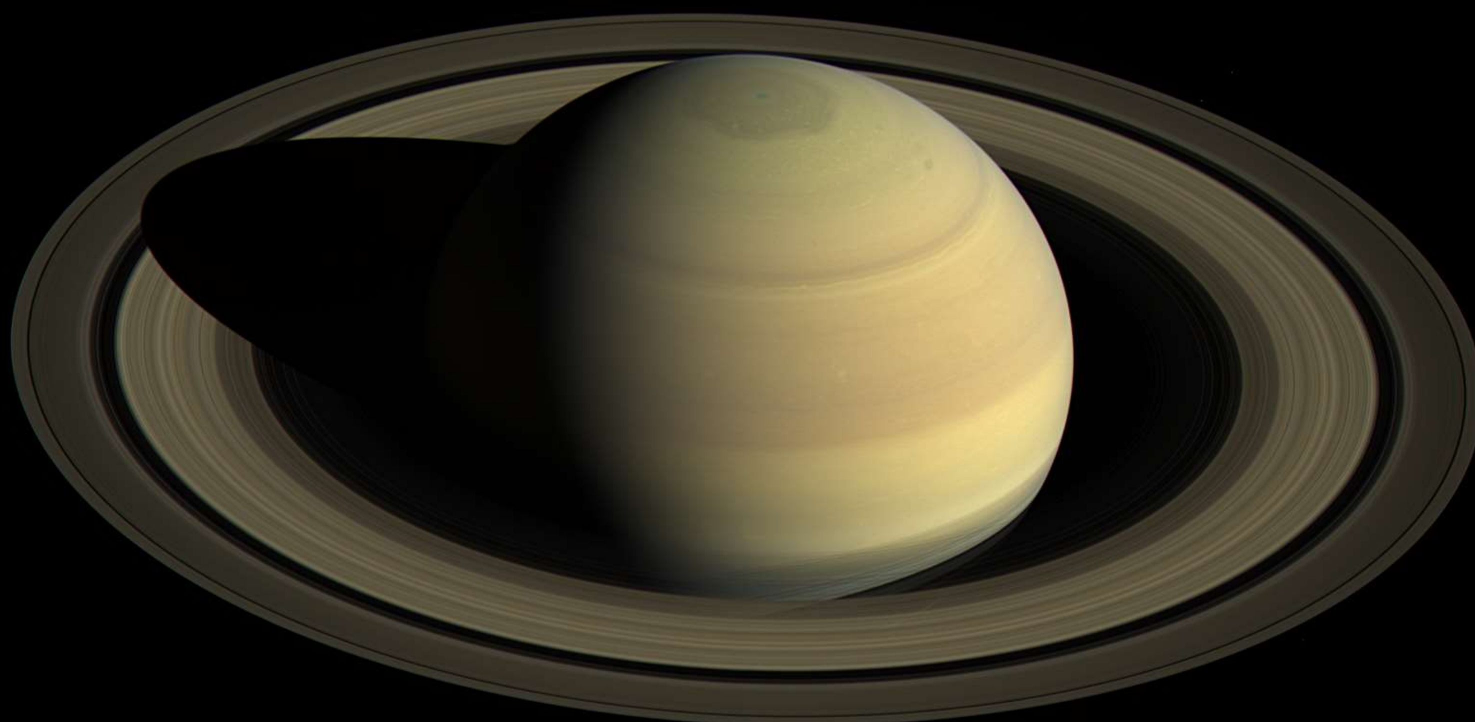
# AST 2002
# Introduction to Astronomy



# A Few Quick Things…

**E-mailing me: Must have AST2002 in the subject**

**Mary Hinkle, Graduate Teaching Assistant:**

**Office Hours: Mon 1:30-3:00pm. PSB 316**

**My office hours: Mon 3:00-4:00pm. PSB 308**

**Tue 3-4 pm. PSB 308**

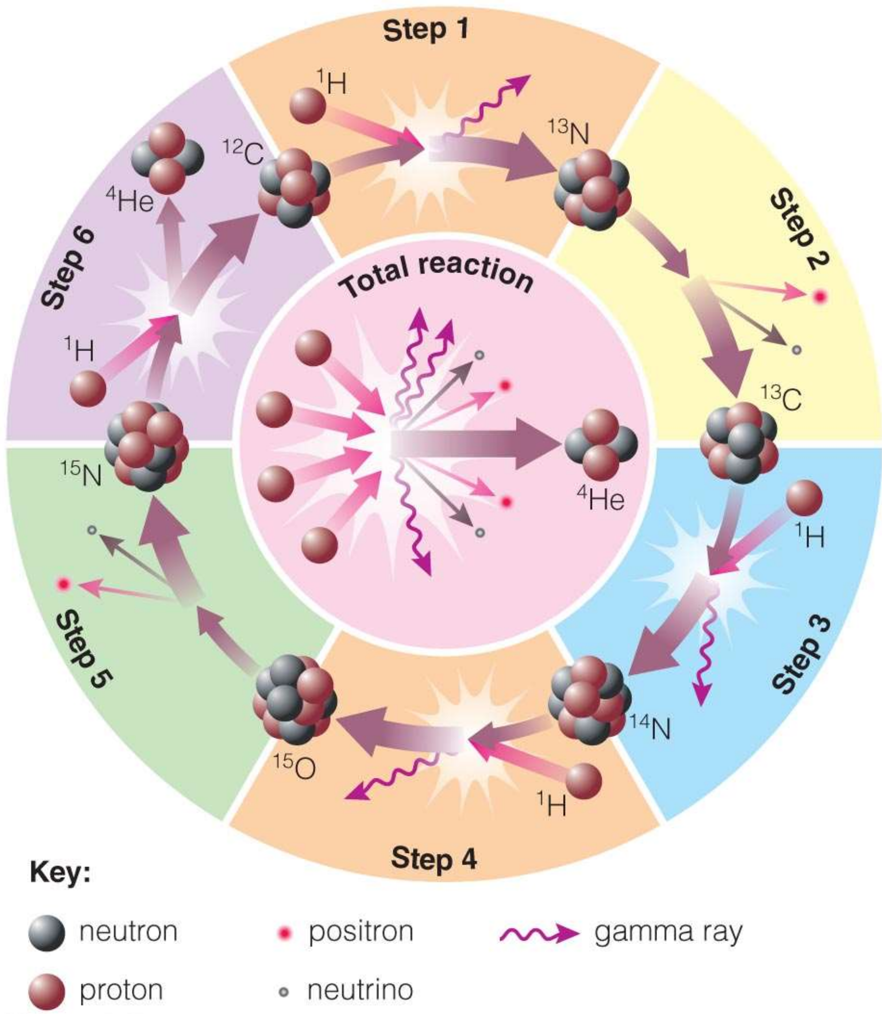
***Last Midterm: Mon 9th April. (Best of 2 will count towards final grade)***

***Final: Friday 27th April. 7am-9:50 am. (on all chapters)***

**LAST Knights Under the Stars Event – Thursday 19th April**

***Opportunity to make up the 1% extra credit that was offered (if you haven't been yet, worth 2%) – Last chance for extra credit..***

