Measurement of ^{19}F(ρ, γ) ^{20}Ne reaction suggests CNO breakout in first stars

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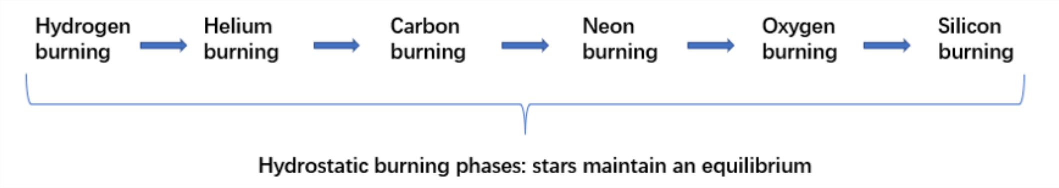
Background

stars: burn hydrogen, produce "metal".



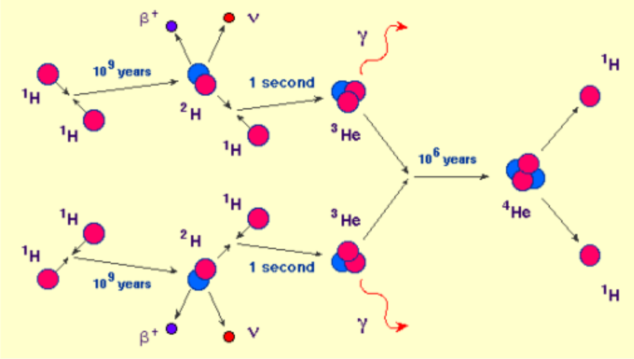
Rate: can depend on temperature and density.

S factor: $S(E) = \frac{E}{exp(-2\pi\eta)}\sigma(E)$, where $\eta = \frac{Z_1 Z_2 e^2}{4\pi\epsilon_0 \hbar v}$

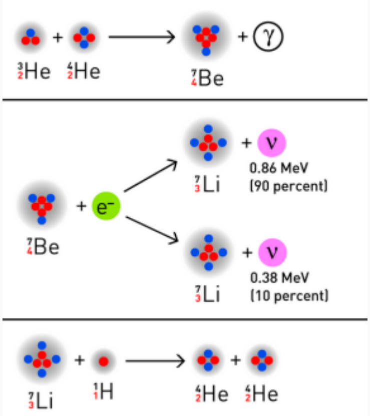
Background

- p-p chain: Burn p, produce ${}^{4}_{2}$He. Dominates in stars with masses less than or equal to that of the Sun.
- CNO cycle: Burn p, produce ${}^{4}_{2}$He. Dominate in stars with masses greater than about 1.3 times that of the Sun.
- 3α process: Burn ${}^{4}_{2}$He, produce ${}^{12}_{6}$C. Begins when central temperature rises to 10^8 K.

