UNIVERSITY OF LOUISVILLE
CENTER FOR RESEARCH IN MATHEMATICS & SCIENCE TEACHER DEVELOPMENT

Classroom Embedded Assessment [CEA] Title: **Star Lifespan and Luminosity**

a. Targeted Performance Expectation(s)

HS-ESS1-1.
Develop a model based on evidence to illustrate the life span of the sun and the role of nuclear fusion in the sun's core to release energy that eventually reaches Earth in the form of radiation. [Clarification Statement: Emphasis is on the energy transfer mechanisms that allow energy from nuclear fusion in the sun's core to reach Earth. Examples of evidence for the model include observations of the masses and lifetimes of other stars, as well as the ways that the sun's radiation varies due to sudden solar flares ("space weather"), the 11-year sunspot cycle, and non-cyclic variations over centuries.] [*Assessment Boundary: Assessment does not include details of the atomic and sub-atomic processes involved with the sun's nuclear fusion.]*

Note: Aspects of this CEA (lifespan of stars, beyond only the Sun) also tie directly to a second PE;
HS-ESS1-3. Communicate scientific ideas about the way stars, over their life cycle, produce elements. [Clarification Statement: Emphasis is on the way nucleosynthesis, and therefore the different elements created, varies as a function of the mass of a star and the stage of its lifetime.] [*Assessment Boundary: Details of the many different nucleosynthesis pathways for stars of differing masses are not assessed.*]

Supplemental Information about Targeted Performance Expectation

Considerations (for both instruction as well as developing this CEA):

- The Sun is too long-lived compared to human lifetimes that we can't directly observe (get evidence) of the life span of the Sun, and so need to get evidence by getting data on a cross-section of stars across Milky Way which are at different phases of their lifespan (snapshots).
- The well-known model (classification system) for representing star lifespans is the Hertzsprung-Russell diagram (H-R diagram) which is a 2-dimensional plot of individual stars on a luminosity (amt. of light emitted from surface – 'brightness' in a sense) vs. temperature (color of star) scale. This model can serve as an organizer that students develop themselves over time and with instruction as a way to capture and represent star life-spans. This CEA will, for example, focus on just the "luminosity" aspect for now.
- Sections of the H-R diagram will be characterized by specific types of stars (e.g. giants, white dwarfs, main sequence)
- Star mass and luminosity are related. The more massive, the brighter (more - , and more energetic - , fusion happening)
- Massive supergiants (like Betelgeuse and Antares) have companion nebula clouds from mass they have expelled due to: high luminosity (energy pushing 'out'); and low surface gravity due to large distance of surface from core (e.g. if Betelgeuse were at center of solar system it would extend past asteroid belt, possibly Jupiter)
- Although it is estimated that 97% of stars in Milky Way galaxy will eventually become white dwarfs, relatively few have ever been found (about 2000 found by 1999; by 2006 the SDSS survey found about 9000 using highly-sensitive techniques). Students can make sense of this discrepancy (although likely very numerous, white dwarfs are very low luminosity and so hard to find with telescopes)

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b. Learning Goal(s)

1. Explain how we get evidence of stars' life spans when we can't watch a star go through it due to long (by human standards) lives.

2. Articulate the balancing pressures between inward-pulling force of gravity and outward-pushing force caused by release of energy via nuclear fusion

3. Develop initial model (a piece of H-R diagram, eventually) to represent range of star luminosity.

c. Instructional Context

Relatively early in the unit, since students will already be familiar with practices such as use of evidence, and what/why models in science are used for. After perhaps 1 or 2 days of tasks to orient them to the unit (e.g. exploration of variety of stars 'out there' in terms of what we see from Earth in terms of brightness, distance …. The unit can be introduced as exploring stars and what we know of them, with the first task simple exploration (e.g. website, texts, resources teacher gives them) which could be a common 'first-task' approach). Students will also need to be introduced to the concept of nuclear fusion – for now a simple perspective along the lines that, when forced together with enough energy, 4 hydrogen atoms can become fused into 1 helium atom, in the process releasing a LOT of energy. Connects to (presumably) earlier chemistry learning about structure of atoms and energy considerations – although it is unlikely that they would have considered energy 'tied up' in the nucleus and rather have focused on energy of electrons in chemical bonding situations.

d. Student Task/Prompt – *see end of document for handout distributed to students*

*NOTE: I recommend the teacher facilitating the first part of the CEA (the phenomenon establishing a storyline and purpose – see first page of student handout) together with the whole class – using question/answer; discussion; short video clips to illustrate aspects of the phenomenon contextualizing this unit; … or any other pedagogical approach to engage the students. Once the students are all familiar with the context of the upcoming task, then can let them individually or in small groups complete the CEA, starting by reading the story, "**The Supergenious Fruit Fly**." (on handout)*

- ***See Student Task Sheet at end.***

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e. Success Criteria

Exemplary student response:

1a). Collect data from many different stars, ideally at different points in their lifespan. This will give you information of what various stages of life might be like for a star.

