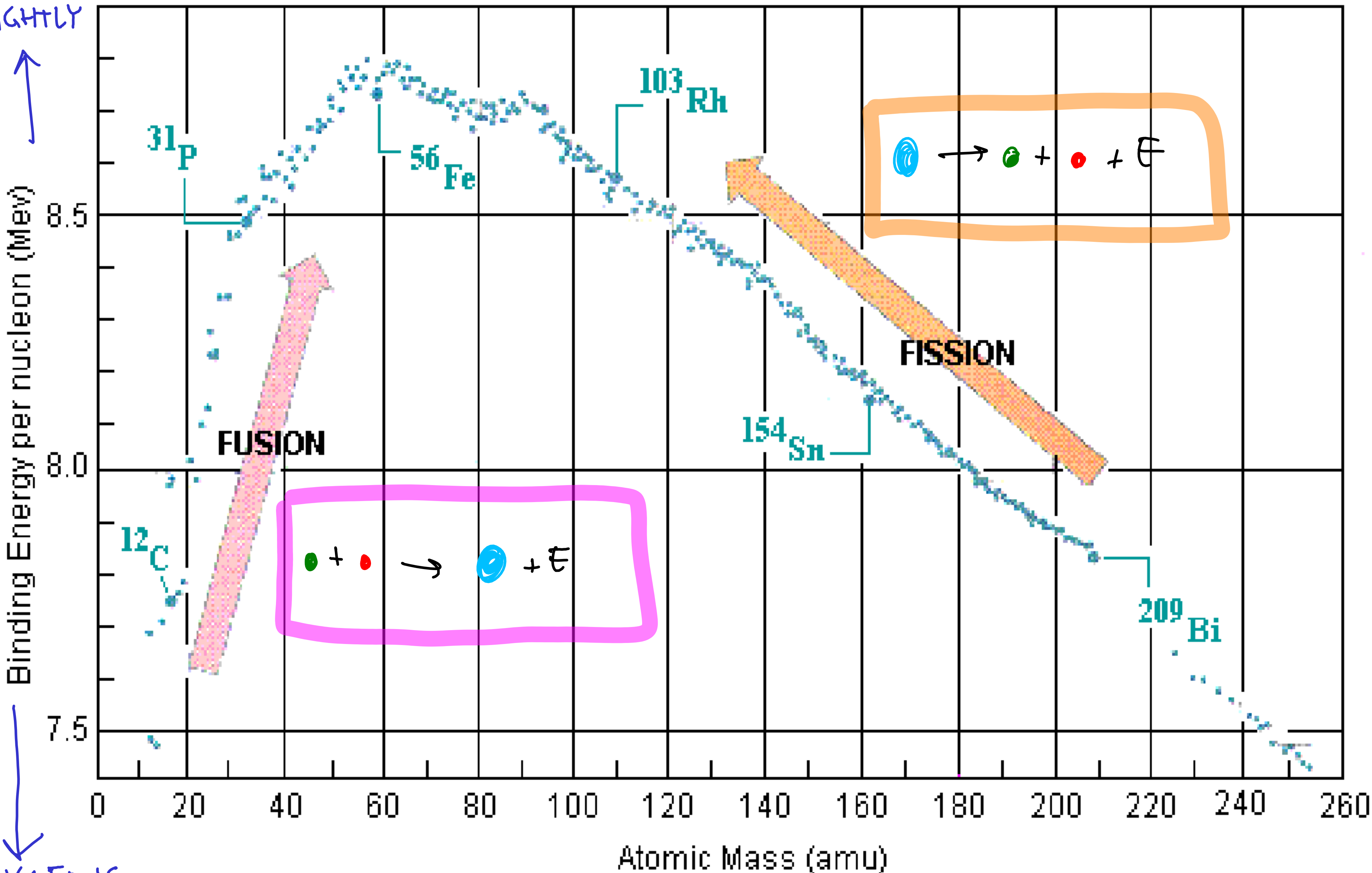
LECTURE 15

PHY 100. NUCLEAR POWER, STARS

NUCLEAR STABILITY AS A FUNCTION OF SIZE

NUCLEONS HELD MORE TIGHTLY

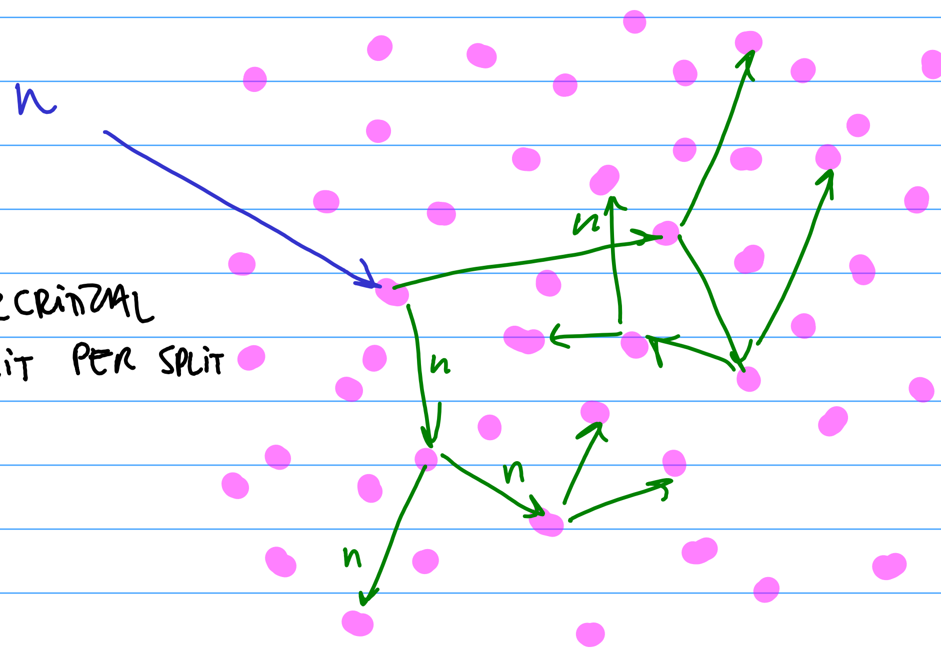


NUCLEONS HELD LESS TIGHTLY

$$^{235}U + n \longrightarrow {}^{93}Rb + {}^{141}Cs + 2n + \gamma's$$

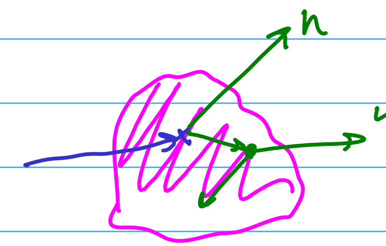
