LECTURE 15

PHY 100. NUCLEAR POWER, STARS

\[ \text{---} \]
NUCLEAR STABILITY AS A FUNCTION OF SIZE

Binding Energy per nucleon (MeV)

Atomic Mass (amu)

Nucleons held more tightly

FUSION

FISSION

Nucleons held less tightly

31P

56Fe

103Rh

154Sn

209Bi

0 20 40 60 80 100 120 140 160 180 200 220 240 260

8.5

8.0

7.5
\[ ^{235}\text{U} + n \rightarrow ^{93}\text{Rb} + ^{141}\text{Cs} + 2n + \gamma \]

**NUCLEAR CHAIN REACTION**

**SUPERCRITICAL**

> 1 SPLIT PER SPLIT

**CRITICAL**

1 SPLIT PER SPLIT

**SUBCRITICAL**

< 1 SPLIT PER SPLIT

**NUCLEAR BOMB:** ALL THE MATERIAL UNDERGO FISSION IN 1 MS

HIGHLY SUPERCRITICAL

SUBCRITICAL
NUCLEAR REACTOR: SLIGHTLY SUPERCRITICAL TO CRITICAL SUSTAINED CHAIN REACTION

CONTROL RODS
MODERATOR

NUCLEAR FUEL RODS

HOT WATER

COOL WATER

HOT STEAM

TURBINE

ELECTRIC GRID
Fusion

\[ ^1_H + ^1_H \rightarrow ^2_He + ^1_H + \text{ENERGY} \]

Deuterium

Lab. Laser Energetics
Rochester (Omega)

Inertial Fusion

Laser

Frozen Deuterium

ITER

Magnetic Confinement

Plasma: gas at very high T

We will see more about fusion in the presentations at the end of semester
Star-Birth Clouds • M16

PRC95-44b • ST ScI OPO • November 2, 1995
J. Hester and P. Scowen (AZ State Univ.), NASA
PLEIADES: YOUNG STARS
RESIDUAL GAS AROUND THEM
Star formation begins in large clouds of gas/dust. Most of it is just hydrogen + He and traces of other elements.

Gravity pulls in

As gas is compressed, it gets hot.

It will radiate the heat (infra red radiation).

Heat radiation pushes out

Gas gets smaller → more heat.
Eventually the temp. at the core rises enough to start H fusion into He.

Core of H Fusion

10 M Degrees

Convection (masses of gas are moved from the cooler surface into the hotter center)

The fusion process takes four hydrogen nuclei (protons) and transforms them into one nucleus of helium plus a lot of energy.

$$4H \rightarrow He + \nu + E$$
When H is exhausted in the core, fusion stops; the core contracts → heats up the H shell around it, which fuses again ↓

LARGE EXPANSION OF STAR → RED GIANT (100 R_☉)

When T becomes 100 K degrees, He is burnt (this lasts around 100 million years). Produces a carbon, oxygen core → VARIABLE STARS (radius oscillates, 2) High luminosity in the end, H is exhausted, if M ≤ 8 M_☉, it will never be high enough to continue fusion of C, O.

→ WHITE DWARF (still hot, but no more fusion)

T_{surface} \approx 10^4 \text{ K}
T_{core} \approx 10^7 \text{ K}
R \approx 1 \text{ R_{Earth}}
L \approx 10^{-4} \text{ L_☉}
Core of C, O
NEUTRONS CAN CAUSE

\[ n + e^- + X \rightarrow n + p + e^- + \bar{\nu} \]
ELEMENTS HEAVIER THAN Fe ARE SYNTHESIZED IN
SUPERNOVA EXPLOSIONS

\( M < 8M_\odot \rightarrow \text{PLANETARY NEBULAE (WHITE DWARF)} \)

\( M > 8M_\odot \rightarrow \text{NEUTRON STAR (PULSAR)} \)

OR

\text{BLACK HOLE}

\begin{align*}
\text{DEAD SHELL OF} & \quad \text{NEUTRON} & \quad \text{BLACK HOLE} \\
\text{STAR HELD UP BY ATOMIC SHELLS} & \quad \text{STAR} & \quad 10 \text{ km}
\end{align*}