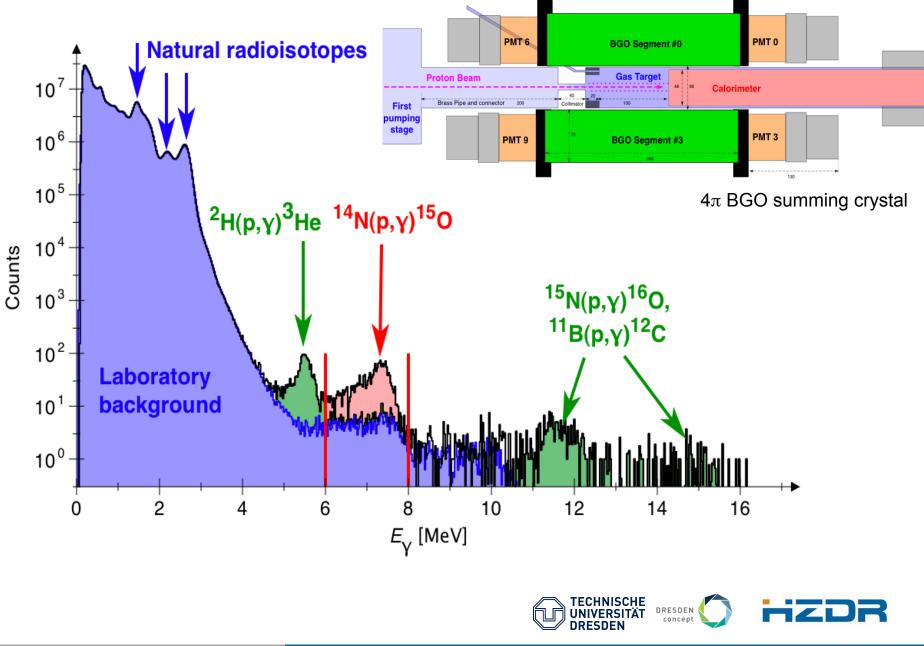
Mitglied der Helmholtz-Gemeinschaft

LUNA halbierte den ¹⁴N(p, γ)¹⁵O-Wirkungsquerschnitt!



Mitglied der Helmholtz-Gemeinschaft

¹⁴N(p, γ)¹⁵O, Messung aller Übergänge mit einem Summendetektor

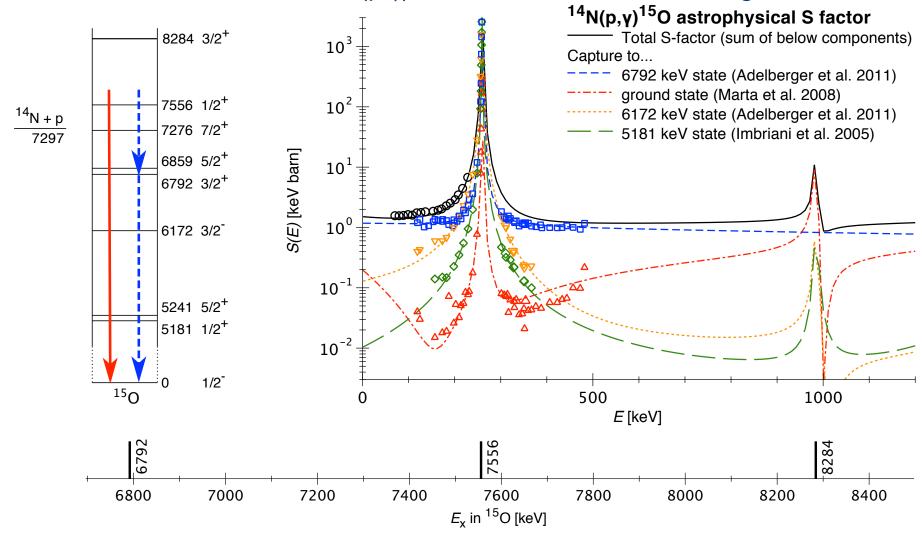


Schröder et al. 1987 10 🗍 ¥ LUNA 2004-2006-2008 3 **TUNL 2005** total S factor [keV barn] 0.3 0.1 only ¹⁵O(GS) 0.03 **Astrophysical** energy range 0.01 -100 200 300 400 0 E_{CM} [keV]





Gesamter S-Faktor von ${}^{14}N(p,\gamma){}^{15}O$, über einen weiten Energiebereich





Mitglied der Helmholtz-Gemeinschaft

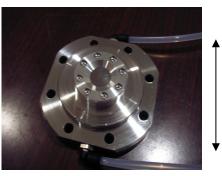
Versuchsaufbau am HZDR Tandetron, Dresden



