Teacher Guide

Lives of Stars

An Interview with Several Stars in the Milky Way
(5 Billion years in the Future)

UPDATED IN 2010

Introduction

This activity is an opportunity for students to learn about the fundamental characterisitcs of stars and their life cycles. Students perform a play as members of an interview with several different stars. As the play progresses, students develop an understanding of the most fundamental concepts in stellar astronomy. The most important ideas are repeated through out the play. At the conclusion of the activity, students will have an understanding of the main three types of stars (red, yellow, and blue stars) and the ways in which these stars differ as they progress through their various stages of life and death.

A star, like our Sun, is an enormous and complex system. In order to model and understand their properties and how they change with time, astronomers and astrophysicists apply the basic ideas in physics to mathematically model a star. Astronomers then use telescopes and other instruments to find observable clues to test these models. The current theory of stellar evolution is based on mathematical and computer models of stars, and are very well supported by a wide variety of astronomical observations of every sort of object in the sky such as stars, galaxies, black holes, supernovae, and nebulae.

TEKS

Astronomy Related TEKS grades 9-12:

112.33(c)-6E: demonstrate the use of units of measurement in astronomy, including Astronomical Units and light years.
112.33(c)-10A: identify the approximate mass, size, motion, temperature, structure, and composition of the Sun.
112.33(c)-10B: distinguish between nuclear fusion and nuclear fission, and identify the source of energy within the Sun as nuclear fusion of hydrogen to helium.
112.33(c)-11A: identify the characteristics of main sequence stars, including surface temperature, age, relative size, and composition.
112.33(c)-11B: characterize star formation in stellar nurseries from giant molecular clouds, to protostars, to the development of main sequence stars.
112.33(c)-11C: evaluate the relationship between mass and fusion on the dying process and properties of stars.
112.33(c)-11D: differentiate among the end states of stars, including white dwarfs, neutron stars, and black holes.
112.33(c)-11E: compare how the mass and gravity of a main sequence star will determine its end state as a white dwarf, neutron star, or black hole.
112.33(c)-11F: relate the use of spectroscopy in obtaining physical data on celestial objects such as temperature, chemical composition, and relative motion.
112.33(c)-11G: use the Hertzsprung-Russell diagram to plot and examine the life cycle of stars from birth to death.
112.36(c)-4B: explain how the Sun and other stars transform matter into energy through nuclear fusion.

Earth and Space Science Related TEKS grades 9-12:

112.36(c)-4B: explain how the Sun and other stars transform matter into energy through nuclear fusion.

Duration

The reading of the interview and the completion of the evaluation questions should take about 1 hour of engaged work if it is done quickly. If more time is needed, you may want to assign some of the questions as homework.

The Cast

Page the photon reporter: an energetic but sensitive photon journalist who is interviewing the Sun for her column in the Local Group Times.
Sol the white dwarf: a kind and friendly star, our Sun at the end of his life. Sol used to be a yellow star. This interview takes place about 5 billion years into the future, when the Sun becomes a white dwarf.
Apollo the blue star: a young bragging and self-aggrandizing star that is full of youthful energy.
Kronos the red star: an old, experienced, and somewhat irritable star who has been around since close to the beginning of time.
Iana the interstellar cloud: stars begin their lives as collapsing globs of gas inside an interstellar cloud or nebula.
Minerva the Red Giant: Minerva is in the next phase of life - a bloated red giant star. Her size could easily swallow up Mercury and Venus and almost Earth.

Assign Roles

Sol and Page have the dominant roles, Apollo and Kronos have many lines, Iana and Minerva have very small parts. There are two possible ways to assign roles…

<u>Individual parts</u>: Each of the six characters can be played by an individual student.

or

<u>As a whole class</u>: This method helps ensure that all students will pay attention. Students in turn, play/read the parts of the characters. Divide the students into groups. Each group will be a different character. Try to make the groups of different skill levels. Each student in each group will take turns reading so that everyone has to read and follow their script.

Ask Guiding Questions

As students act out the interview, ask guiding questions to focus students' attention on physics or chemistry concepts. For instance, as Sol is contracting under his own weight and getting hotter during his protostar stage, ask students to think about the ideal gas law.

Pressure × Volume = Number of particles × k × Temperature of the gas
PV = NkT

$$\frac{Force}{Area} = \text{Pressure} = \frac{N}{V}kT$$

In a star, the pressure changes with radius. This changing pressure is what holds a star up, keeping it from collapsing. At each layer, the outward push of the gas is balanced by the inward pull of gravity on the gas.

Example:
If the core shrinks, its volume decreases. For the pressure to balance out the force of gravity, the temperature must go up. It's like a bicycle pump. Compressing the air inside the pump raises the temperature of the gas. That's why the pump feels hot after doing the work to inflate a bicycle tire.