NUCLEAR CHAIN REACTION

^{235}U



SUPERCRITICAL

> 1 SPLIT PER SPLIT



CRITICAL

1 SPLIT PER SPLIT

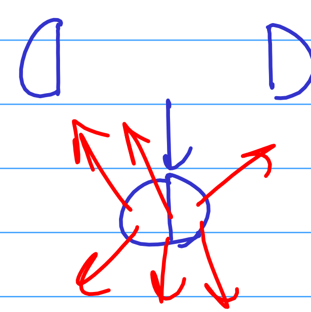
SUBCRITICAL

< 1 SPLIT PER SPLIT

NUCLEAR BOMB: ALL THE MATERIAL UNDERGO FISSION IN 1 ms

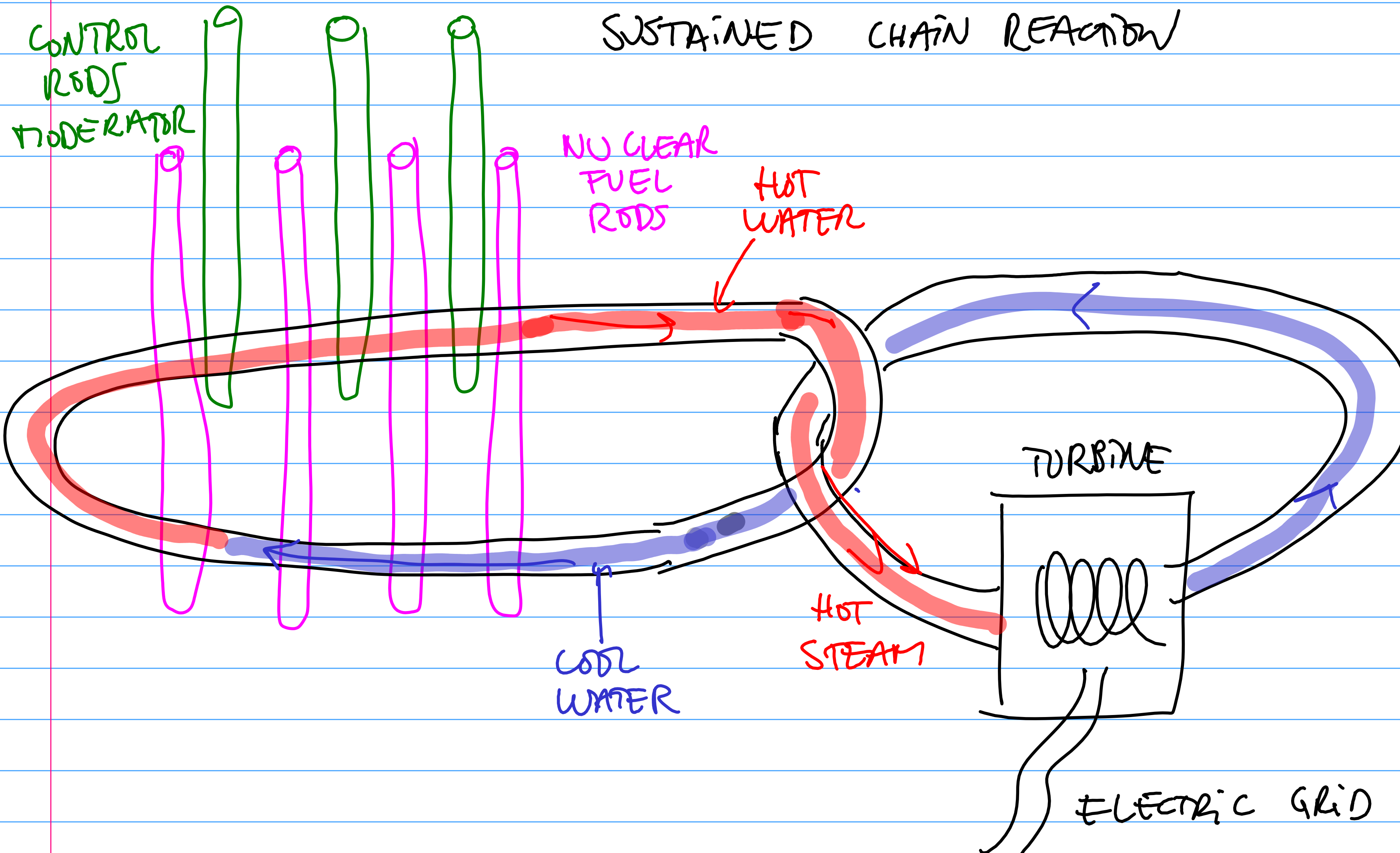
HIGHLY SUPERCRITICAL

SUBCRITICAL