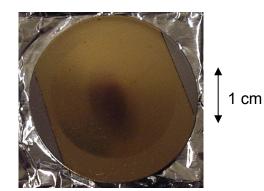


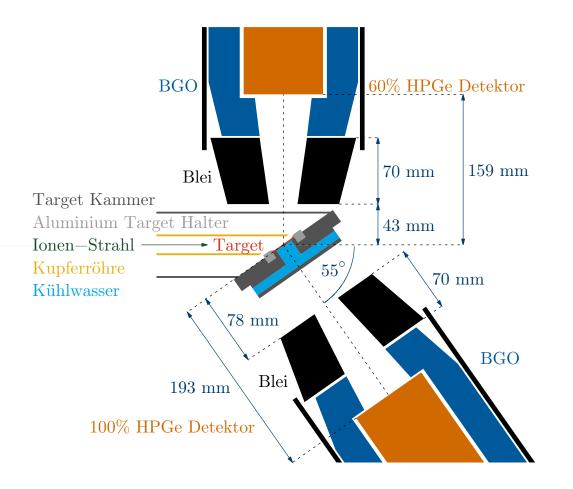


Detektoren und Targets





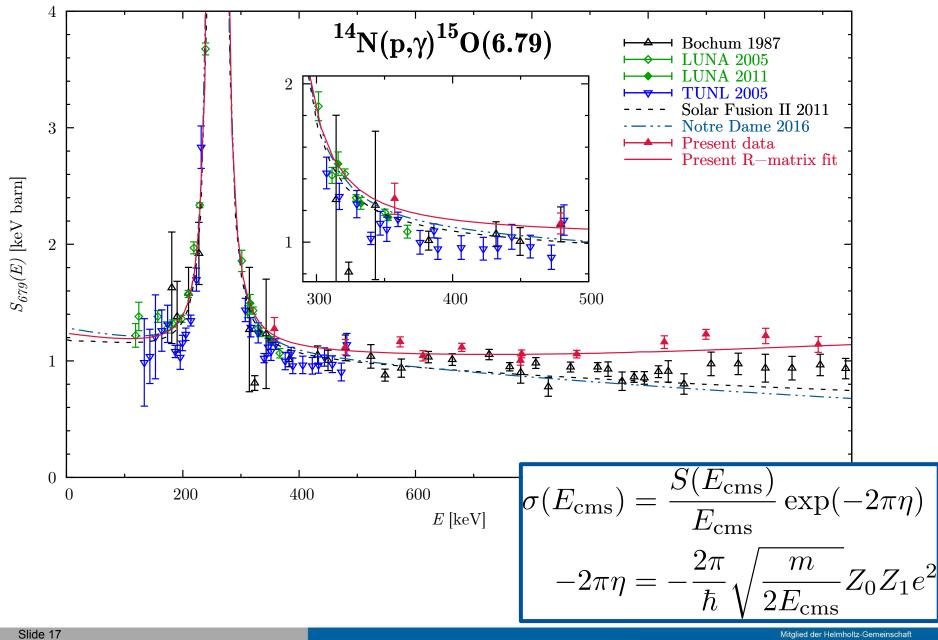






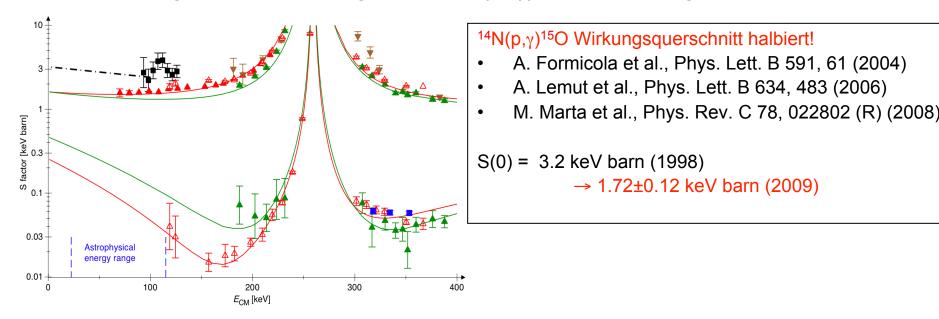
Mitglied der Helmholtz-Gemeinschaft

Wirkungsquerschnitt (als S-Faktor) der ¹⁴N(p,γ)¹⁵O(6.79 MeV)-Reaktion



Mitglied der Helmholtz-Gemeinschaft

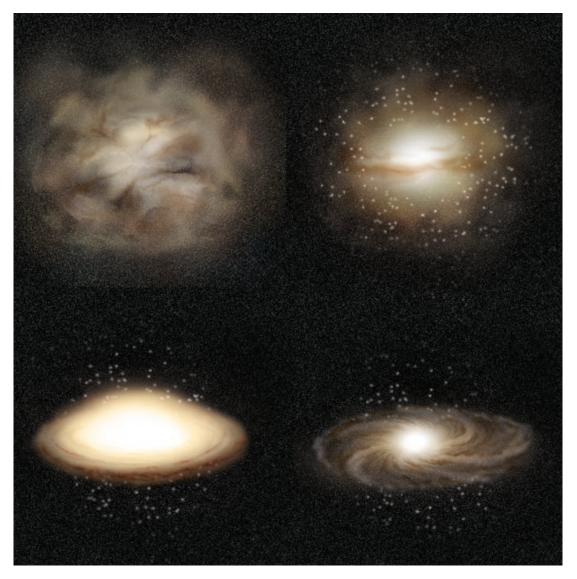
Auswirkungen des niedrigeren ${}^{14}N(p,\gamma){}^{15}O$ -Wirkungsquerschnitts



