Ay 7A – Fall 2009
Section Worksheet 11
Birth, Life, and Death: The Life Cycle of Stars[1]

Using the following stages of stellar evolution, construct flow charts for each of the three ranges of initial (i.e., zero-age main sequence, or ZAMS) mass: $\lesssim 0.08 M_\odot$, $\sim 0.08 M_\odot$–$8 M_\odot$, and $\gtrsim 8 M_\odot$
In the flow charts be sure to indicate where evolutionary paths split and specify the criteria that determines which stars follow which paths.

black hole (BH) | brown dwarf (BD) | carbon & oxygen (CO) fusion
core-collapse supernova (CC-SN) | CNO cycle dominates fusion
gamma-ray burst (GRB) | helium (He) fusion | horizontal branch (HB)
hydrogen (H) shell burning | Kelvin-Helmholtz (KH) gravitational contraction
main sequence (MS) | neutron star (NS) | nova | p-p chain dominates fusion
planetary nebula (PN) | pulsar (PSR) | red giant (RG) | red supergiant (RSG)
type Ia supernova (SN Ia) | white dwarf (WD) | X-ray burst (XRB)

$\lesssim 0.08 M_\odot$:

KH → BD

$\sim 0.08 M_\odot$–$8 M_\odot$:

KH → MS → ($\lesssim 2 M_\odot$) p-p chain → H shell fusion → RG → He fusion → HB → PN →
MS → ($\gtrsim 2 M_\odot$) CNO cycle → H shell fusion

→ WD (The End for single stars and some binaries) → (binary with some accretion) nova
→ WD (The End for single stars and some binaries) → (binary with lots of accretion) SN Ia

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$\gtrsim 8 M_\odot$:

KH → MS → CNO cycle → H shell fusion → RG → He fusion → HB → CO fusion → RSG →

→ ($\lesssim 20 M_\odot$) NS (The End for some stars) → (binary with some accretion) XRB
→ ($\lesssim 20 M_\odot$) NS (The End for some stars) → (rapid rotation, large $\vec{B}$, pointing at $\oplus$) PSR

→ CC-SN → ($\gtrsim 20 M_\odot$) GRB → BH (THE END)

[1] Thanks to former BADGrad Katie Peek for inspiring this worksheet with her version for Ay 10.

Why Does the Sun Shine?
(The Sun Is a Mass of Incandescent Gas)
by They Might Be Giants[2]

What's wrong with this song? Comment on which lines are accurate and which are not so accurate.

Chorus:

The Sun is a mass of incandescent gas[3]

``Incandescent'' means glowing or luminous from heat, so that's OK, but the Sun is mostly plasma[4], not gas (though the outermost layers are certainly gas otherwise we'd see no spectral features).

A gigantic nuclear furnace

Yes.

Where hydrogen is built into helium

The Sun does indeed fuse hydrogen to helium.

At a temperature of millions of degrees

The Sun's core temperature, where fusion takes place, is about 10^7 K $\approx 1.8 \times 10^7$ °F, so that's correct.

Yo ho, it's hot

By terrestrial standards, yes.

The Sun is not

A place where we could live

Yes.

But here on Earth there'd be no life

Without the light it gives

Actually, scientists have found organisms living on the ocean floor near hydrothermal vents that never get any sunlight. These lifeforms apparently do not need sunlight to live, although for them or the Earth or the hydrothermal vents that they depend on to develop in the first place, the Sun was probably necessary.

We need its light

Yes.

We need its heat

Yes.

We need its energy

Yes.

Without the Sun,

Without a doubt,

There'd be no you and me

Yes!!

<Chorus>

[2]The music video can be found at http://www.youtube.com/watch?v=Zbgul1NpEA8

[3]© J. Linnell and J. Flansburgh, 1987.

[4]This factual error bothered the band so much that they wrote a different song a few years ago called "Why Does the Sun Really Shine (The Sun Is a Miasma of Incandescent Plasma)": http://www.youtube.com/watch?v=sLkGSV9WDMA

The Sun is hot

By terrestrial standards, yes.

It is so hot that everything on it is a gas.

Yes, though some stuff is a plasma, see the very first comment.

Iron, copper, aluminum, and many others.

While these aren't the main constituents of the Sun, in does actually have trace amounts of Fe, Cu, Al, and many others.[5]

The sun is large.

By terrestrial standards, yes.

If the sun were hollow, a million Earths could fit inside,

$V_\odot/V_\oplus = (R_\odot/R_\oplus)^3 \approx 1.3 \times 10^6$ so that's pretty good.

and yet, the Sun is only a middle-sized star.

We know there are many, many more low mass stars than high mass stars in the Universe, but on the absolute range of stellar masses, the Sun is indeed pretty close to the middle.

The Sun is far away

By terrestrial standards, yes.

About ninety-three million miles away!

1 AU $\approx 1.5 \times 10^{13}$ cm $\approx 92.96 \times 10^6$ miles, so that's good.

And that's why it looks so small.

The wonder of angular sizes on the sky!

And even when it's out of sight, the Sun shines night and day.

Yes...

The Sun gives heat

Yes.

The Sun gives light

Yes.

The sunlight that we see

Yes.

The sunlight comes from our own Sun's atomic energy

Yes.

Scientists have found that

the Sun is a huge atom-smashing machine.

This is really a semantics issue I have since when people talk about ''atom-smashing'' they are usually referring to breaking apart atoms (i.e., fission), usually in the context of atomic bombs or nuclear reactors. However, we often refer to fusion reactions in the Sun as ''smashing together four protons to create a helium nucleus'' so this line's not too bad.

The heat and light of the Sun come from

the nuclear reactions of

hydrogen, carbon, nitrogen, and helium.

Yes, sort of. Certainly the Sun is fusing H to He and it is not currently fusing He, C, or N themselves to higher elements. Also, even though the p-p chain is the dominant form of fusion in the Sun and is thus responsible for most of the Sun's energy, there are still some CNO cycle reactions occurring as well (and of course this process involves C and N, as well as H and He.)

<Chorus>

[5] C&O, Fig. 15.16 shows the abundances of elements in the Solar photosphere. Basically it's about 90% H, about 9.9% He, and 0.1% other stuff (what astronomers call "metals").