# The CNO Cycle

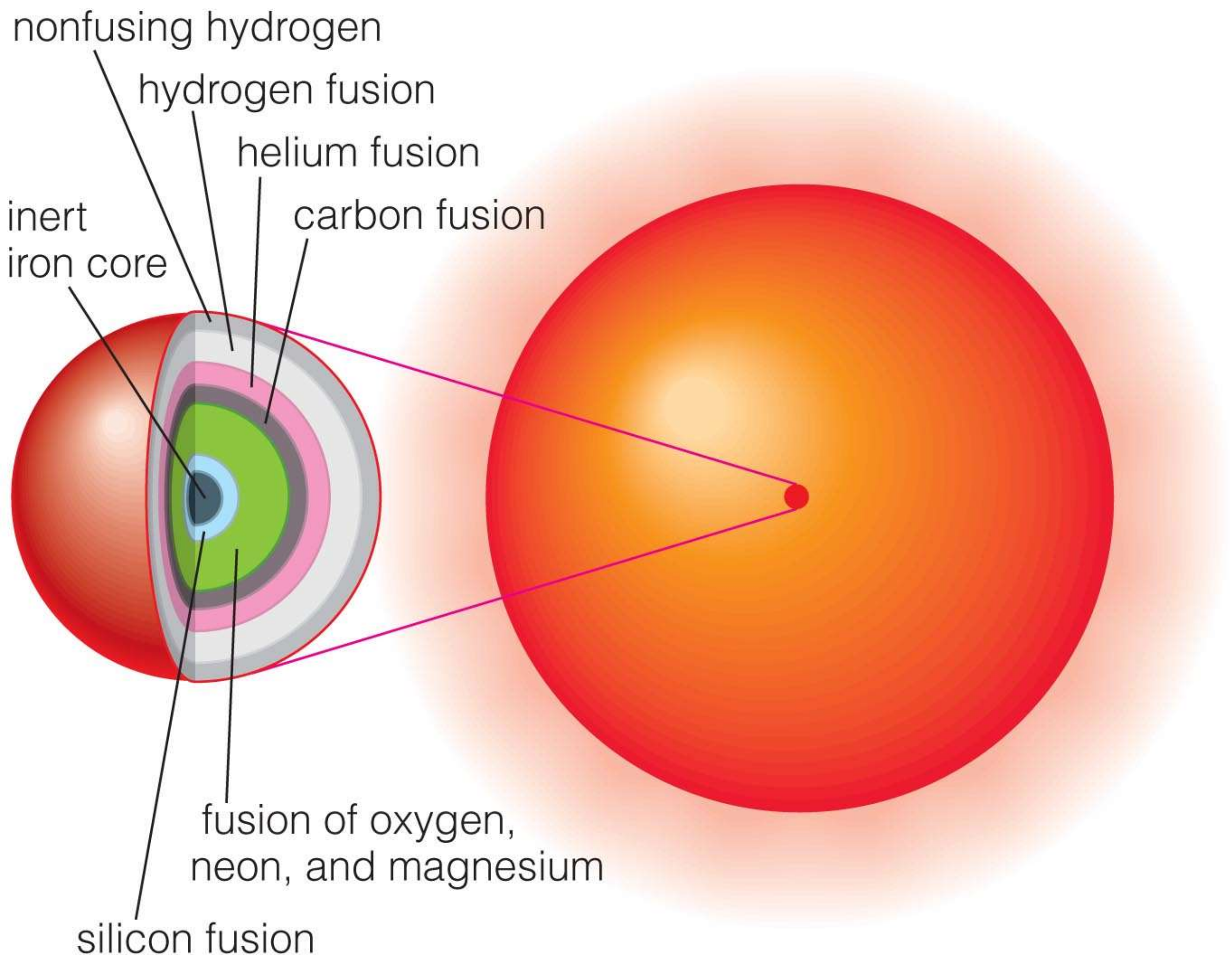



Stars with M > 1.5 $M_{Sun}$ have sufficient temperatures and pressures to initiate this process (~ 15 million K needed)

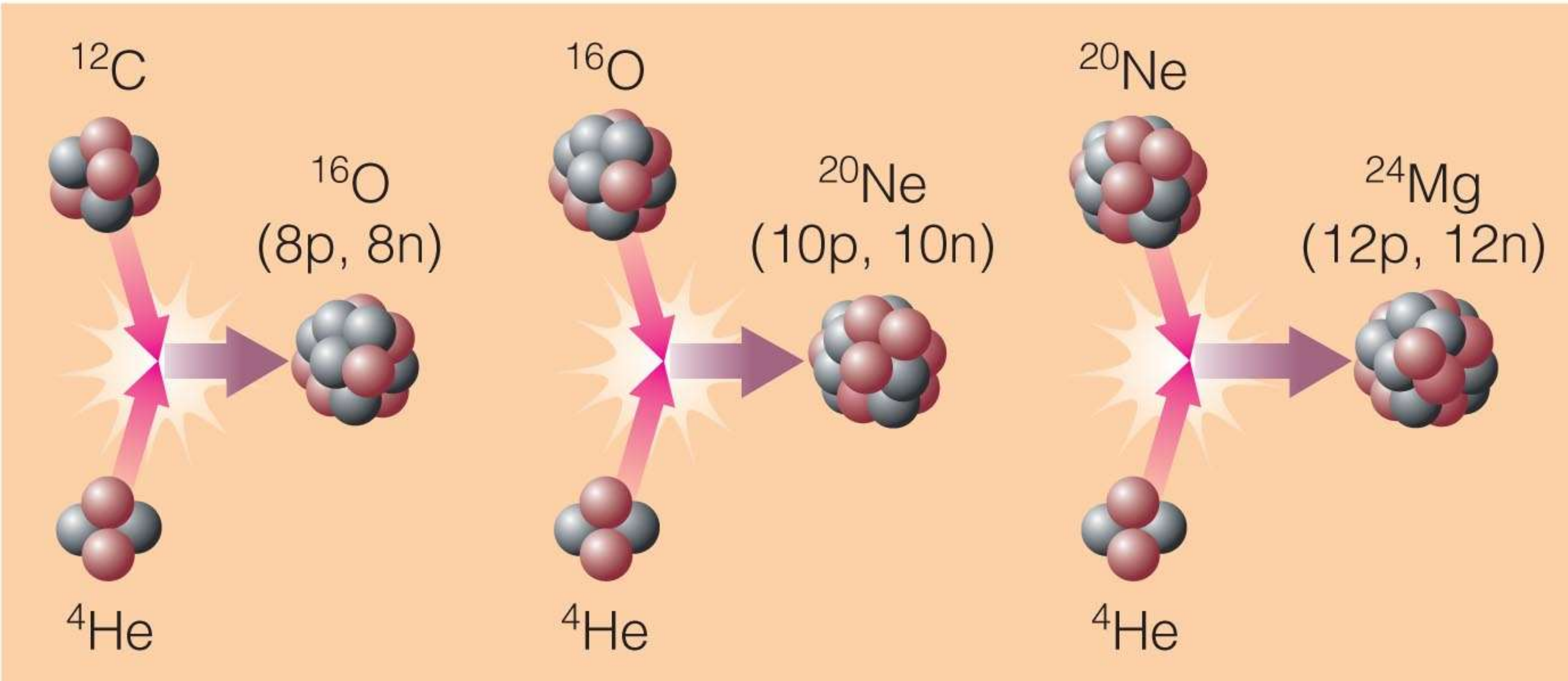
The reaction is ***equivalent*** to the proton-proton chain reaction.