SUPERCRITICAL

NUCLEAR REACTOR : SLIGHTLY SUPERCRITICAL ↔ CRITICAL
SUSTAINED CHAIN REACTION



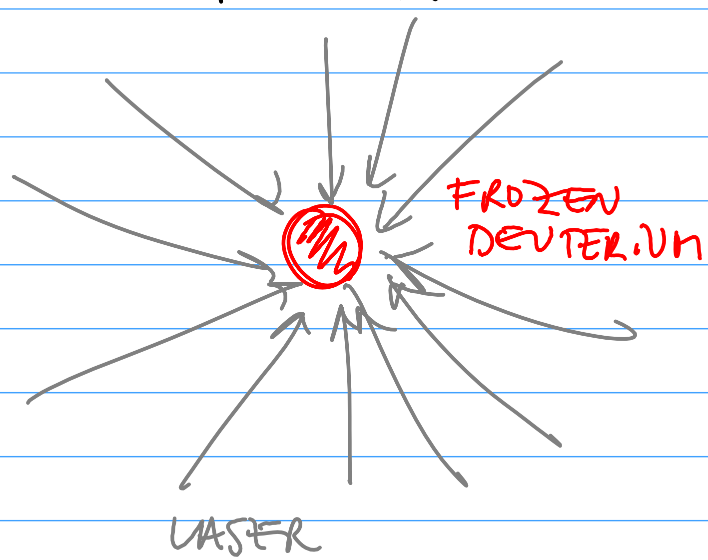
FUSION

$${}^{2}_{1}H + {}^{2}_{1}H \longrightarrow {}^{3}_{2}He + {}^{1}_{0}n + \text{ENERGY}$$

DEUTERIUM

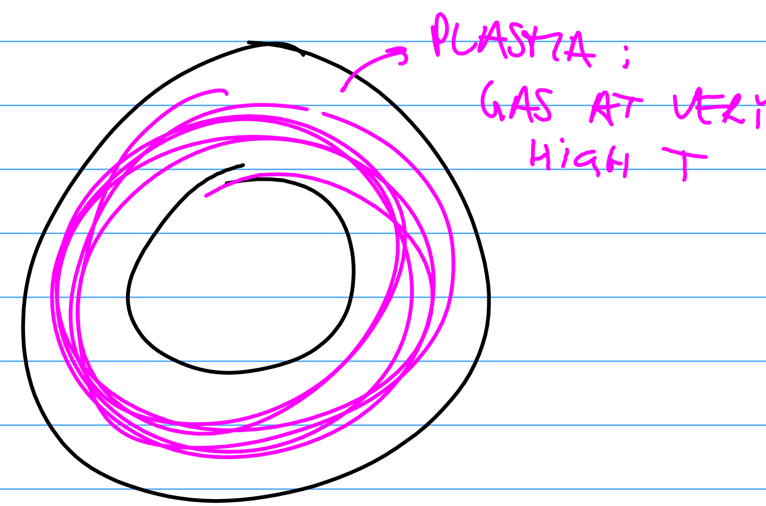
LAB. LASER ENERGETICS ROCHESTER (OMEGA)