Before beginning the interview, it may be helpful to review the following:

Key concepts and terms:

Speed of light	Potential energy
Scientific Notation	Kelvin
Nebula	Luminosity
Light year	Magnitude
Galactic year	Proton
Planetary nebula	Electron
Conservation of Energy	Positron/neutrino
Kinetic energy	Hydrostatic equilibrium

Recommended Preparation:
Review vocabulary. Review Scientific Notation and distance measurements in space. Put up photos (usually downloaded from web sites and/or posters) of a star field with multiple colors of stars, a red giant, the sun, a nebula, a supernova, a dying star like Eta Carinae, etc. The more photos that can cover the chalk boards, walls, doors, ceiling, the better but do not put them up until the day of the interview.

Beginning the Activity

Engage

Read the following to students:
"Our galaxy, by conservative estimates, contains 100 billion stars. The small number of stars we can see at night are the nearby stars in our tiny neighborhood of our galaxy. Stars are not eternal, but live long lives compared to our lifetime. Over time they change. Just like you can look at a family photograph and tell who is young or old, astronomers can observe stars to estimate their stage of life."

Pass out one 3 x 5 inch index card to each student.
Ask students to write about what physical processes they think are going on inside a star like our Sun. Tell them that grammar, punctuation, spelling, etc. does not count. Drawing is fine. But they must be writing or drawing for 2.5 minutes without stopping. Students can ask for additional index cards.

Ask students to share their responses. Summarize the responses on an overhead projector for everyone to see.

Review the students' responses. Help students identify the ones related to forces, motion, conservation of energy, gas laws, and nuclear fusion. Tell students to keep these concepts in mind as they act out and discuss the interview with a white dwarf.

Lives of Stars

An Interview with Several Stars in the Milky Way
(5 Billion years in the Future)

Cast of Characters:

Page – the photon reporter for the Local Group Times.
*Sol - our Sun in the distant future as a white dwarf (Sol was once a **yellow** star).*
*Apollo – a very large, hot, bright, young **blue** star.*
*Kronos – a very small, cool, dim, old **red** dwarf star.*
Iana – an interstellar cloud where stars are born.
Minerva – a red giant.

1) Fill in the blank spaces in the table (either while you are reading or after you have finished):

Character	Color while on main-sequence	Mass while on main-sequence (in solar masses)	Life-time on main-sequence (in years)	Luminosity while on main-sequence (in solar luminosity)	Diameter while on main-sequence (in solar units)	Type of Star After Collapse
Kronos				0.16	0.15	White Dwarf
Sol		1	10^{10}	1		
Apollo	Blue		7×10^6		9	

Prologue

PAGE: I'm here with three stars from the local stellar neighborhood: Sol, Apollo, and Kronos. Sol is a white dwarf, but for most of his life he was a yellow star. He's famous for being the star that was home to Earth and its humans about 5 billion years ago. They used to call him the "Sun". Welcome Sol.

SOL: Thanks Page, it's a pleasure to be here.

PAGE: Next to Sol is Apollo. Let me tell you, Apollo is gigantic! And extremely bright! I can barely see anything else through his glare.

APOLLO: Hey, what can I say? I'm a blue star, that's how we roll.

PAGE: And last but not least, there's Kronos. I almost didn't even notice you were here Kronos. You're so small and just barely glowing red.

KRONOS: Well, its not like I haven't heard that before. Thanks for having me.

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A galactic is year is about 225 million years.

The universe is currently estimated to be **13.7 billion** years old (the play is set 5 billion years in the future).

PAGE: Okay guys, I'm curious about all three of your lives as stars. But Sol, since you've already reached the last stage of your life and are the most experienced, I'll be directing most of the questions towards you.

SOL: Sounds good to me.

PAGE: Alright, let's get started. So, Sol, how old are you?

SOL: Many ages of those hotter, brighter stars like Apollo. I have orbited this galaxy 45 times. So, I'm 45 galactic years old.

PAGE: Well, let's put that in some perspective for our readers … 45 times around the galaxy? For someone living this far out in the galactic suburbs, that's about 10 billion years.

SOL: I prefer "45".

APOLLO: Whoa Sol, you're old! Using your galactic time-scale, I'm only like two weeks old!

KRONOS: Hey big guy, watch who you're calling old. I'm older than Sol. In fact I'm almost as old as the entire universe, about 80 galactic years.

PAGE: Wow Kronos, that's over 18 billion years.

KRONOS: Let's just say "80".

Act I: The Nebula

PAGE: So Sol, tell me about the beginning.

SOL: In the beginning? Oh, you mean my life and not the whole universe.
My memory is hazy for that time in my life. Like all stars, I was born in a giant gas cloud. The cloud was a vast cold clump of hydrogen, helium, a little lithium, and tiny bit of most everything else. A fragment of the cloud collapsed into a ball. As I shrunk, I got hotter and hotter.