- Overall, four 4 protons are consumed, and a helium nucleus is generated
- The $^{12}C$ acts as a catalyst in this reaction (it returns to its original state)
- This reaction proceeds more efficiently than the proton-proton reaction which makes more massive stars even more luminous

# Multiple Shell Burning



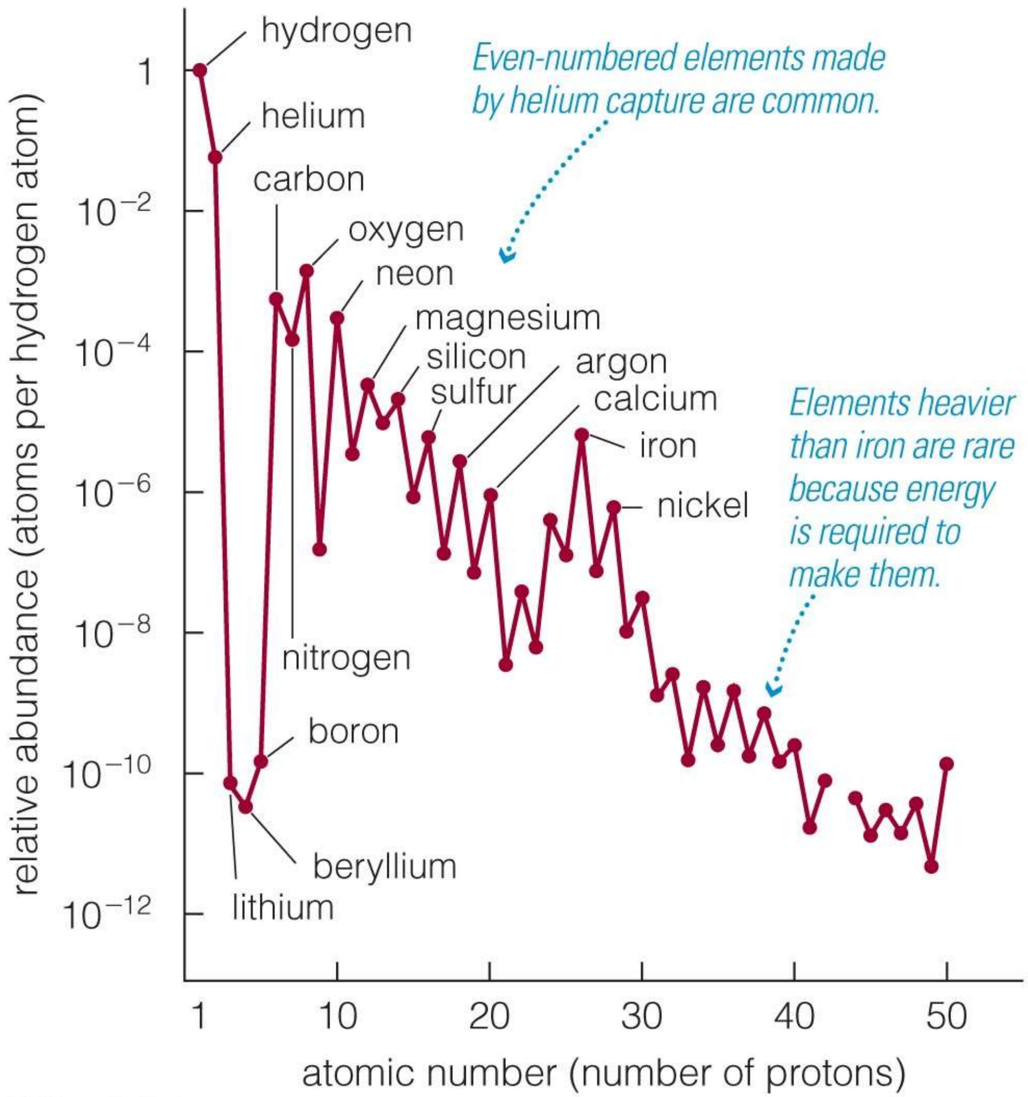
# Helium Capture Processes




**a** Helium-capture reactions.

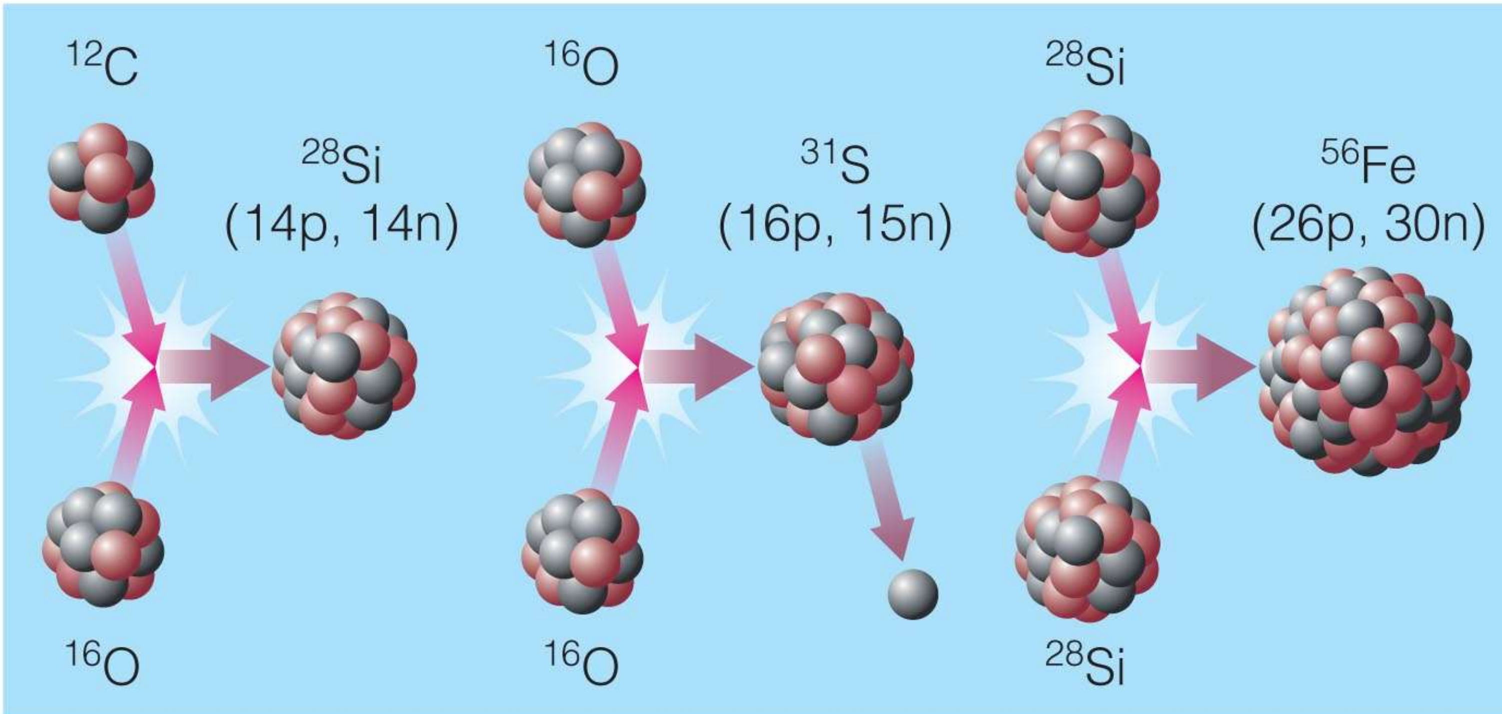
*High core temperatures allow helium to fuse with heavier elements.*

