Plan of Lecture
White Dwarfs

Review of exam.

Isolated white dwarfs.

Binary evolution and white dwarfs.

Accreting white dwarfs.

- **Classical novae.**
- **Type Ia supernovae!**

Review of First Exam

Mean and median both about 120/150.

Very well done!

Not an easy exam...

Remember to answer all parts of the exam.

H-R diagram: seven object classes!

Quantitative problems were the most difficult.

I've written a document to give practice in solving quantitative problems.

Under "Material to Help You Out".

Challenge Questions

1. How does the ISM differ between types of galaxies?

2. Why is star formation common in colliding galaxies?

3. What would life be like in orbit around an M star?

4. How would stellar evolution change for a Population III star?

Isolated White Dwarfs

Just the facts:

$M \sim 0.1\,M_\odot - 1.4\,M_\odot$.

$R \sim 10^{3-4}$ **km.**

$\rho \sim 10^{6-9}$ **g cm**$^{-3}$**.**

$T_{\rm surf} \sim (1-3) \times 10^4$ **K.**

Masses of isolated WD are not easy to measure, but there seems to be a peak around $\sim 0.6\,M_\odot$.

Larger MS stars lose more mass.

No WD with $M > 1.4\,M_\odot$; Chandrasekhar mass!

Structure of White Dwarfs

At the very surface, free from high density, atoms have space and are normal.

Their type depends on the star's evolution.

Very low mass: hydrogen.

Higher: helium.

Higher yet: C, N, O, Ne, Mg,...

Further down, nuclei are so close that they aren't atoms anymore.

Nuclei in a sea of degenerate electrons!

Central nuclei can be C, N, O for low-mass; Ne, Si for high-mass.

More About Degeneracy

White dwarfs have no heat source (they just cool off); pressure supplied by degeneracy.

This gives them a weird structure:

Heavier WD are *smaller*!

Why? Pressure comes from density. More mass, more gravity means more density to support it.

Comparison 1: a rock.

Constant density.

Gravity is not important.

Comparison 2: a main sequence star.

If more massive, less dense overall.

Pressure comes from radiation.

Lots more radiation for high M!

Cooling of White Dwarfs

A white dwarf basically has no way to generate new energy.

No more fusion.

Can't contract much (degenerate!).

Therefore, all it does is cool.

After few billion years, outer parts are cool enough that they can crystallize!

Releases some extra heat.

Theoretical cooling curves have been calculated for various mass white dwarfs.

Coolest white dwarfs are the oldest.

Can estimate age of galaxy!

Binary Evolution

Isolated white dwarfs go gently into that good night. What about binaries?

To answer this, think about how a star might evolve differently in a binary.

If binary is wide, small difference.

Close, expansion truncated.

Matter from one star can get close enough to flow onto the other.

Called *accretion*.

At what point does this happen?

Consider orbiting system.

"Lagrange points", equilibrium.

Called Roche lobes here.

Symbiotic Binaries

Two stars in a binary, A and B.

$M_A > M_B$.

A evolves faster than B.

Becomes a red giant.

Transfers mass to B.

B can become more massive than A.

"Algol paradox": more evolved star is less massive.

In principle, cycle of mass transfer can repeat: symbiotic stars.

Eventually, get white dwarf with MS companion.

Accreting White Dwarfs

If WD and MS star are separated widely (detached binary), they just orbit.

Sirius A and B.

However, if they are close or MS star evolves to giant, mass transfer occurs to WD.

White dwarf is very compact, so matter hits hard.

Surface speed: $\sim 10^{-2}c$**!**

Releases $\sim 10^{-4}Mc^2$ **of energy.**

Compare: $\sim 10^{-9}Mc^2$ **for gasoline.**

Causes WD to glow, very hot.

A Different Type of Fusion

The matter transferred to WD is from outer layers.

Mostly hydrogen, helium.

In principle can be fused, but outer layers of WD are much too cool.

But wait: if you get two nuclei really close, they can fuse even at low temp.

Called pycnonuclear fusion.

As matter piles up on the WD surface, the bottom parts become denser and degenerate.

If fusion starts, it heats up matter.

Can increase fusion rate.

Increases temp.

Runaway!

Classical Novae

The process just described produces what are called *classical novae*.

Despite confusion, these are completely distinct from core-collapse supernovae.

Supernova: collapse of massive star.

Nova: thermonuclear burst on WD.

What happens when the energy is released?

Grav. binding energy: $10^{-4}Mc^2$**.**

H burning: $7 \times 10^{-3}Mc^2$**.**

There is therefore more than enough energy to drive away the layers that were accreted.

This does not disrupt star; a given binary can have many novae.

Type Ia Supernovae

There is, however, a more violent event.

Suppose an accreting WD is just below the Chandrasekhar mass.

As it acquires a little more mass, it collapses.

Just like core collapse SN? Not quite!

Massive star: Fe core (no fusion).

$1.4\,M_\odot$ **WD: C, O, Ne, Mg core.**

Therefore, lots of fusion can happen, explosively.

Destroys entire star.

This is a Type Ia supernova.

Not related to other supernovae!

More On Type Ia Supernovae

Empirically, Type Ia supernovae are "standard candles"; with correction, have fixed luminosity.

Used to probe cosmology.

However, there are still many unanswered questions.

Even the basic mechanism is not absolutely settled.

Sub-Chandrasekhar WD burning?

Collision of two WD?

How does burning propagate?

Also, how would WD get to that mass anyway?

Novae remove lots of mass!

Need steady burning.

Accretion-Induced Collapse

One more possibility exists, that has never been observed.

Suppose Chandrasekhar-mass WD adds a little more matter.

Unlike in Type Ia SN, suppose there isn't enough nuclear energy to blow apart star.

Are we left with a rapidly spinning NS?

The idea has been resurrected many times, but no agreement about whether it could happen.

Summary

WD are endpoints for low-mass ($M_{\rm init} < 8\,M_\odot$) stars.

Most of the mass is degenerate.

In binaries, WD can accrete.

Classical novae.

Type Ia supernovae.

Challenge: what would you expect to see from an accretion-induced collapse?