PAGE: What happened to tip off this collapse?

SOL: There was just enough mass for gravity to pull it together against the outward push of atoms bouncing about. Throughout my life, I have been at the mercy of this balance between thermal pressure and weight. Oh, I could go on and on about this pressure I'm under.

PAGE: Hang on, let's talk about that balance.

SOL: Conservation of energy…the kinetic and potential energies balance

$$2E_K + E_P = 0$$

When I started to collapse, then the kinetic energy of the atoms no longer balanced the potential energy of the gas.

$$2E_K < E_P$$

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PAGE: But it's all just gas. It's not a liquid or solid. How can gas collapse?

SOL: Gas is matter. Matter (and energy) tells space how to curve, and space tells matter how to move. A very intelligent human that once lived on Earth said this – he was called "John Wheeler." Let me introduce you to Iana. She can tell you how a huge volume of gas can form a star.

IANA: Thanks Sol. Anyway, for a star to form, a huge mass of gas has to curve space enough so that the gas would rather move toward a central point instead of bounce around randomly. And by huge mass, I mean a few hundred times Sol's mass. Other interstellar gas clouds are even bigger!

APOLLO: Like the one that I came from!

Act II: Protostar

PAGE: (talking to Sol again) So as your size shrunk, you got hotter?

SOL: Yes. A lot like waking up, I suppose. As my density increased, my internal temperature had to go up. I was trading potential energy for kinetic energy.

IANA: To put it another way, the speed of the atoms zipping around increased. But as all the gas moved toward the same central point, the volume of the whole cloud decreased. You would think that as the temperature of the gas increased, the cloud would expand. But because there was so much gas, and the volume was contracting, the gravitational force won.

SOL: Thanks for the subtle foreshadowing there, Iana.

PAGE: So, how much time are we talking about?

IANA: Oh not very long – a moment in a star's life. 100,000 years, or less than half of a galactic year.

PAGE: Okay Sol, you are getting smaller and hotter. When do you become a star?

SOL: I was just a kid – it happened so fast you know. But I was getting hotter and hotter as I kept shrinking. It didn't seem like it was slowing down. I felt caught and unable to determine my own destiny, or even density.

PAGE: What about your luminosity – the energy you were releasing per second? Were you shining enough to be noticed?

SOL: Oh yes, I was young and bright for a time. My luminosity was huge – thousands of times more than when I became a star. I was also very big and felt bloated.

PAGE: With all these changes going on in your youth – the shrinking and the heating - did you feel stable at all?

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SOL: All stars enjoy their youth, but it was so turbulent. Sometimes, I wondered if I would ever reach hydrostatic equilibrium.

PAGE: "Hydro"- what?

SOL: Hydrostatic equilibrium: I stopped shrinking when the gas and radiation pressure balanced my weight throughout my interior.

PAGE: So that's the end of your protostar youth?

SOL: Not quite.

Act III: Life on the Main Sequence

PAGE: Sol, I'm starting to understand what a life you've had, and it has only begun! So far, you have aged only 13 million years, just about 1/20 of a galactic year. You were ready to become a star.

SOL: That was a day to remember. My core temperature had risen to 10^7 Kelvin. And then it happened. Quietly, it just happened.

PAGE: What? What happened?

SOL: Fusion. Hydrogen fusion. The temperature and pressure in my core rose so high that when two hydrogen atoms collided, a new atom formed - deuterium. The deuterium then interacts with more hydrogen atoms in a series of reactions called the 'proton-proton chain'. In the end, four hydrogen nuclei (protons) become one helium nucleus, 2 positrons, and 2 neutrinos.

PAGE: Wait, those two positrons did not last long in a core full of protons and electrons.

KRONOS: You're right. The positrons quickly found electrons inside the dense core. The positron and electron completely annihilated each other in a gamma-ray photon flash. And the two neutrinos just flew away.

PAGE: Oh, so that's where the energy comes from. What you're basically saying is that deep inside of you, gravity caused your temperature and pressure to be so high that it triggered a nuclear reaction?

KRONOS: Exactly. The reaction converts hydrogen into helium and also releases energy that heats up all the surrounding gas.

APOLLO: Eventually, the energy makes it to our photospheres where it escapes as light into interstellar space.

PAGE: Wait, so this has happened to all three of you?

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SOL: Yep, every stars begins its life in the same manner more or less. And as long as a star is fusing hydrogen into helium, it is considered to be a 'main sequence' star. Those are the good days of a star's life. I'm past that stage nowadays, but Apollo and Kronos are still there.

APOLLO: Right, and some stars got here more quickly and shine more brightly too, like me!