# Evidence for Helium Capture Processes




We observe Higher abundances of elements with even numbers of protons

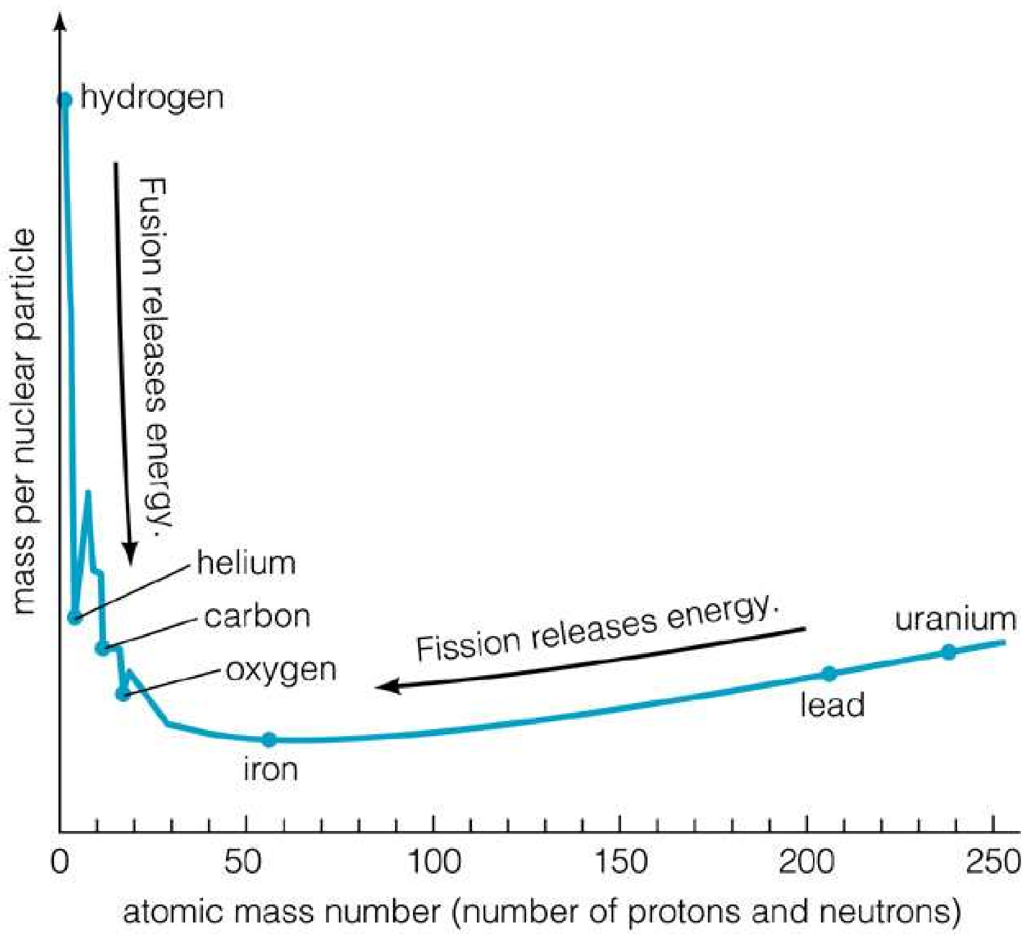
# Advanced Nuclear Burning



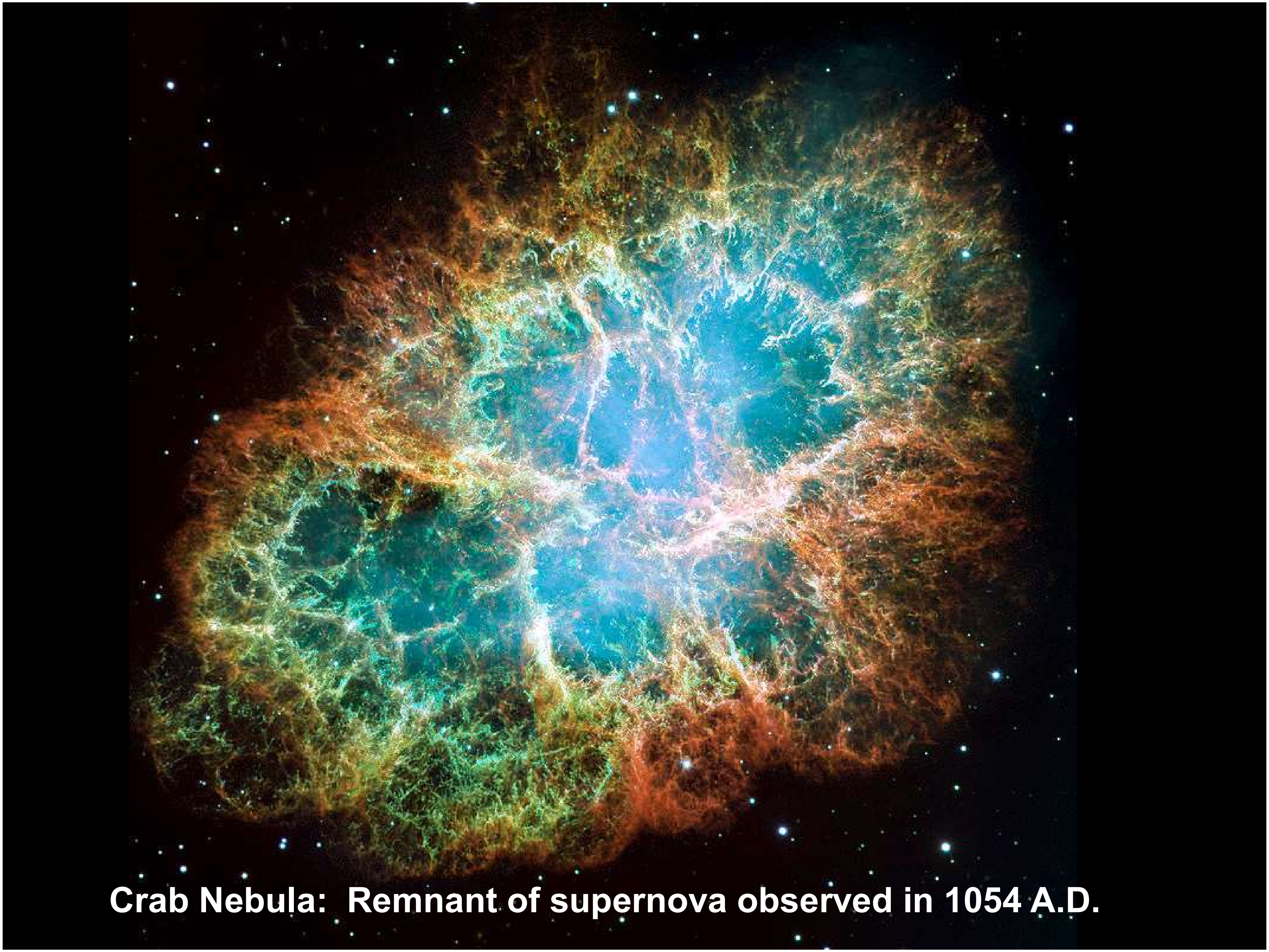

**b** Other reactions. (Note: Fusion of two silicon nuclei first produces nickel-56, which decays rapidly to cobalt-56 and then to iron-56.)

*Core temperatures in stars with >8$M_{Sun}$ allow fusion of elements as heavy as iron.* ***Why does it stop at Iron?***

# Iron – The End of the Line?

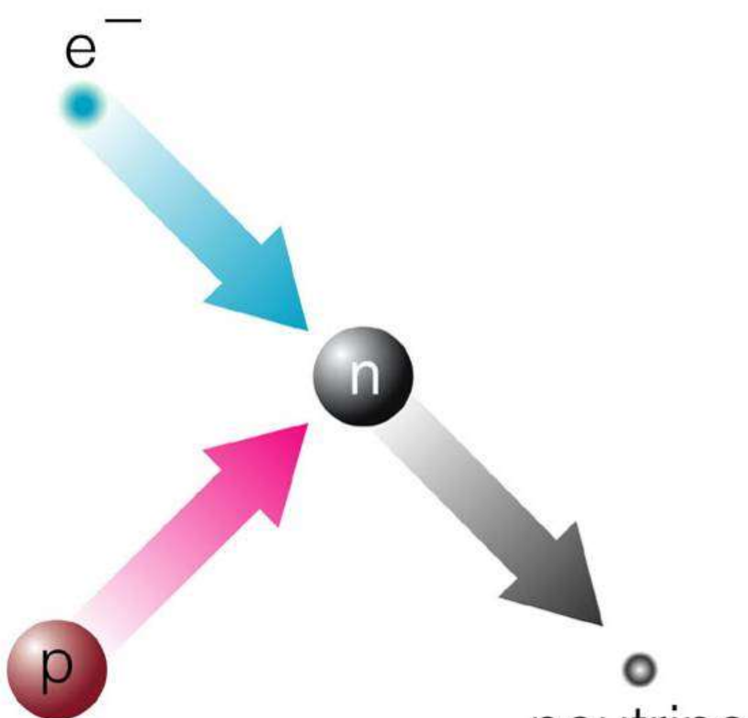



- The amount liberated per reaction generally drops as you approach $^{56}Fe$.
- $^{56}Fe$ is bottom of the energy valley. Making heavier elements is possible, but will require energy input.
- To make the elements beyond Fe requires two processes….
  - **R-process**
  - **S-process**



Crab Nebula:  Remnant of supernova observed in 1054 A.D.

