Exam 2 – Score Statistics

Letter Grade	Score Range	No. of Students
A	53 – 60	35
A⁻	50 – 52	16
B⁺	48 – 49	9
B	45 – 47	15
B⁻	42 – 44	17
C⁺	39 – 41	10
C	36 – 38	9
C⁻	33 – 35	14
D	30 – 32	9
F	< 30	11

Total # Exams: 157

Mean = 42/60 = 71%

Breakdown by letters:

A : B : C : D : F

51 : 41 : 33: 9: 11

33%: 26%: 21%: 6%: 7%

The Most Frequently Missed Questions

- *A brown dwarf has approximately the same radius as:*

Jupiter; also as a red dwarf, but this was not one of the choices. Many people chose the white dwarf, a few the Earth (same size as a white dwarf), a few chose a neutron star. The image below, from 10/9 class slides, should prod your memory. This should have come up in addressing question 1 on the Exam 2 Study Guide.

An unusual property of stars supported by degeneracy pressure is the *inverse* relation between mass and radius. The masses of brown dwarfs are lower than white dwarfs, so their radii are ***larger.***

The Most Frequently Missed Questions

- *"Which [exoplanet search] method was used to find the first confirmed exoplanet, 51 Peg b?"*

This is just a factual question. Despite the fact that we discussed it in class on Oct. 11, and even watched a video about it on Oct. 9, less than half the class got this question right. In fact, 51 Peg b was explicitly mentioned as one of the objects you should know, on slide 27 of the Card file from Nov. 1.

- *"Which property [of an exoplanet] requires the transit method?*

"Requires" means that you can't determine the property using any other method. The only method that gives you the planet's radius is the transit method; the others – positional wobble, Doppler or radial velocity wobble, are all determined by the planet's mass. We extensively discussed which methods tell you what about the planet; for instance, see Card from Oct. 11.

The Most Frequently Missed Questions

- *"What is a planetary nebula?"*

There was a lot of guessing on this straightforward factual question. Besides being one of the major stages in the life a lower-mass star, this was one of the questions on Quiz 6.

- *"What is the product of the CNO cycle of nuclear reactions?"*

The CNO cycle is one of the ways that stars can fuse H to He. This was question 2 on the Exam 2 Study Guide.

- *"Which element must have been made in a supernova?"*

See lecture slides and the Card slide from Oct. 25.

- *"Why does the period of a pulsar slowly increase?"*

Because the rotation (spin) rate is slowing down. See Card fo;e from 10/30.

Exam 2 Essay Questions

1. Compare the properties of red and brown dwarfs.

- ***mass***: the brown dwarf has less than **0.08 $M_{\odot}$**, the red dwarf must be a little more massive
- their ***radii*** are similar (see picture a couple of slides back)
- ***temperature***: brown dwarfs are cooler than red dwarfs
- the brown dwarf is supported by electron degeneracy ***pressure***, the red dwarf - a MS star – by thermal pressure
- the red dwarf ***produces energy*** by H-fusion in its core; the brown is just radiating away stored thermal energy (like the white dwarf or baked potato)
- the red dwarf is at the lower end of the Main Sequence and will stay there for a very long time due to its long MS lifetime. The brown dwarf is further down and to the right, but will evolve along a cooling track (line of constant radius) over time.

Exam 2 Essays, cont'd.

2. On NASA's *Kepler* satellite.

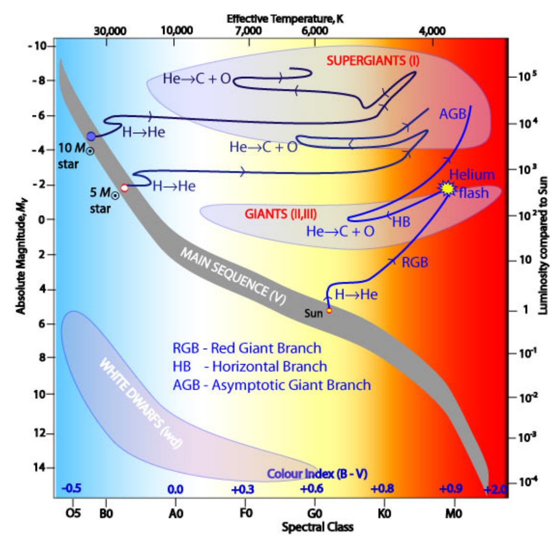
- *Kepler* uses the **transit** method to search for exoplanets.
- It has been highly successful, finding (so far) several thousands of possible planets around other stars (including numerous cases of entire planetary systems)
- *Kepler* data – or any transit data – give you the **radius** of the planet as well as the orbital period (see a few slides back)
- If you want to know the planet's **mass**, you need to add information obtained from another method, such as the **Doppler wobble**, that results from the gravitational tug. Knowing both mass and radius, you can estimate the density. Also, if the planet transits the star, spectra taken at that time can show you what the planet's atmosphere is made of.