KRONOS: Yeah, yeah…keep bragging. I'm not impressed.

APOLLO: Whatever old man, you're just jealous because you're so small and dim.

KRONOS: (to Page) In my long life, I've seen thousands of stars like Apollo. Trust me, he won't be around for very long…his kind never are.

PAGE: I don't get it. If Apollo and Kronos are both main sequence stars, then how come they are so different?

SOL: Mass. Mass basically decides everything for a star, from how bright it is, to how long it will live, and even how it will end its life.

PAGE: Why is that?

SOL: When a star has more mass it will have a stronger gravitational field, especially in its core. More gravity means higher temperatures and pressure, and that affects the speed and type of nuclear reactions that can occur. More mass means more nuclear reactions and more energy.

PAGE: Okay, then how much do you weigh Sol?

SOL: Well, I've lost some weight recently, but when I was a main sequence star I weighed exactly one. One solar mass.

PAGE: And Kronos, what about you?

KRONOS: I weigh one-tenth of a solar mass, so 0.1

PAGE: Apollo?

APOLLO: Twenty-five solar masses! Booyah.

PAGE: Wow. Obviously we can't just put you guys on a scale to find out how massive you are. How might a distant observer figure out your mass?

SOL: There are several methods, some more complicated than others. But there is one very easy way to get a general idea of a main-sequence star's mass: Color.

KRONOS: Small red stars like me are usually the light weights.

SOL: Yellow stars like I used to be are the middle weights.

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APOLLO: And blue stars , such as myself, are the heaviest. We're the brightest too…I'm 30,000 times brighter than Sol was when he was a main-sequence star.

PAGE: Good to know. Well I think we've covered how stars grow up to get to the main sequence…let's talk about what happens after that.

SOL: That's where each star's evolution really starts to become different, again depending on our mass.

PAGE: Then let's just focus on you for a while Sol. I believe we left off where you were consuming enormous amounts of hydrogen during fusion…

SOL: Ah, alas. My hydrogen mass in the core slowly decreased until there wasn't enough going into fusion. Those photons carried the energy to my outer layers, excited the gas, and held up my weight. They kept me in hydrostatic equilibrium, you know: the outward push of gas pressure and radiation pressure (I'm really hot) balances the inward pull of gravity.

PAGE: Uh oh. Gravity didn't let go, huh?

SOL: No, it did not. It controls my fate. I'm trapped. So as my hydrogen mass fell, and my core temperature fell, I felt gravity's grip once more. I began to collapse again.

PAGE: Hang on; I'll get the Kleenex… I didn't think that finally fulfilling your life's ambition and reaching star-status would be so upsetting...

Act IV: Sol's Post Main-Sequence Life

PAGE: Did you notice anything as the hydrogen in your core got used up? Did you feel empty and unfulfilled? What happened next?

SOL: Remember, the hydrogen fusion process results in helium. So after 40 galactic years of fusion, a lot of helium remained. By that time, my core had mostly become helium, with only a shell of hydrogen still fusing.

PAGE: So, at that time, your core wasn't hot enough, nor dense enough, to begin fusing helium?

SOL: Not yet. As the helium core collapsed, its temperature and density increased to the point where the kinetic energy of helium nuclei collisions overcame electromagnetic repulsion. For the helium to stick and fuse, the core had to reach 10^8 Kelvin, ten times hotter than before.

PAGE: So, your core was getting hotter and hotter. What about the hydrogen fusion shell?

SOL: Oh, that just got hotter! The fusion rate went up, and my outer envelope of gas expanded. My outside layers were puffing up and my inside was collapsing at the same time!

PAGE: How awful and uncomfortable! How long did this last?

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He is Helium,
Be is Beryllium,
C is Carbon

SOL: About half a galactic year; that's 10^8 years in numbers. I just got bigger and bigger. At the end, I was back to my old protostar size and luminosity, but my interior was considerably different. My core kept shrinking, with its density and temperature increasing while the outer gas envelope just seemed to balloon away. I thought that I was just going to evaporate into space! I think it is time to meet another neighbor who is a bit older than I was at that time in my life. She has already experienced this transformation. Meet Minerva, a red giant.

MINERVA: Good to see ya up close Sol. I'm feeling queasy these days. I remember that stage at the beginning of my red giant phase when my outer layers were beginning to expand and my core was collapsing. Oh, I felt awful. Still do.

PAGE: So, at the peak of your expansion, what finally happened to your core?

SOL: Oh the drama continued. Finally, the core temperature reached 10^8 Kelvin and its density got up to 10^8 kg/m^3. Suddenly, the helium fused to ignite a "triple-alpha process":
Two helium nuclei collide and fuse to make beryllium and release energy:
He + He → (yields) Be + energy
Then, just before the beryllium breaks down, another helium collides and fuses with it to make carbon and release energy:
He + Be → (yields) C + energy

MINERVA: That ignition, or helium flash, released more energy than I had radiated over 30,000 years as a main sequence star. You might think that this ignition would of blown me apart. I just burped. The core was so compacted that most of that helium flash energy just kicked the motor on.