# What is happening?




Remember that the Chandrasekhar limit of 1.4 Msun indicates that this is the upper limit that electron degeneracy pressure can stop further collapse…

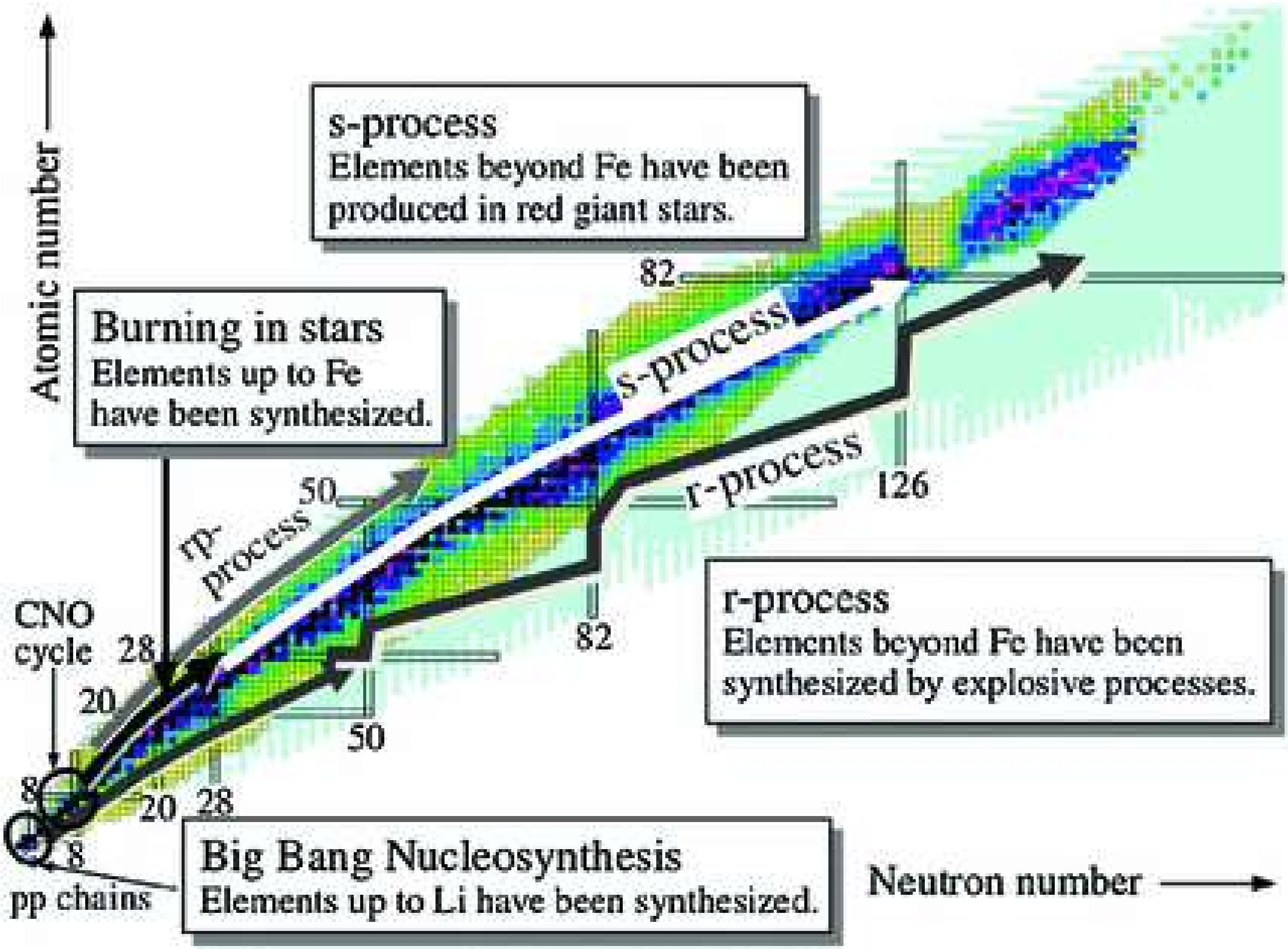
**Eventually gravity wins…**

The electrons and protons combine to form neutrons…

A neutron star forms within seconds and is only ~10 Km diameter…

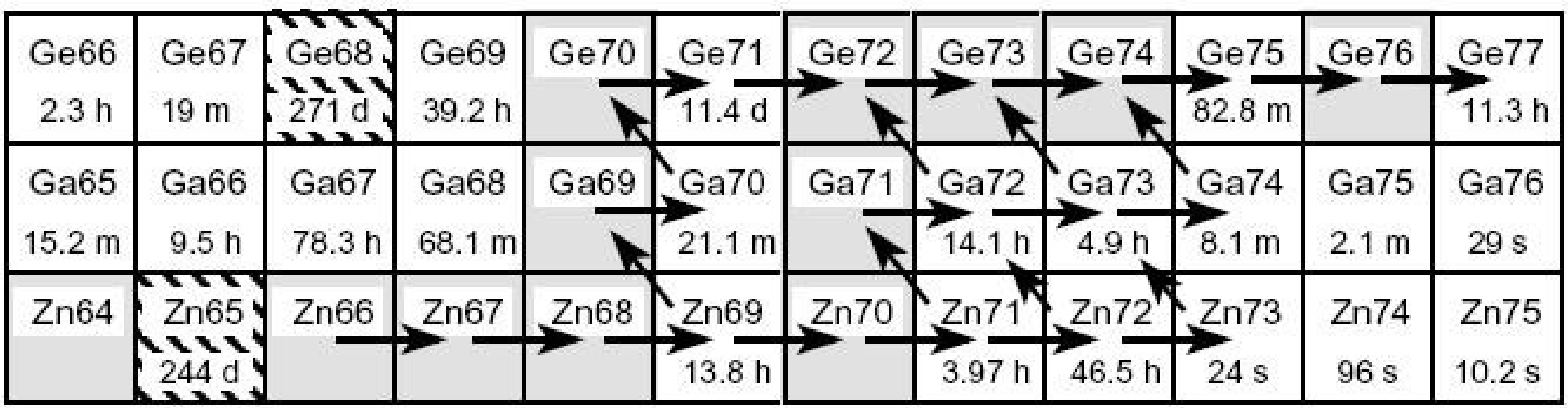
The outer layers are suddenly in free-fall… so what causes them to explode so violently?