INERTIAL FUSION



ITER

MAGNETIC CONFINEMENT



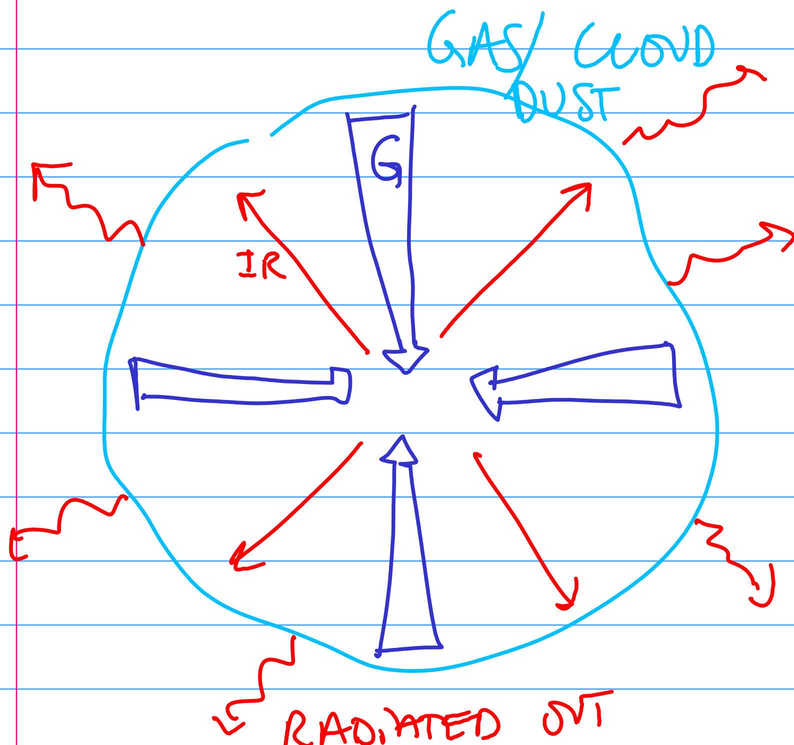
WE WILL SEE MORE ABOUT FUSION IN THE PRESENTATIONS AT THE END OF SEMESTER

Star-Birth Clouds · M16 HST · WFPC2

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.



GRAVITATION PULLS IN

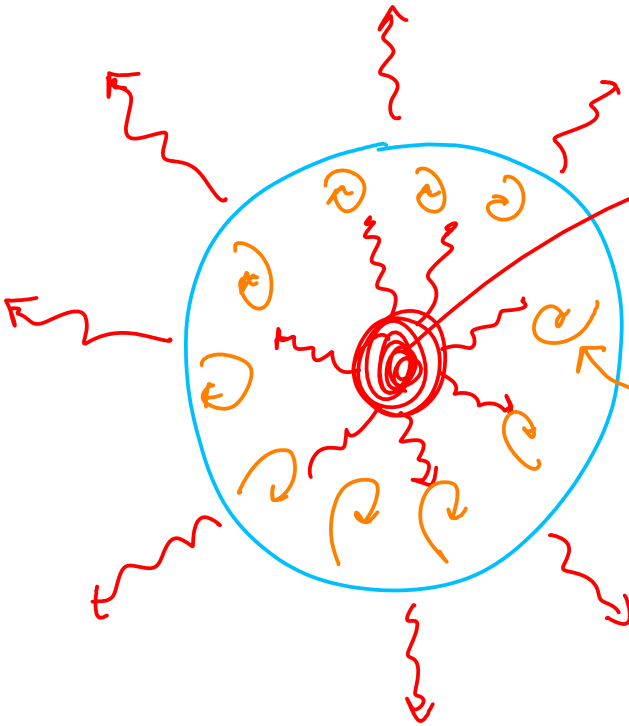
AS GAS IS COMPRESSED : IT GETS HOT

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.