> Should include the concept of cross-sectional sampling as an alternative to watching one individual (person or star) throughout an entire lifespan.

1b). Need to find a way to sequence the various stars from youngest to oldest, so that you can map out what happens in order during a star's lifespan.

> NOTE: Other responses possible. For example, could indicate that you need to know which characteristics of stars are important for influencing the lifespan. It turns out that star mass is a critical feature that leads to very different lifespan trajectories and ultimate outcomes.

2). The outward pushing force of the energy generated during nuclear fusion balances the inward gravitational pull. As the energy is generated at the core, it flows outward and eventually, after a long time, reaches the surface of the Sun and becomes part of the light and heat we see coming off the Sun every day. This outward flow of energy opposes gravity.

> NOTE: Other ways of characterizing this concept are acceptable. Primarily looking for the role of nuclear fusion happening at the Sun's core due to gravitational pressure, and then recognizing that this produces a force counter to gravity.

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3a). Groups can be in any order:

Sun Alpha Centauri A 51 Pegasi Tau Ceti	Betelgeuse Antares	Sirius B Procyon B G240-72

3b)

luminosity	
high	Betelgeuse Antares
	Sun Alpha Centauri A 51 Pegasi Tau Ceti
low	Sirius B Procyon B G240-72

3c) Compared to our Sun, these stars are all very bright, very large in mass and diameter, and are also by far the youngest stars.

These stars are all very similar to our Sun in brightness, mass, and diameter. There is some variation in their ages but all of the ages are pretty old.

Compared to our Sun, these stars are all very dim and very small, but have masses not so different from our Sun. For their tiny size, that means they must be very dense. Their ages varied the most of any group.

3d) **Group 3** (with Sirius B, Procyon B, and G240-72) varied most. **Luminosity** is the variable which varied most.

3e) Best…within the third group, the brightest (Sirius B, by close to 10 times) is also the youngest by far. This pattern holds for the middle brightness (Procyon B, about 10 times brighter than dimmest) which is the middle age, and the dimmest (G240-72) is also the oldest.

Teacher NOTE: White dwarfs (this category of stars) no longer have an internal energy source because they stopped nuclear fusion and collapsed on themselves – which explains the high density. Their brightness is a result of continuing glow from the leftover energy that is slowly dissipating over billions of years, so younger=brighter makes sense with less time to radiate away the residual energy.

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f. Next Instructional Steps

Depending on responses. Most students will probably be able to respond to #1a) based on analogy of fruit fly with people (you can add the language of "cross-sectional sample" for the students), some might have trouble with #1b) sequencing idea.

With 1b), it is unlikely that many will think about idea that some features of stars may determine DIFFERENT lifespans, and so can bring that idea to front by continuing the analogy with fruit fly/people. For example, if you know that some people do NOT have regular, reliable access to clean water and nutritious food (like in some parts of our world), then their lifespan will likely be different from others who do (can cite some longevity statistics of select countries).

2) The response you are only looking for the broad idea of outgoing energy supplying counterpressue. If available, a desktop radiometer (a device for sensing the flux of electromagnetic radiation – looks like a light bulb with a small spinning 'weathervan' inside) can be used to demonstrate the concept that electromagnetic radiation (e.g. energy from nuclear fusion) can create a 'pushing force.'

3a) likely mostly correct. Can have other students explain their reasoning if some did not get this.

3b) is simple ordering once 3a) is correct. *TEACHER NOTE: I've organized this vertically because that is H-R diagram orientation for luminosity, which this will eventually become as they add to it*.

3c) Some students have trouble writing what they can verbalize. If true for some of your students, perhaps suggest they first "say the answer" and then (maybe with phone?) listen to the recording and write from that. A scaffold to support them in communicating via written words.