# Element Formation Overview



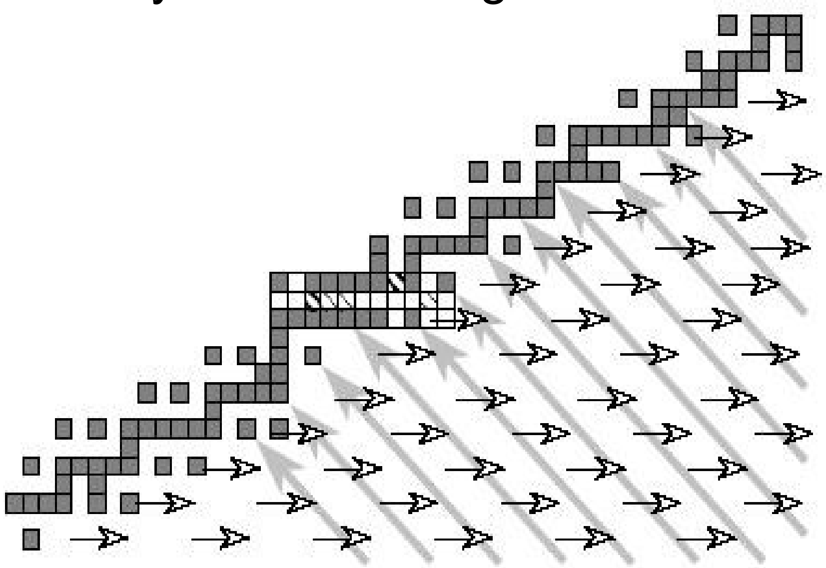
# S-Process (Slow Process)

- Occurs in outer layers of giant stars
- Some reactions liberate neutrons.
- The larger nuclei tend to have a larger capture cross-section for neutrons and can absorb lots of neutrons.
- This puts energy into the atom, pumps up its atomic number, and pushes it into really unstable isotopes (look at $^{66}$Zn going to $^{73}$Zn.
- Then beta decay turns a neutron into a proton, pushing the atom up the periodic chart.
- This makes about 75% of isotopes heavier than Fe

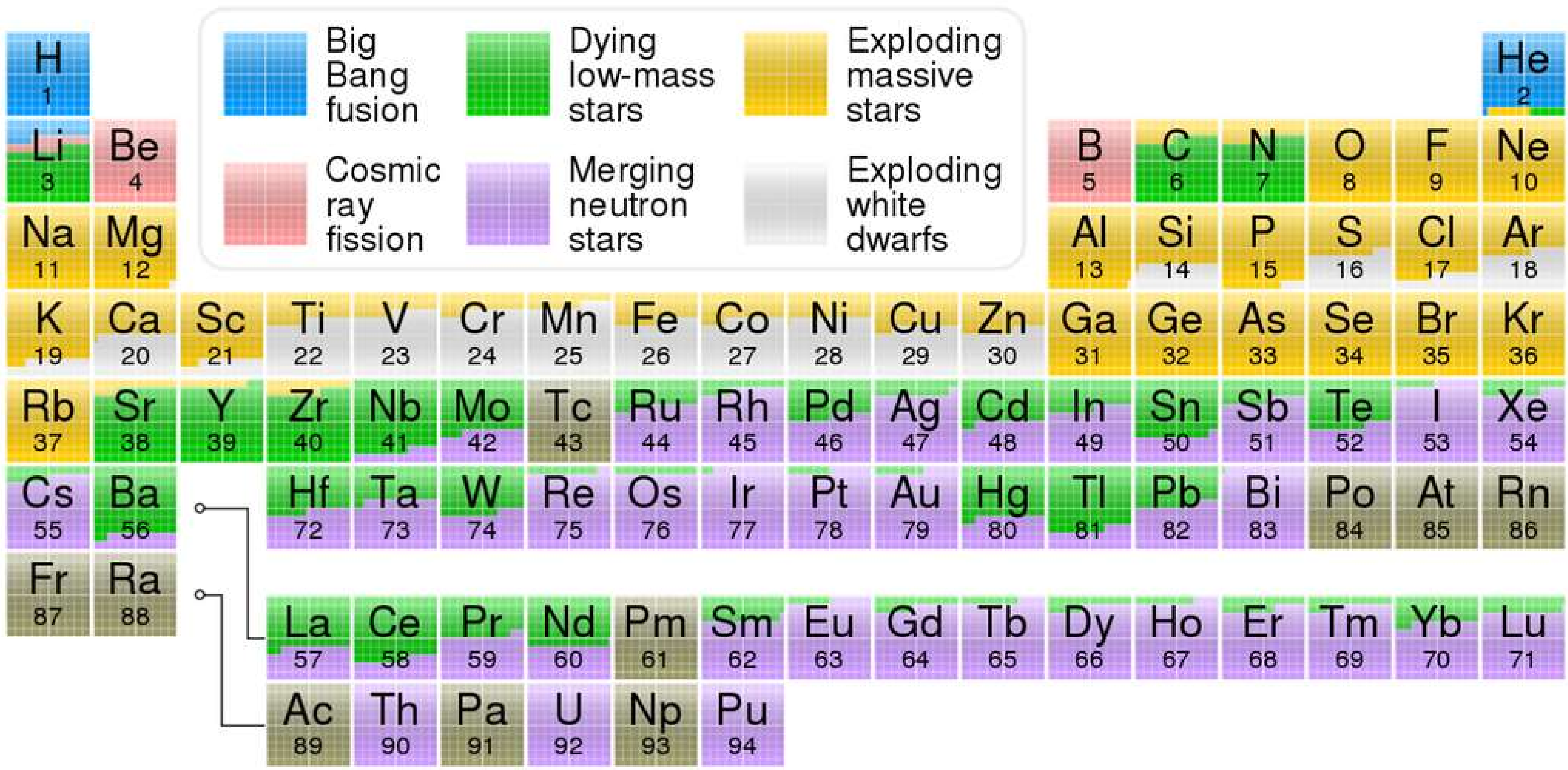


# R-Process (Rapid Process)

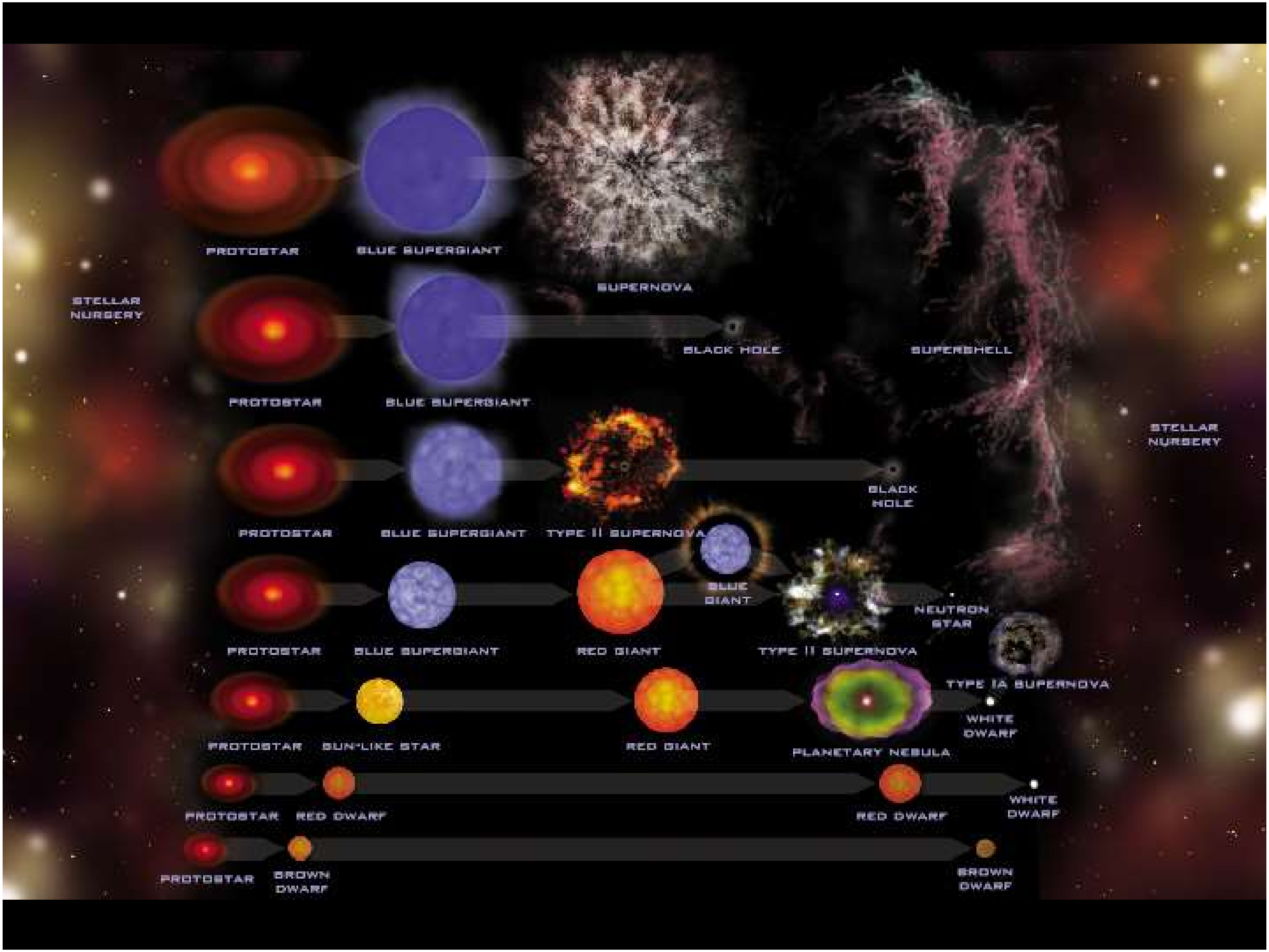
- Occurs while the supernova is in the process of ripping apart a star, the stellar material is flooded with neutrons.
- During the few seconds (or milliseconds) of the explosion neutrons are absorbed much faster then the atoms can decay, so the isotopes are pushed far to the right on the chart.
- THEN decay begins and continues moving up and to the left until stable configurations are reached.
- BUT so many neutrons are absorbed during this RAPID process that it allows nuclides to decay to a wide range of stable configurations.