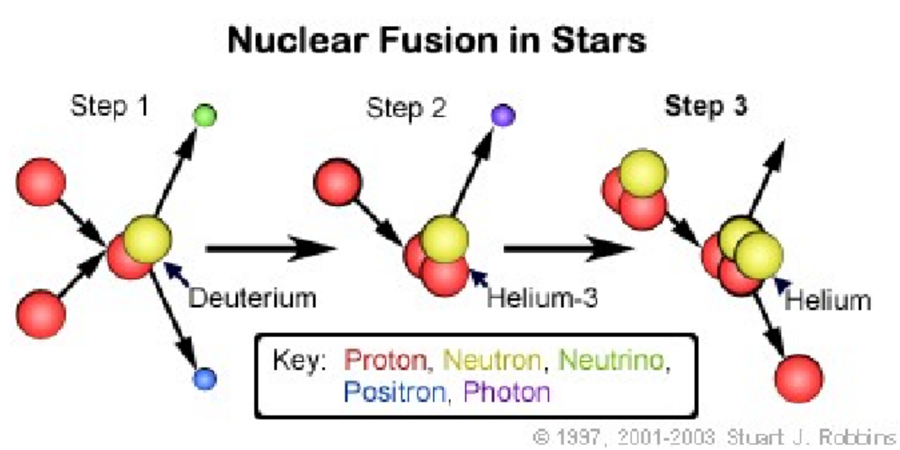
CORE OF H FUSION

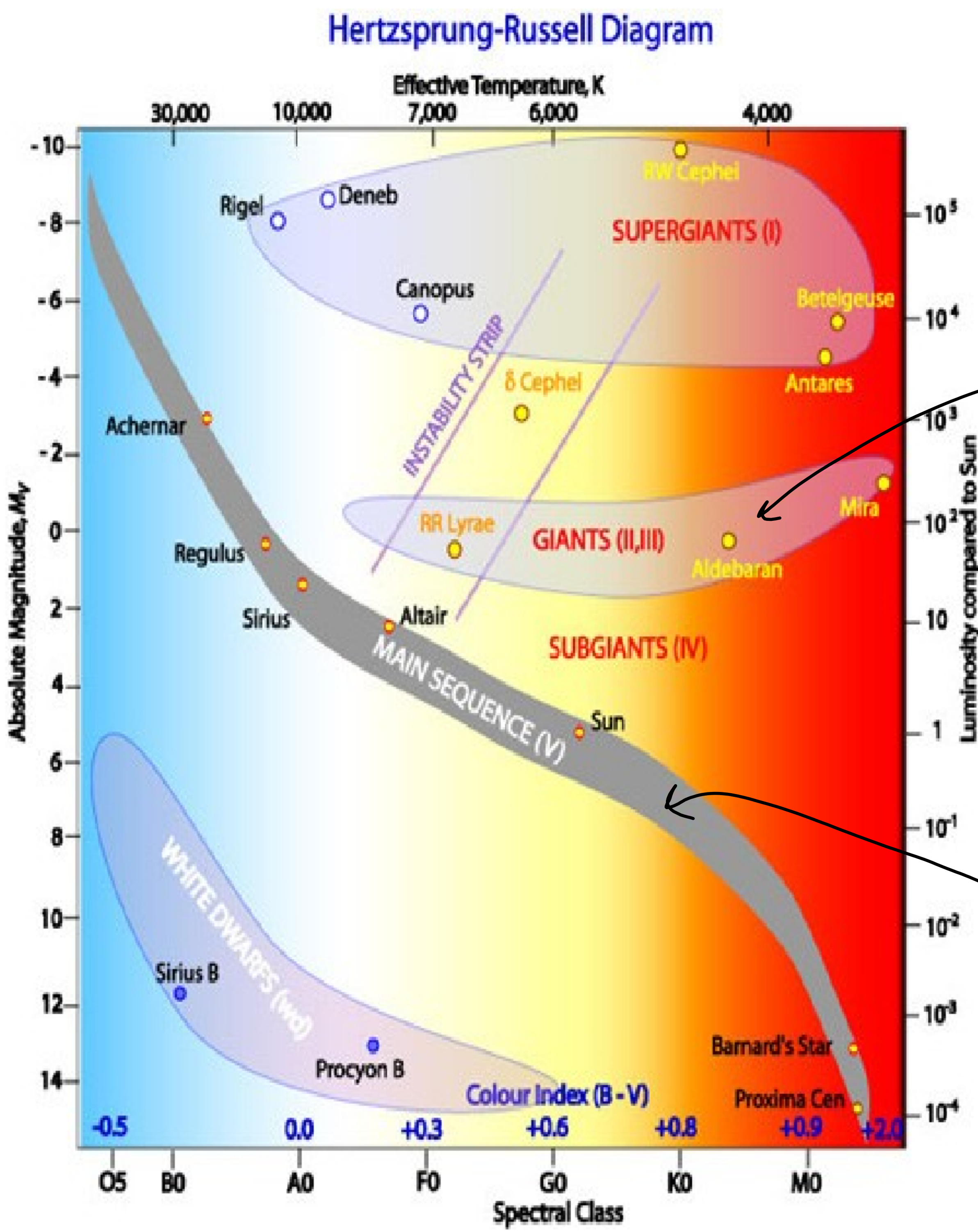
10 M DEGREES

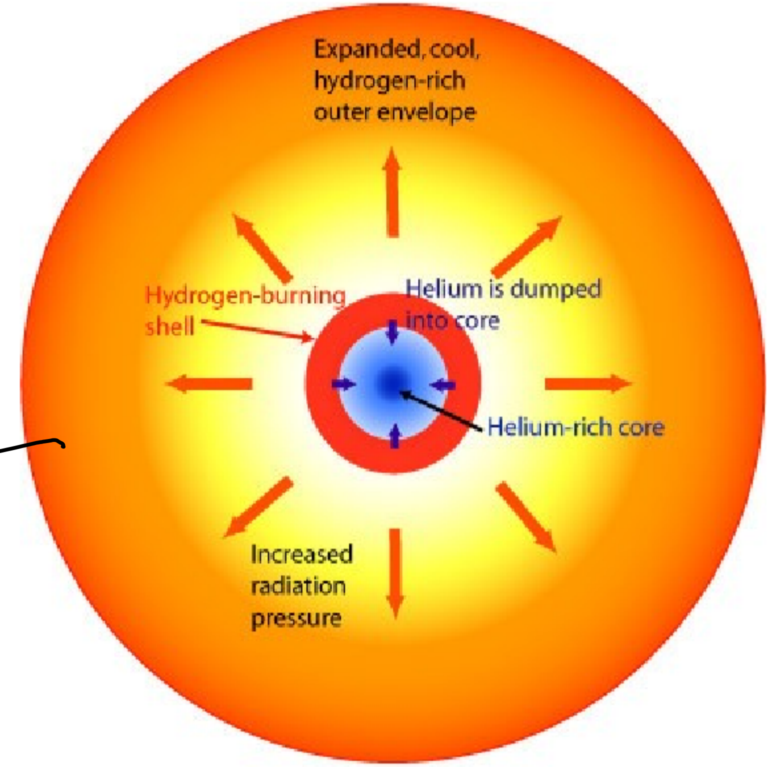
CONVECTION CELLS (MASSES OF GAS ARE MOVED FROM THE COOLER SURFACE INTO THE HOTTER CENTER)

THE FUSION PROCESS TAKES FOUR HYDROGEN NUCLEI (PROTONS) AND TRANSFORMS THEM INTO ONE NUCLEUS OF HELIUM PLUS A LOT OF ENERGY

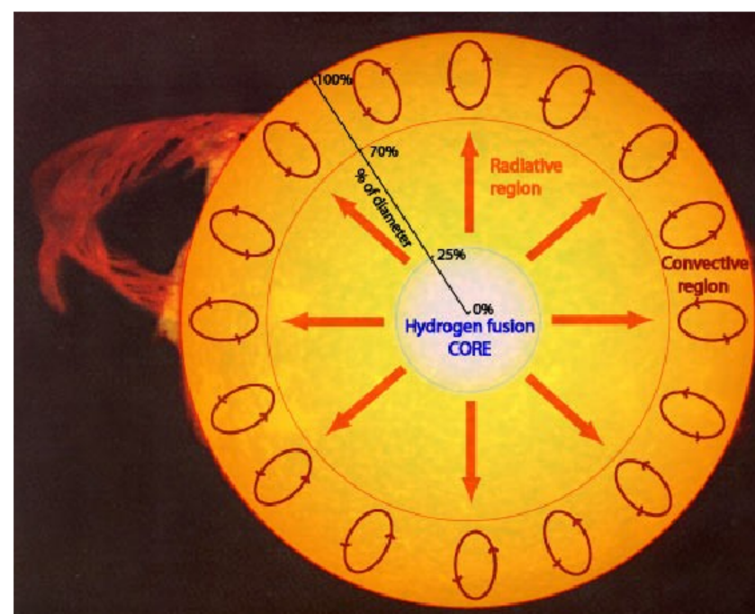
$$4H \longrightarrow 1He + 1p + E$$







Hydrogen Shell Burning on the Red Giant Branch



WHEN H IS EXHAUSTED IN THE CORE, FUSION STOPS: He CORE CONTRACTS → HEATS UP THE H SHELL AROUND IT, WHICH FUSES AGAIN

↓

LARGE EXPANSION OF STAR
RED GIANT (100 $R_\odot$)

WHEN T BECOMES 100 M DEGREES, He IS BURNT (THIS LASTS AROUND 100 M years). PRODUCES A CARBON, OXIGEN CORE → VARIABLE STARS (RADIUS OSCILLATES ×2) HIGH LUMINOSITY

IN THE END, H IS EXPULSED, IF $M < 8 M_\odot$, T WILL NEVER BE HIGH ENOUGH TO CONTINUE FUSION OF C, O.

→ WHITE DWARF (STILL HOT, BUT NO MORE FUSION) SLOW DEATH.