PAGE: Kicked what on?

MINERVA: Oh, I meant started up the helium fusion.

SOL: You paint quite a picture, Minerva.
Over the next moment, about 10^5 years, the core settled into stable helium fusion surrounded by a shell of hydrogen fusion.

PAGE: Did you lose any significant mass during this violent and brief time in your life?

SOL: Yes, these explosive core changes produced strong convection currents in my outer envelope that blew about 20 to 30 percent of it out into space. So, my outer envelope of gas got hotter.

MINERVA: Yep, I remember feeling like I was gonna hurl that whole time.

PAGE: The helium core consumed helium rapidly, because of the high temperature. Plus, you didn't start off with a lot of helium.

SOL: Only about 24% of my initial mass before this stage was helium. As a red giant, most of it was inside an Earth-size core. This triple-alpha fusion lasted only a few million years. But I had a burst or two left.

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PAGE: Yet another? When does it end?

SOL: I was out of helium in the core. My core was mostly carbon, surrounded by a shell of fusing helium, and an outer shell of fusing hydrogen. My inside was like an onion with lots of layers! The core collapsed further, with little to support it against its weight. Since it was so small and massive, the gravitational force was incredibly strong.

PAGE: So, the core and shells must have been even hotter this time?

SOL: Yes, it's amazing how the core changes in such short time. But its fusion days were limited. The hydrogen shell dumped helium ash onto the helium fusion shell. Then the helium shell dumped its carbon ash into the carbon core. This core continued to contract, which shrank the outer shells. And that just drove the temperatures up in the whole core. As a result, I bloated up again, into yet another red giant. I was huge, my outer atmosphere almost encompassed Earth's orbit.

MINERVA: I may look big and bright, but there's not much of me to go around. Look at me, I look big, but I've only got about 0.8 solar masses of gas in there.

PAGE: Well, finally all the available gravitational potential energy was spent. The fusion stops, leaving the carbon core. What happens next?

SOL: Just before the core went out, the outer envelope transformed into a beautiful sight. A series of helium fusion flashes destabilized the gas, and caused pulsations. The gas rose and fell a few times until finally, it rose fast enough and escaped. The gas shell rushed away from the core with a dazzling display of color – a planetary nebula.

PAGE: And the core stayed there, just to sit and cool?

SOL: That's it. And now, I have entered my second life. I am no longer a star, because I'm not shining by fusion. But at least I'm back in equilibrium.

MINERVA: Now you can retire and write a book. Bye y'all, I'm headin' back to the home star cluster, husband, and kids. I adopted a protostar. That boy is nearly as big as me! Hopefully, he will shrink down to star size and shine on his own before long.

Act V: Apollo and Kronos Post Main-Sequence

PAGE: So Apollo, we haven't heard from you in a while. What's in store for your future?

APOLLO: Me, I've got big plans of course. Just like Sol, I'm planning on fusing more than just hydrogen…a lot more. Because I've got so much mass and gravity, my core will be able to keep creating elements as the pressure and temperature go higher and higher. We're talking at least 3-billion Kelvin (3×10^9 K). Also like Sol, my size, color, and brightness will fluctuate as I quickly evolve past the main-sequence.

PAGE: What elements will you be creating?

APOLLO: Helium, then Carbon, Neon, Oxygen, Silicon, and Iron. At my peak, I'll be creating all of these at once; each one in a different shell. My interior will look like layers of an onion.

PAGE: Then what?

APOLLO: Then I'll explode in the biggest, brightest, most awesomest explosion in the universe: a Supernova! For a brief time I'll outshine the entire galaxy!

PAGE: Wow! After that I'd assume there would be nothing left of you.

APOLLO: Actually, I've got so much mass that there will still be a lot of me left over. And without the outward pressure from nuclear fusion, I will no longer be able to maintain hydrostatic equilibrium. Gravity will cause me to collapse into an infinitely small and dense point.

PAGE: Really? What will you be then?

APOLLO: Only one of the most exotic and overpowering objects in the universe – a Black Hole. Pretty impressive right?

KRONOS: Thankfully, one of the key characteristics of black holes is that no information what-so-ever can leave them, including bragging. It won't be very long until we don't hear from Apollo anymore.

APOLLO: It's sad but true. I'll be a black hole in less than a million years.

PAGE: That's a blink of an eye in astronomical time scales.

APOLLO: The blue star motto: "Live fast and die young."

PAGE: So Kronos, what are your future plans?