3d) Potentially some could choose the middle group, which has some variation in age and a little in luminosity. If so, encourage an "order of magnitude" type thinking. Tau Ceti luminosity is only about half of Sun, and Alpha Centauri A is less than twice Sun. So luminosity varies by less than 2x either bigger or smaller than Sun for middle group. Likewise age, which varies less than 2x from Sun. By contrast, for 3rd group, the luminosity varied most because smallest-to-largest is in the vicinity of 100 times difference! Much bigger than 2x difference. Age for this 3rd group varied by about 20x from smallest to largest, which is more than any other group but still less than luminosity.

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3e) Answers will vary widely here, which is fine since you will plan to explicitly address this question. You simply wanted to stimulate students' first ideas. Your next instruction will help students to notice the age/luminosity relationship, and then help them to understand the radiative cooling cause of this relationship (perhaps with lab exercise that has them heating up some water with thermometer inside, and then documenting the falling temperature with time – creating a physical tabletop model of radiative cooling to understand the process in stars at end of their life). This exploration will lead directly to concept that these are "later stage" stars since they no longer produce their own energy, thus must come after in lifespan stage compared to stars which do still create energy.

Some students may notice the relationship present in the top group – very massive, large stars which are VERY luminous, but are also very young. Students can be guided to explain that relationship, also perhaps with lab bench physical model. You can do a teacher demonstration comparing the burning of a big ball of (loosely packed) toilet paper in an inflammable container (Pyrex? So they can see inside). Then burn a smaller ball of stacked cardboard. The TP burns bright, hot, and fast (doesn't "live" long) but the cardboard burns/smoulders more slowly, but lasts a lot long. Can be a useful analogy for considering how massive stars "burn hot, fast, and die young."

g. Student Work Samples

None

h. Reflection and Revision

None

NOTE: Student handout begins on next page

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Star Lifespan and Luminosity

Because our Sun is the foundation of all life on Earth, it has played a large role in humankind's thinking since prehistoric times. For example, some historic cultures thought of the Sun as a god of sorts, and all people paid attention to influences of the Sun such as day/night (for hunting, farming, various life activities) and temperature. Even today in a technological culture with artificial light and temperature-controlled living spaces, we think of how the Sun connects to big complex issues such as climate change or smaller personal decisions such as using sunblock or clothing to prevent skin cancer.

Although we know the Sun does vary sometimes, beyond Earth-related interactions such as weather that can make the Sun appear brighter or dimmer, or Earth's tilt in its annual orbit that can make the Sun feel hotter or colder at different seasons, the Sun itself tends to not vary too dramatically. Year after year, century after century, the Sun more or less goes on in a steady fashion with only small variations.

Which leads to us wondering… is the Sun basically static (unchanging in major ways) forever, or is there a pattern to how the Sun might change over many, many, many years. Connecting with how we know people change in systematic ways over years, from an infant, to a young child, to a teenager, to adult, to old age – we can outline in broad ways how this change across a person's lifespan is predictable, even though the details vary with every person.

What is the lifespan of our Sun? or more generally, What is the lifespan of stars?

GETTING EVIDENCE OF STAR LIFESPAN

Since the Sun (or other stars) don't appear to change dramatically from year to year, maybe it just takes longer? But how can we get evidence to understand a star's lifespan if we can't watch a particular star go through all of it during our own lifetime?

Let's explore how we might get that evidence by first considering a fictional story of …

The Supergenius Fruit Fly!

(*important fact: a fruit fly lifespan is approximately 45 days*)

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The Supergenius Fruit Fly

Once there was a supergenius fruit fly who was curious about lots of things. She was particularly curious about the large humans who were constantly in her space while she was busy in the tabletop fruit bowl trying to reproduce the next generation before her 45-day lifespan was over. She wondered, "*Do these large creatures stay the same forever, or do they also undergo regular changes over the course of a lifespan like I do*?" But in her noticings in the first 3 weeks of her life, which was now half over, she did not notice any big differences in the one person who kept checking the fruit bowl.

Thinking that maybe those changes happen over a much longer lifespan, she devised a way to get evidence to figure out what a human lifespan might be like. She observed many DIFFERENT people, and over a few days this is what she saw, and used this evidence to construct a lifespan of a human.

The End

(OK, so this story won't win any prizes…)

1. Explain how you can use this fruit-fly-technique to get evidence of stars' lifespans. Include:
   a) what types of evidence you would collect, and why? _____

   _____

   _____

   _____

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1b) In addition to the specific evidence you collect, what else is needed in order to describe a star's lifespan? _____

_____

_____

_____

One thing we know about most stars is that they are HUGE – over 1,000,000 Earths could fit inside the Sun, and our Sun is only a medium-sized star!