$T_{surface} \sim 10^4\,K$

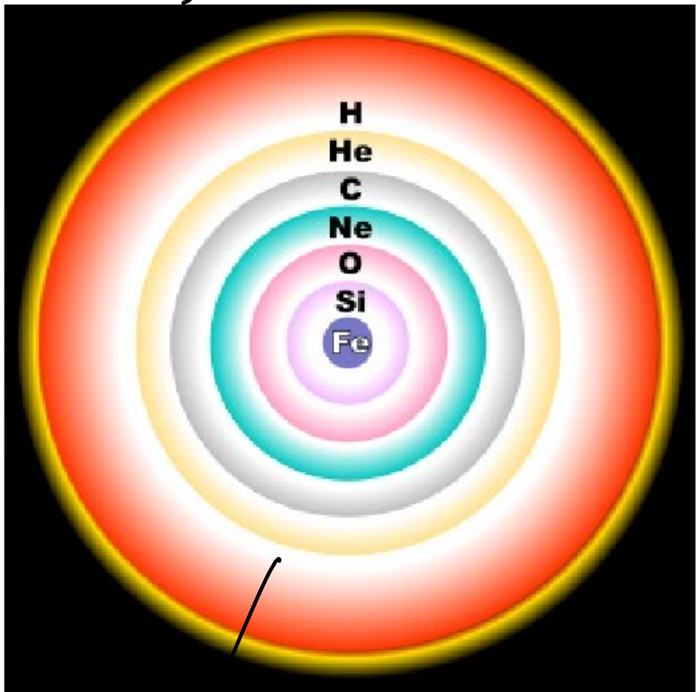
$T_{core} \sim 10^7\,K$

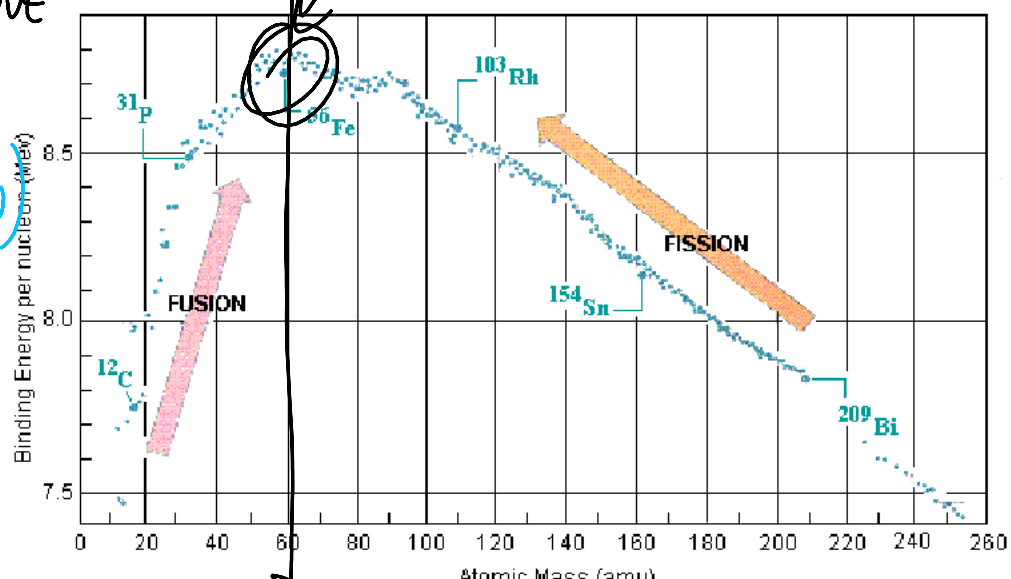
$R \sim 1\,R_{EARTH}$

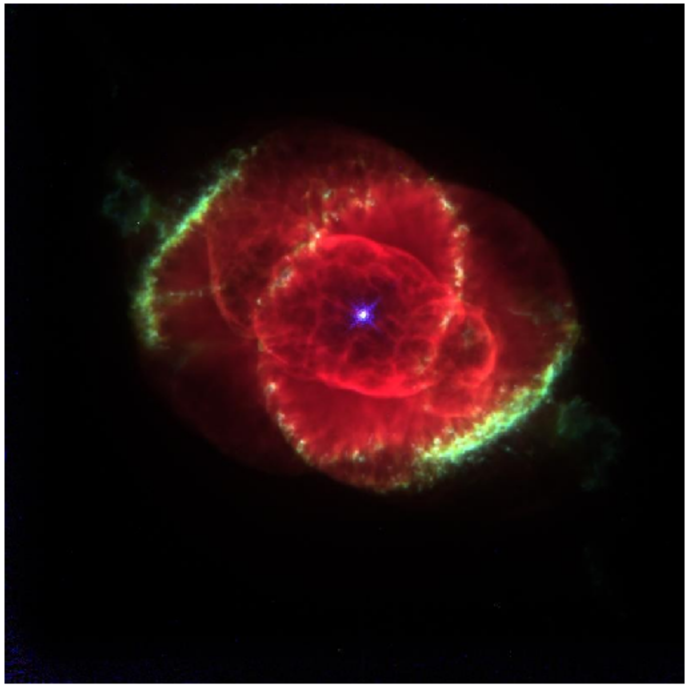
$\mathcal{L} \sim 10^{-4}\,\mathcal{L}_\odot$