- 1. Unabhängige untere Schranke für das Alter des Universums: 14±2 Ga.
- 2. Bessere Reproduktion der Kohlenstoffhäufigkeiten in Roten Riesen.
- 3. Es ist möglich, den Stickstoffgehalt im Kern der Sonne über die emittierten CNO-Neutrinos zu bestimmen.



Altersbestimmung sehr alter Sterne (in Kugelsternhaufen)

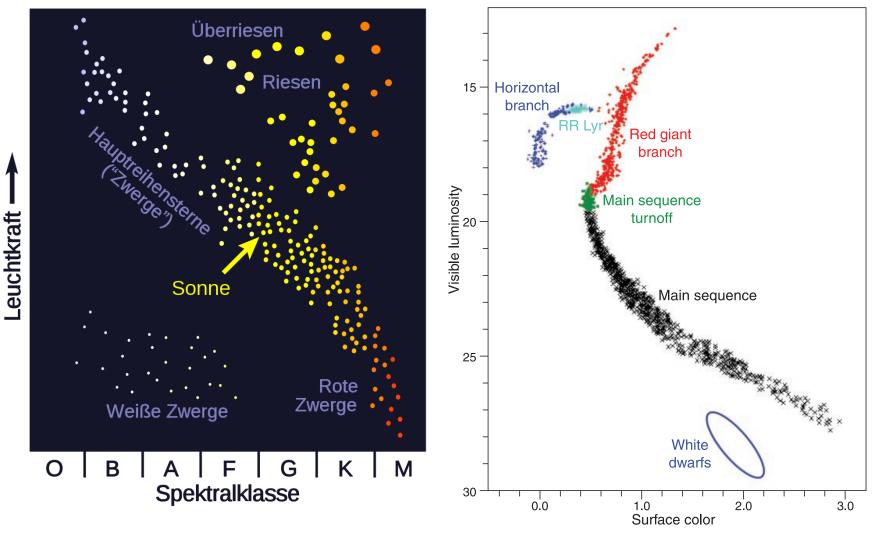


Krauss & Chaboyer (2003)



Mitglied der Helmholtz-Gemeinschaft

Altersbestimmung sehr alter Sterne (in Kugelsternhaufen)

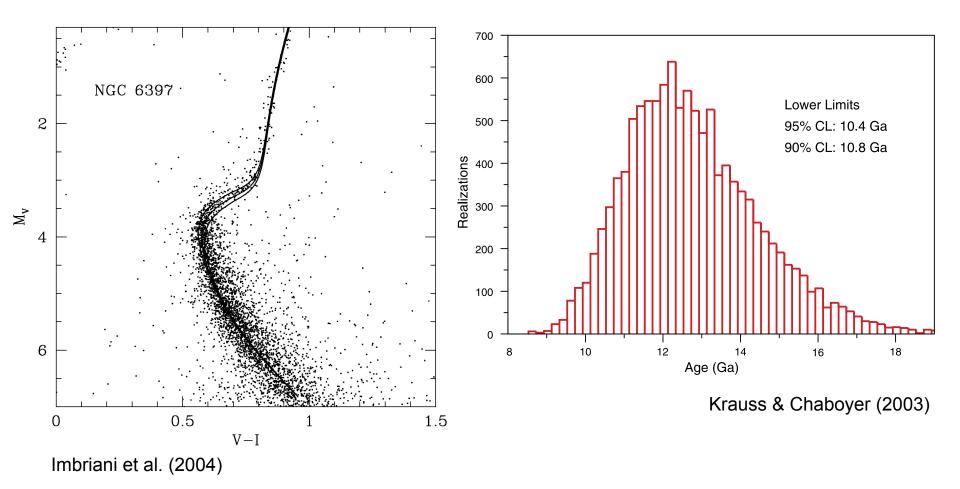


→ Hertzsprung-Russel-Diagramm, Abzweigen von der Hauptreihe

Krauss & Chaboyer (2003)



Altersbestimmung sehr alter Sterne (in Kugelsternhaufen)



→ Hertzsprung-Russel-Diagramm, Abzweigen von der Hauptreihe



Mitglied der Helmholtz-Gemeinschaft

Zusammenfassung

- Nukleokosmochronologie mithilfe von Uran und Thorium
- Bestimmung des Alters von Kugelsternhaufen mittels des CNO-Zyklus