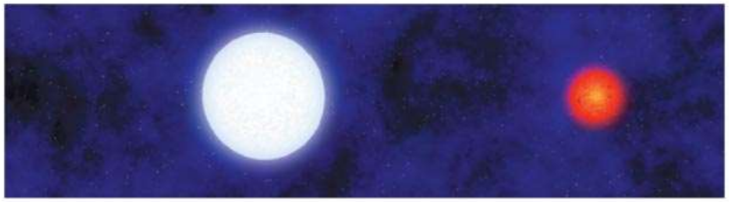
# Where were the Elements Made?



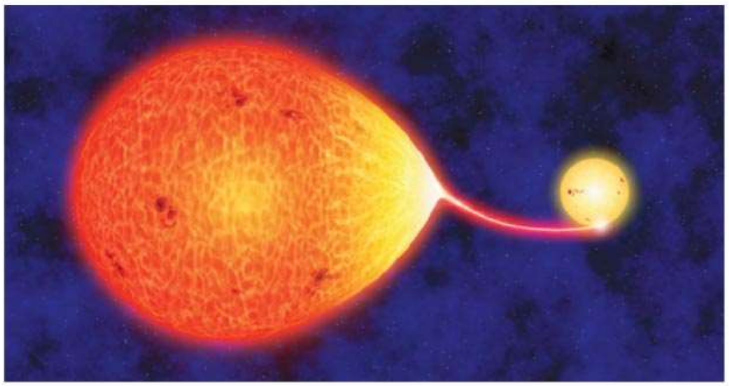

**Elements in Purple only confirmed in the past year or so…**


STELLAR NURSERY
PROTOSTAR
BLUE SUPERGIANT
SUPERNOVA
PROTOSTAR
BLUE SUPERGIANT
BLACK HOLE
SUPERSHELL
PROTOSTAR
BLUE SUPERGIANT
TYPE II SUPERNOVA
BLACK HOLE
STELLAR NURSERY
PROTOSTAR
BLUE SUPERGIANT
RED GIANT
BLUE GIANT
TYPE II SUPERNOVA
NEUTRON STAR
TYPE IA SUPERNOVA
PROTOSTAR
SUN-LIKE STAR
RED GIANT
PLANETARY NEBULA
WHITE DWARF
PROTOSTAR
RED DWARF
RED DWARF
WHITE DWARF
PROTOSTAR
BROWN DWARF
BROWN DWARF

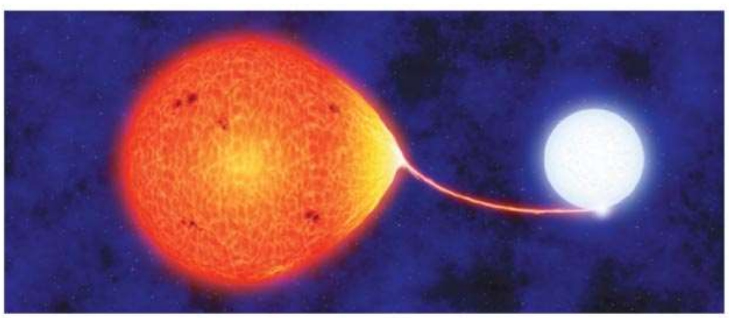
# The Algol Binary Star System



Algol shortly after its birth. The higher-mass star (left) evolved more quickly than its lower-mass companion (right).



Algol at onset of mass transfer. When the more massive star expanded into a red giant, it began losing some of its mass to its normal, hydrogen core fusion companion.



Algol today. As a result of the mass transfer, the red giant has shrunk to a subgiant, and the normal star on the right is now the more massive of the two stars.

- Stars in Algol are close enough that matter can flow from the subgiant onto the main-sequence star.
- The star that is now a subgiant was originally more massive.
- As it reached the end of its life and started to grow, it began to transfer mass to its companion (*mass exchange*).
- Now the companion star is more massive.
- *What would happen if the companion star drawing mass were a ~ 1.4 $M_{sun}$ white dwarf?*

# iClicker Question

Which of the following is not a difference between the evolution of a low-mass star and a high-mass star?

A. Low-mass stars spend more time on the main sequence than high-mass stars

B. Low-mass stars convert hydrogen into helium in their cores through a different set of reactions than high-mass stars do

C. Low-mass stars end their lives as white dwarfs, and high-mass stars end as neutron stars or black holes

D. Low-mass stars don’t make elements heavier than carbon and high-mass stars do

E. None of the above (all are differences)

# iClicker Question

Which of the following is not a difference between the evolution of a low-mass star and a high-mass star?

A. Low-mass stars spend more time on the main sequence than high-mass stars

B. Low-mass stars convert hydrogen into helium in their cores through a different set of reactions than high-mass stars do

C. Low-mass stars end their lives as white dwarfs, and high-mass stars end as neutron stars or black holes

D. Low-mass stars don’t make elements heavier than carbon and high-mass stars do

**E. None of the above (all are differences)**

# iClicker Question

What is the net product of the CNO cycle?

A. Helium

B. Carbon

C. Nitrogen

D. Oxygen

E. All of the above

# iClicker Question

What is the net product of the CNO cycle?

A. **Helium**

B. Carbon

C. Nitrogen

D. Oxygen

E. All of the above

# The Exam… what to expect

**Exam will be in Class on Friday 9th Feb**

***- When you come in, please make sure you have plenty of space when you chose a seat***

***Do Bring:***

- Scantron

https://ucfsga.com/services/free-scantrons-and-blue-books/

- Pencil (2B or #2 recommended)
- Make sure you know your PID
- Scientific Calculator
- An ID – you will need your ID to hand in the exam.


***Don't Bring:***

- Books, notes, or phones

# The Exam… what to expect

- **The Exam will consist of 40-45 multiple choice questions.**
- **There will be 5 matching questions at the start**
- **Followed by 10 true/false questions**
- **There will be ~5 questions that are meant to tease your brain…**

***It will be based mostly on the lecture content BUT the general knowledge questions may rely on content within the books (chapters 10-13 of the essential cosmic perspective, chapters 14-23 of the OpenStax book)***

***THIS GUIDE MAY NOT COVER ALL THE MATERIAL THAT MAY BE ON THE EXAM, FOR THAT YOU SHOULD COVER ALL LECTURE MATERIAL AS WELL AS THAT FROM EITHER TEXT BOOK!!***

***Some material only covered in class could be on the exam…***

# Study Guide – Chapter 10

10.1. Detecting Planets Around Other Stars

How do we detect planets around other stars?