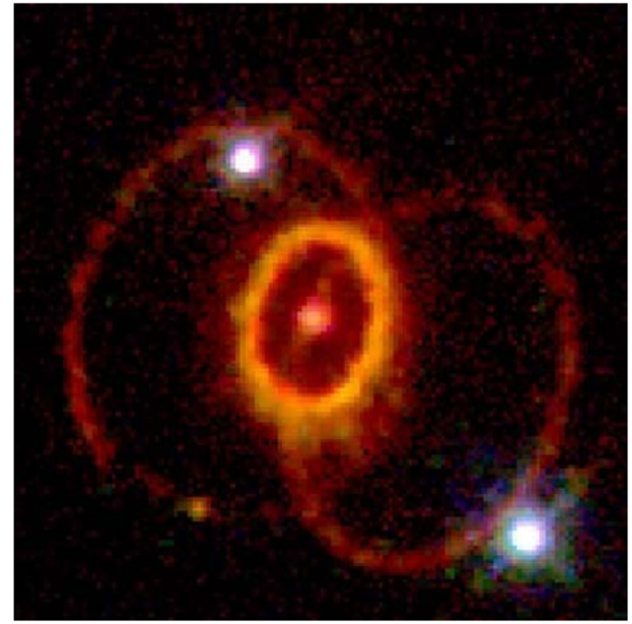
CORE OF C, O

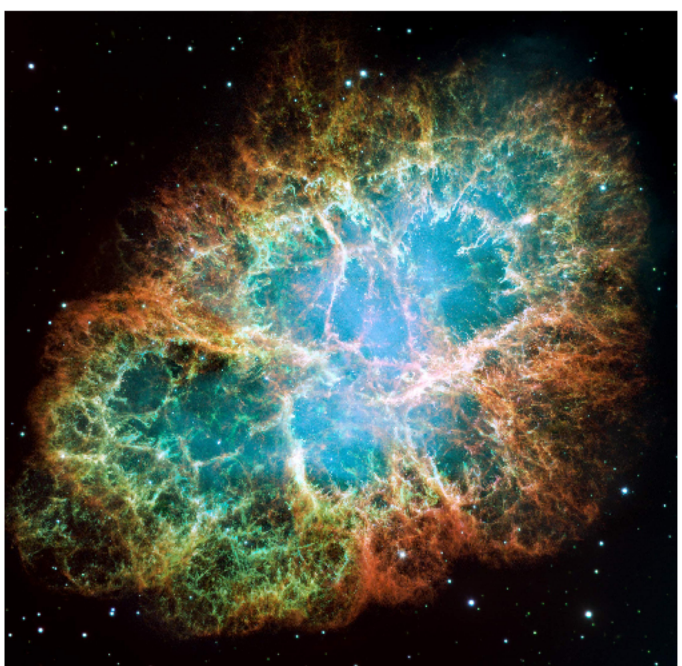
$M > 8 M_\odot$ → KEEP BURNING:

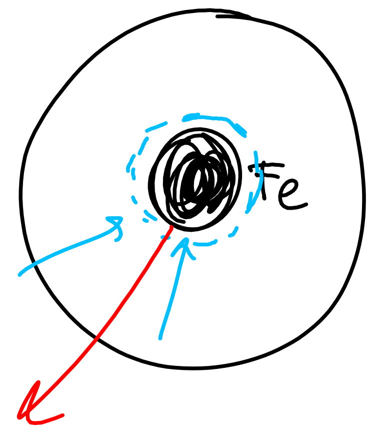












EXPLOSIVE BURST

NEW ELEMENTS

NEUTRONS CAN CAUSE

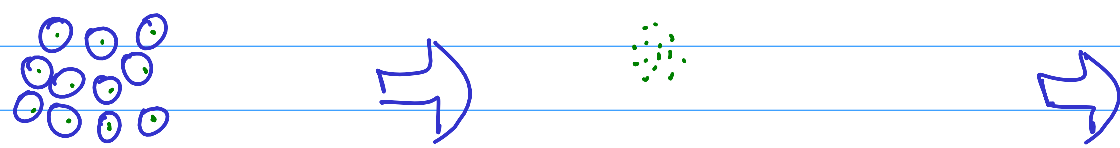
$$n + {}^{A}_{Z}X \rightarrow {}^{A+1}_{Z+1}X + e^- + \bar{\nu}$$

$$n \rightarrow p + e^- + \bar{\nu}$$

ELEMENTS HEAVIER THAN ^{56}Fe ARE SYNTHESIZED IN SUPERNOVA EXPLOSIONS

$M < 8 M_\odot \longrightarrow$ PLANETARY NEBULAE (WHITE DWARF)

$M > 8 M_\odot \longrightarrow$ NEUTRON STAR (PULSAR)
OR
BLACK HOLE



DEAD SHELL OF STAR HELD UP BY ATOMIC SHELLS

NEUTRON STAR

10 km

BLACK HOLE