With all of that mass, that means gravity is also strong, especially inside the Sun when you are close to the core, with all of that mass being gravitationally pulled toward the core. But because the mass doesn't continue to be pulled directly into the Sun's core, there must be something 'pushing back' inside the Sun to balance out the gravitational pull.

2. What deep inside the Sun is balancing the strong inward-pulling force of gravity so that the overall Sun stays essentially the same size for a long time? *(Hint – it is related to the nuclear fusion idea we recently explored.)* Explain your thinking about how that works.

_____

_____

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_____

In addition to other possible evidence about individual stars that scientists might collect, one obvious and important feature is its **brightness**. The idea of 'star brightness' is actually a bit tricky since we have to collect that evidence from Earth – if a bright star were far away, it would look relatively dim. And, if a dim star were nearby, then it might appear bright in comparison to most other stars.

Scientists also have techniques for estimating distances of stars, and so knowing the distance lets us take the observed brightness from Earth and transform it into actual brightness of the star itself – as if you could see the star from right next to it. Rather than brightness, which can be an unclear term, astronomers usually use the term "***luminosity***," which is the amount of energy (or light) being emitted from the star's surface. Scientists are also able to get estimates of a star's mass by observing how it gravitationally interacts with nearby objects.

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In addition to luminosity and mass, astronomers can use that data plus other information such as a star's rotation rate (which varies at known rates depending on the age of a star) and light spectrum (which gives information about its composition) to compute an estimated age of a star.

Table 1 has data for a few select stars that the work of many astronomers over time have contributed to.

Table 1. Approximate Quantities for a few Select Stars

Star	**Luminosity** (in "solars" where 1 solar = luminosity of our Sun)	Approx. **mass** (in "solar masses" using mass of our Sun as reference)	**Age** (millions of years)	**Diameter** (in "solar diameters")
Our Sun	1	1	4,600	1
Betelgeuse	140,000	18	10	700
Antares	100,000	15	11	700
Sirius B	0.0025	1	250	0.008
Alpha Centauri A	1.5	1.1	5,500	1.22
51 Pegasi	1.3	1.11	7,000	1.24
Procyon B	0.00055	0.6	1,880	0.012
Tau Ceti	0.45	0.8	5,800	0.8
G240-72	0.000085	0.81	5,690	0.0098

3. As a first step for exploring possibilities for modeling the lifespan of the Sun, use the data in Table 1 to:

a) Arrange the 9 stars in Table 1 into 3 "mostly similar" groups (*put in boxes below*)

b) Order the groups by luminosity (lowest on bottom, highest luminosity on top) on the vertical axis (*next page*)

c) Write brief descriptions for each of the 3 groups, comparing how they are similar or different from the other groups (*next page*).

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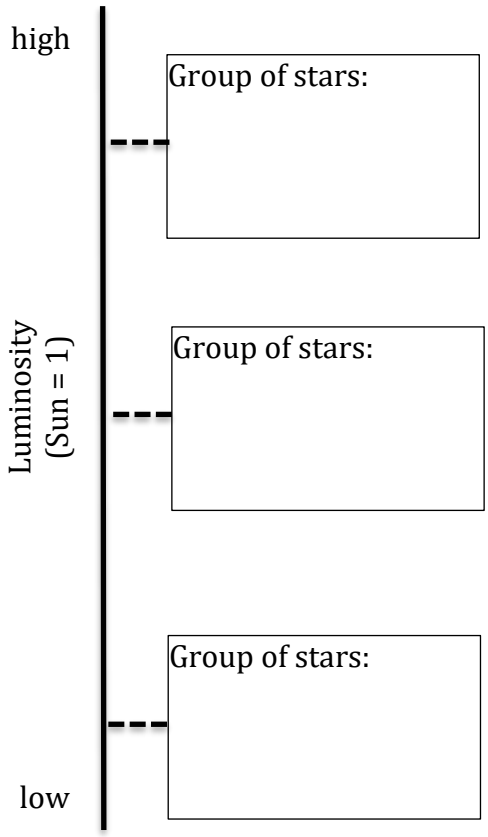
3b) ↓

3c) Description how similar/different from other groups ↓



_____
_____
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_____
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_____

d. For one of the 3 groups, one of the variables in Table 1 still varies quite a bit within the group. Identify which group and which variable ranges widely.

which group:_____ which variable:_____

e. Offer any thoughts, guesses, or questions that might help you start to explain why that one particular variable might vary so widely for this one group.

_____
_____
_____
_____

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