KRONOS: Well, not very much for a long, long time. I'll be fusing hydrogen for at least another six trillion years. I've got a long life on the main-sequence ahead of me. Even though I'm the oldest one here, I'm really just getting started.

PAGE: Six trillion years!? That's a six with twelve zeroes after it!

KRONOS: Yes, it almost seems like infinity, but there will be an end. Eventually I will fuse all my hydrogen into helium. And since I'm not massive enough to fuse helium, I won't have much of a post main-sequence life…I'll simply quietly collapse to become a white dwarf, kind of like Sol.

PAGE: What do you mean – "kind of"?

KRONOS: Well, I won't be going through any of the 'giant' phases, and in the end I'll only be made of helium.

SOL: And remember, I'm all carbon now. But we'll still both be called white dwarfs.

Act VI: Settling Down

PAGE: Do you like the name "white dwarf?"

SOL: I think that the name is misleading. Not all of us are white. That color only depends on our surface temperature. At this point in my life, mostly what I do is cool down and radiate light. And I'll continue to cool down until I eventually turn cold and dark, billions and billions of years from now.

KRONOS: When we get to that point, I guess you could call us "black dwarfs", though no such thing exists yet because the universe hasn't been around long enough for something like that to form.

PAGE: Red dwarfs and white dwarfs such as yourselves are the two most common types of stars in space right now, so I'm sure we'll be seeing a lot of black dwarfs in the far off future.

APOLLO: There's going to be a lot of black holes around too, though I wouldn't say you'll be "seeing" a lot of us.

PAGE: Well guys, that concludes our interview. Thank you very much and good luck with the rest of your stellar lives.

SOL, APOLLO, and KRONOS: Thank you!

Evaluation:

2) What term in astronomy describes the balance between the force of gas/radiation pressure and the force of gravity?

3) Describe the process of hydrogen fusion that happens in the cores of stars.

4) We met two different red stars in the play: Kronos and Minerva. What are three major differences between these two?

ANSWERS *(in bold italics)*

Evaluation:

…Question # 1 is on the very first page of the student guide…

1) Fill in the blank spaces in the table (either while you are reading or after you have finished):

Character	Color while on main-sequence	Mass while on main-sequence (in solar masses)	Life-time on main-sequence (in years)	Luminosity while on main-sequence (in solar luminosity)	Diameter while on main-sequence (in solar units)	Type of Star After Collapse
Kronos	***Red***	***1/10 (0.1)***	***6×10^{12}***	0.16	0.15	White Dwarf
Sol	***Yellow***	1	10^{10}	1	***1***	***White Dwarf***
Apollo	Blue	***25***	7×10^{6}	***30,000***	9	***Black Hole***

2) What term in astronomy describes the balance between the force of gas/radiation pressure and the force of gravity?