- Why is this challenging in the visible?
- What wavelengths make this easier? Why?
- What are the main techniques for detecting exoplanets?
  - Astrometric
  - Transits
  - Doppler Shift
- What is the difference between direct & indirect detection?
- What are the bias of each technique?
  - Do we still think what we used to about Hot Jupiters?

# Study Guide – Chapter 10

10.2. The Nature of Planets Around Other Stars

What properties of extrasolar planets can we measure?

- What information can you learn from each technique?
  - Size? Orbital Period? Mass? Radius? How do we get density?
- What spacecraft are used for each technique?
- Approximately how many systems have been identified with each technique?

How do extrasolar planets compare with planets in our Solar System?

- If you are given two properties of the orbital period, orbital distance, or mass of the star could you compare how the system would behave relative to that of our Solar System?
- What are the range of densities and other properties observed for exoplanets?

# Study Guide – Chapter 10

10.3. The Formation of Other Planetary Systems

Do we need to modify our theory of Solar System formation?

- How would Hot Jupiters pose a problem for nebula theory?
- What possible mechanisms for planetary migration could occur?
  - Stellar winds versus migration and cyclization of orbits.

Are planetary systems like ours common?

- How common in the universe are planets? Earth-like planets?
- How many lie in the habitable zone?
- How does the habitable zone change with different types of stars?
  - How might it affect civilization and the origin of life if there were a high-mass star versus a low-mass star??

# Study Guide – Chapter 11

11.1. A Closer Look at the Sun

Why does the Sun Shine?

- The Sun is very luminous – how much energy does it output? What is luminosity?
- How long could chemical burning or gravitational contraction provide?
- How old is the Earth, and how do we know this?
- What is the source of the Sun's energy?
- What is the difference between nuclear fission and nuclear fusion?
  - Can you give examples of where both occur?

What is the Sun's Structure?

- Approximately what is the temperature and density of the Sun as a function of radius?
- Can you describe where, the approximate temperature and density, and what occurs in the following regions?
  - Corona, Chromosphere, Photosphere, Convection zone, Radiation zone, Core.

# Study Guide – Chapter 11

What is the Sun’s Structure?

- What is the Solar Wind?
- How do we have evidence for convection on the surface of the Sun?

11.2. Nuclear Fusion in the Sun

How does nuclear fusion occur in the Sun?

- How does the proton-proton chain reaction generate energy?
  - Why is  a high temperature needed for fusion to occur? Coulombic repulsion?
- What else is produced from the p-p chain reaction?
  - Positrons – what happen to them?
  - Neutrinos – what happens to them?
  - Gamma rays – what happens to them?
- What is the solar thermostat, and how does it work?
- How does the energy from fusion get out of the Sun?
  - How do neutrons and photons escape the Sun? How long does it take?
  - What else do we know about Solar Neutrinos? What is the Solar Neutrino problem?

# Study Guide – Chapter 11

- How do we know what is happening inside the Sun?
  - Observations of neutrinos reveal what?
  - What other techniques are there and what do they reveal?

- 11.3. The Sun-Earth Connection
- What causes Solar activity?
  - How does the Sun rotate and how does this influence the magnetic fields?
  - What is the 11-year cycle? What is the 22-year cycle?
- How does solar activity vary with time?
  - What are Sunspots? When do they peak?
  - What are Solar Flares?
  - What are coronal mass ejections, and how can they interfere with Earth?
  - How does the Solar Wind interact with Earth?
  - How does solar activity relate to global warming? Is there a link?

# Study Guide – Chapter 12

12.1. Properties of Stars

How do we measure stellar luminosities?

- What is luminosity? How does it vary with distance?
- What is apparent brightness?
- What is magnitude? What is apparent magnitude?
- What kind of variations do we observe for stars?
    - Which are most common? Are there any patterns?
- How can we use stellar parallax to measure the distance of stars?

How do we measure stellar temperatures?

- Stefan-Boltzmann law (hotter bodies emit more radiation)
- Wien’s law (maximum shifts to lower wavelengths for hotter bodies)
- Spectra are the best way to determine:
    - Temperature
    - Spectral type – patterns of molecules versus ions versus hydrogen lines…

# Study Guide – Chapter 12

- Spectral type – patterns of molecules versus ions versus hydrogen lines…
- OBAFGKM series… remember this!

How do we measure stellar masses?

- What techniques? Are these similar to those for exoplanets?
  - What information is given by each?
- Newton's formulation of Kepler's 3rd law…
  - Given 2/3 of orbital period, radius and velocity we can determine mass of systems
  - How? Easiest way is to compare to our Solar System
  - Plus using binaries (or binaries with another binary) to constrain masses…

## 12.2. Patterns Among Stars

What is the Hertzsprung-Russel diagram?

- What is being plotted against what??
- Can you relate size & temperature to bodies on the H-R diagram?

What is the significance of the main sequence?

- How does mass affect how long a star will stay on the main sequence?

# Study Guide – Chapter 12

What are giants, supergiants, and white dwarfs?

- Where are these located on the H-R diagram?
- What can you tell about a star that is a giant?

12.3. Star Clusters

What are the two types of star clusters?

- Which one (open or globular) would you use to better constrain the age of the Milky way? Why?

How do we measure the age of star clusters?

- What is the main-sequence turn off point?
- Be able to explain trends in terms of the life sequence of stars…

# Study Guide – Chapter 13

13.1. Star Birth

How do stars form?

- What is the interstellar medium?
- What are the conditions necessary for stars to form?
  - Temperature? Density?
- What features do we typically only observe with young stars?

How massive are newborn Stars?

- What is the lower limit to the size of a star? Why?
- What is the upper limit to the size of a star? Why?
- What is degeneracy pressure?
  - Does it depend on temperature?
- How do we categorize stars based on their mass?
  - E.g., based on life sequence, or interior, or internal processes
  - Approximately same ranges for low, intermediate and high-mass…

# Study Guide – Chapter 13

13.2. Life as a Low-Mass Star

What are the stages of a low-mass star?

- Hayashi tracks onto the main sequence… T-Tauri phase.
- Main sequence…
- **Red Giant Branch** – broken solar thermostat. H shell burning
  - What is the triple alpha process? What does it make, what does it not make?
- **Helium Flash** – only in low mass stars where degeneracy pressure reigns. The onset of helium fusion…
- **Horizontal Branch** – helium core fusion (and hydrogen shell fusion)
- **Asymptotic Giant Branch** – helium core exhausted, carbon-oxygen core remains and shell fusion of helium and outer shell burning of hydrogen makes an even larger star…

How does a low-mass star die?

- What is the process, what is left behind?
- What is the size-mass relationship and mass limit on a white dwarf?

# Study Guide – Chapter 13

13.3. Life as a High-Mass Star

What are the life stages of a high-mass star?

- Undergo CNO cycle rather than p-p cycle
  - What are the similarities? What are the differences?
- Main sequence…
- Supergiant with multiple shells with ever shorter lifetimes of elements remaining in the core as they fuse to eventually form Iron
  - Is there a helium flash? Why or why not?
  - Is the process gradual or ‘jerky’ like for low mass stars?

How do high-mass stars make the elements necessary for life?

- What is helium capture?
- What other elements can form within the cores of stars?
- How do heavier elements form?
- What particle induces the r- and s-processes to form heavier elements?

# Study Guide – Chapter 13

How does a high-mass star die?

- Why does it matter than Iron collects in the core?
- What happens to the Iron in the core?
  - Degeneracy pressure versus gravity – who wins?
- What are the properties of a neutron star?
  - Minimum mass?
  - Approximate size?

13.4. Stars in Close Binaries

How are the lives of stars with close companions different?

- Understand that binary systems can interact with each other and ‘steal’ mass from one another which can affect whether they are main sequence or giant stars
  - Why does this happen? Where is all the mass (gravity) in each star?

# Good Luck!