p-p chain



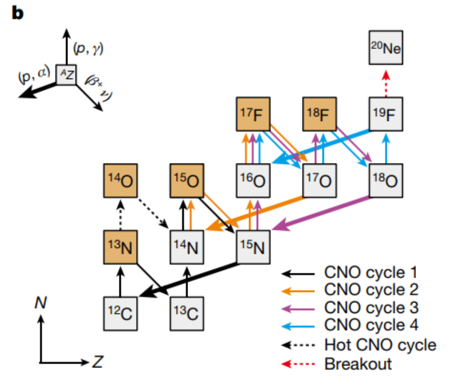
Branch 1: 85%

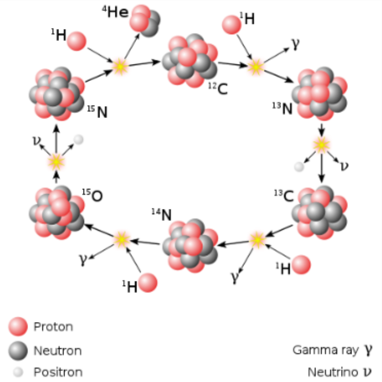


Branch 2: 15%

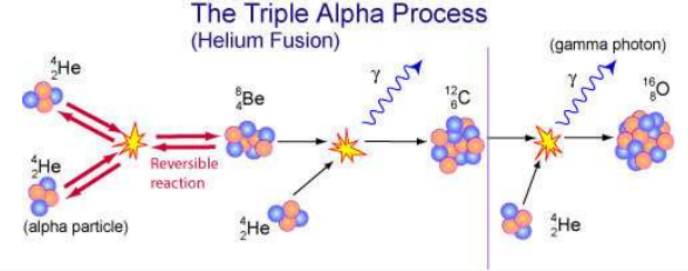
CNO cycle

Cold and hot CNO cycle. For hot CNO cycle: Timescale for fusion is faster than the timescale for beta decay. Hydrogen burning is limited by beta decays instead of proton captures.

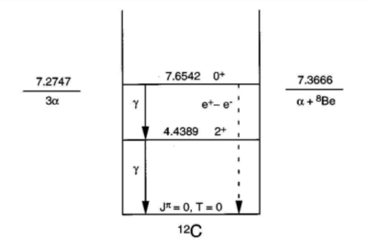




3α process



$$^4_2He + ^4_2He \rightarrow ^8_4Be \quad (-0.0918\ \text{MeV})$$
$$^8_4Be + ^4_2He \rightarrow ^{12}_6C + 2\gamma \quad (+7.367\ \text{MeV})$$

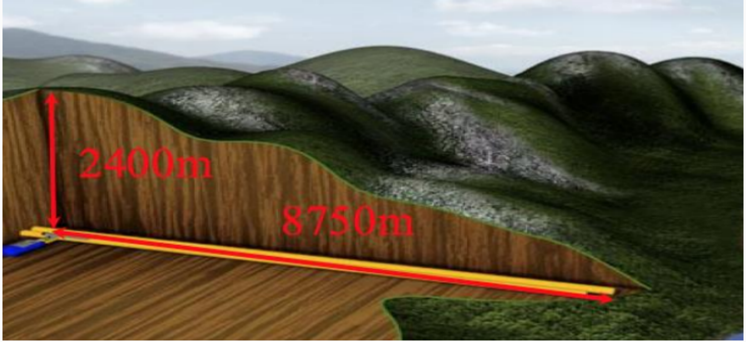


(An excited state of carbon-12: 7.596 MeV)

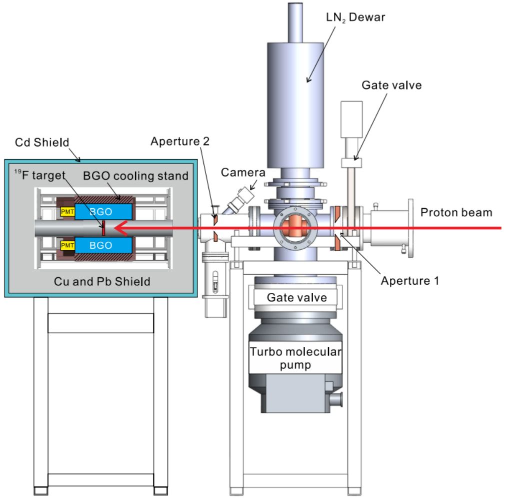
Experiment

Problem: Small cross section at gamow energy, strong cosmic-ray background radiation on the Earth's surface.

China JinPing Underground Laboratory (CJPL): about 2,400m of vertical rock overburden.



Experiment



Extended Data Fig. 1 | The schematic view of the experimental set-up. The proton beam bombarded on the implanted ^{19}F target through two apertures. The beam spot on the last aperture was monitored by a camera. A LN_2-cooled trap extended close to the target to reduce the carbon build-up. The γ-rays were detected by a 4π BGO array with massive shielding.