Hydrostaic Equilibrium

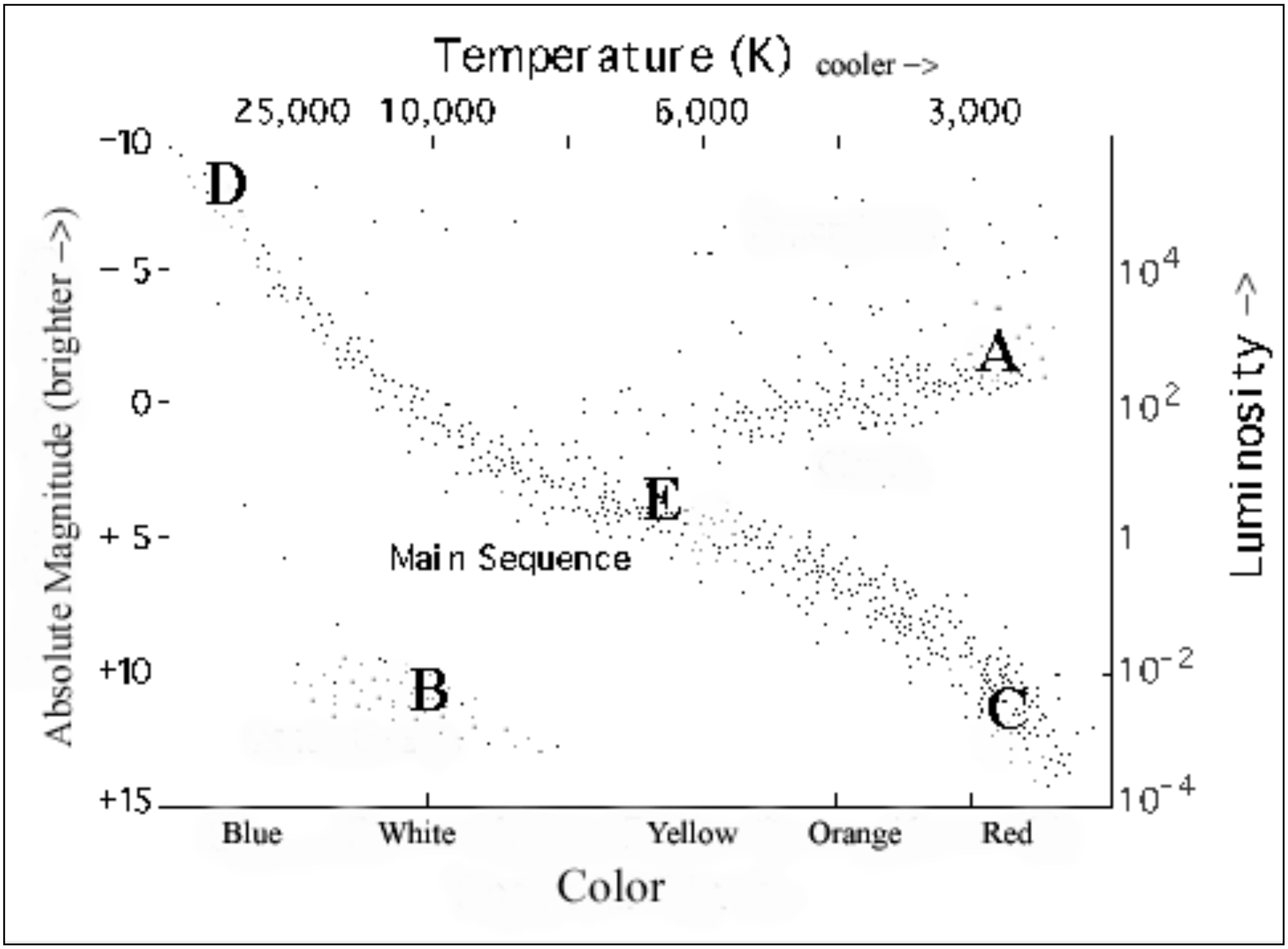
3) Describe the process of hydrogen fusion that happens in the cores of stars.

When the core temperature reaches 10^7 Kelvin, two hydrogen atoms collide to form a new atom – deuterium. The deuterium then interacts with more hydrogen atoms in a series of reactions called the 'proton-proton chain'. In the end, four hydrogen nuclei (protons) become on helium nucleus, 2 positrons, and 2 neutrinos. The positrons interact with electrons and both are quickly annihilated in a gamma-ray photon flash. The two neutrinos simply fly away.

4) We met two different red stars in the play: Kronos and Minerva. What are three major differences between these two?

Kronos is a red dwarf, Minerva is a red giant
Mass – Kronos is 0.1 solar masses, Minerva is 0.8 solar masses
Size – Kronos is small, Minerva is huge
Brightness – Kronos is very dim, Minerva is extremely bright
Temperature – Kronos is much cooler than Minerva
Longevity – Kronos is very old and will live for trillions of years, Minerva will soon turn into a white dwarf

5) Below is a Hertzsprung-Russell diagram which plots a star's color(temperature) vs. its luminosity(brightness). Each dot on the diagram represents an individual star. Main-sequence stars fall on the line that runs from the top-left to the bottom-right of the diagram:



On the diagram, write in the letter of each star in the part of the diagram where you think it belongs:

A) Minerva the solar-mass star that is now fusing helium in her core

B) Sol at the end of his life, after he collapsed

C) Kronos the small old star

D) Apollo the massive young star

E) Sol while he was fusing hydrogen in his core

NOTE: This is the version of Question #5 that is in the Student Guide. There is an easier version of this question on the last page of this Teacher Guide. You may choose to print or project the easier version for lower grade-level classes…

The answers for the easier version are: II, IV, V, I, and III

6) If you look at a distant galaxy and notice that it contains a lot of bright blue stars in its spiral arms and dim red stars in between the arms, where would you say that the most star formation is happening? Why?

Most star formation is happening in the spiral arms. Bright blue stars are very young and do not live for very long, so the presence of blue stars always indicates a very active star-forming region of a galaxy.

7) If you look at a distant galaxy and notice that it contains many dim red stars but almost no blue stars, would you assume that this galaxy has a lot of extra gas, or very little extra gas? Why?