Exam 2 Essays, cont'd.

3. Properties of AGB (Asymptotic Giant Branch) stars.

- AGB stars lie in the **upper right** of the HR diagram, above the red giants and below the red supergiants (see next slide)
- Their surfaces lie at very large radii (distance from the center of the star), where the gas is cool and has low density. This is in dramatic contrast to their very small, hot, dense cores, which are approaching or at the state of electron degeneracy.
- AGB stars have multiple energy sources. In the early part of the AGB phase the core may still be contracting, although this stops when the electron degeneracy pressure increases to the point that it can counteract gravity. Additionally, both He and H are fusing in shells outside the core (this doesn't happen at the same time, but that's a detail you don't need to know).

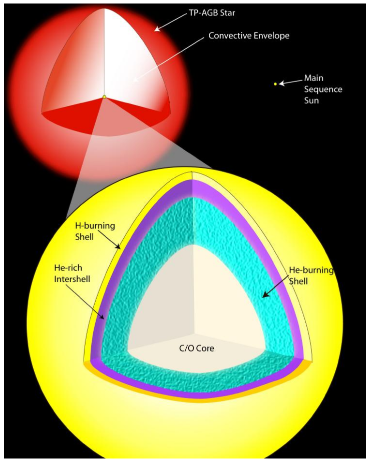
Evolutionary Tracks for Various Masses



He-Core Exhaustion: The Asymptotic Giant Branch ("AGB" Star)

When all the He is used up in the core, the core begins contracting again, which heats it up, causing He fusion to occur in a shell above the core.

This is the "double shell-burning" phase, which has an inner He-burning and and outer H-burning shell.



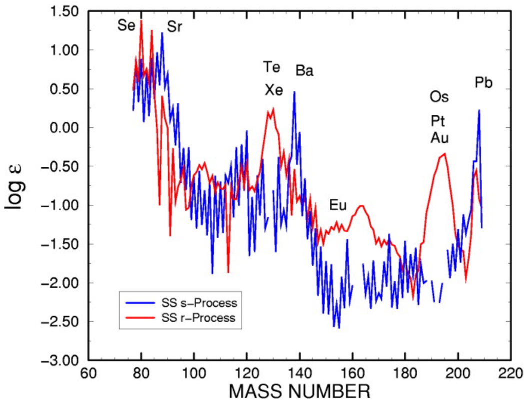
Exam 2 Essays, cont'd.

4. Where & how are C and the elements heavier than Fe made?

- Nucleosynthesis was discussed on 10/23 and the 11/1 Card.
- C is produced in the "triple-alpha" process, where three He nuclei are fused to make one C nucleus. This occurs late in stellar lives, e.g. the horizontal or AGB phases of low-mass stars; or in a higher-mass star after its first red giant stage.
- Elements heavier than Fe are made by adding neutrons to nuclei, as described in a video clip featuring Neil deGrasse Tyson. There are two ways in which this can happen. In the slow or "s" process, neutrons are added slowly, one at a time. This occurs in AGB stars. The rapid or "r" process involves flooding nuclei with lots of neutrons. We think this happens in core-collapse supernovae from massive stars.

Trans-Iron Elements in the Solar System

About half the nuclei in the Solar Sytem heavier than iron came from the slow, or s-process in AGB stars, the other half from the rapid, r-process in supernovae



Truran, Cowan, Pilachowski & Sneden PASP (2002)

Exam 2 Essays, cont'd.

5. "All pulsars are neutron stars (NS), but not all NS are pulsars."

- Pulsars are recently "born," still rapidly rotating and strongly magnetic neutron stars. They emit detectable radio "pulses" only for a limited period of time after emerging from a supernova. As they radiate radio (synchrotron) emission, they are losing energy, and therefore they are slowing down and their magnetic fields are getting weaker. Eventually they are no longer observable *as pulsars*.
- But even after it's slowed down and has become less strongly magnetic, the neutron stars are still there! They are cooler and slower, but still the same size – they cannot contract, due to neutron degeneracy pressure. Indeed, they cool and fade along a "cooling track," like white dwarfs (baked potatoes).