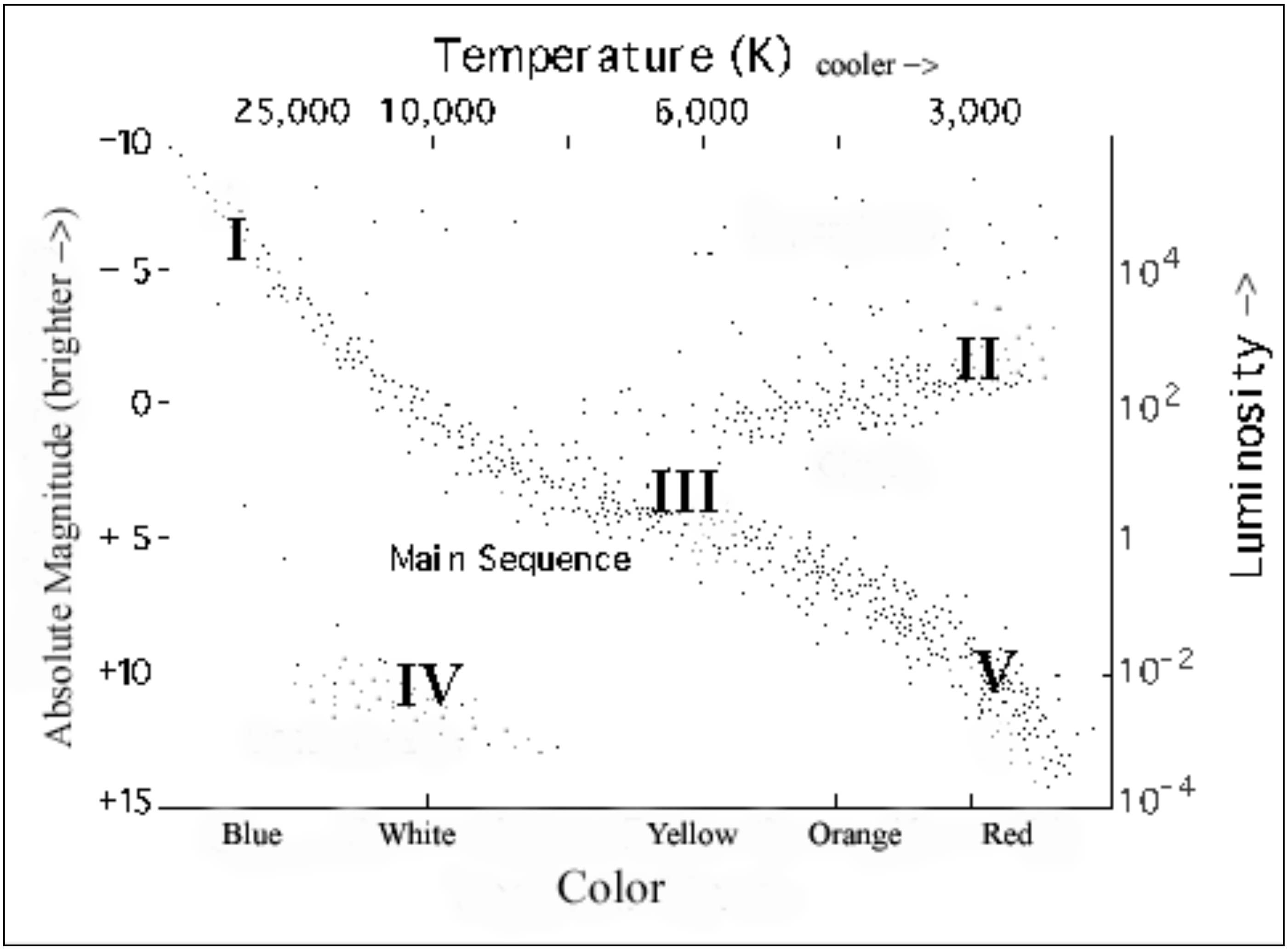
This galaxy has very little extra gas. Extra gas will produce new stars (blue stars). If there is no sign of new stars, then that likely means that there is not enough gas around to produce any more new (blue) stars.

8) Scientists are very interested in finding planets around stars that may be able to support intelligent life. Should they be looking around high-mass stars or low-mass stars? Why? (hint: most scientists believe that it takes billions of years for intelligent life to evolve.)

Low-mass stars would be the best candidates for having planets that support intelligent life, primarily because they have very long and stable lives – providing the conditions that are likely necessary to allow life to evolve. A blue star would not live long enough for one of its planets to be able to evolve intelligent life. The environment around a blue star would also likely be too intense, unstable, and violent for life.

Alternate Question #5

5) Below is a Hertzsprung-Russell diagram which plots a star's color(temperature) vs. its luminosity(brightness). Each dot on the diagram represents an individual star. Main-sequence stars fall on the line that runs from the top-left to the bottom-right of the diagram:



Match the character and their stage in their life cycle to their corresponding position on the Hertzsprung-Russell diagram:

Character/Star-type	**Roman numeral corresponding to Position on the HR diagram (I, II, III, IV, or V)**
Minerva the solar-mass star that is now fusing helium in her core	________
Sol at the end of his life, after he collapsed	________
Kronos the small old star	________
Apollo the massive young star	________
Sol while he was fusing hydrogen in his core	________