THE UNIVERSE IN THE CLASSROOM

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# Stellar Evolution (a la Chez Stella)

**by Michael Chabin**
The Urban School

At first, you are aware of nothing, nothing at all. It is dark. You are warm and comfortable -- *very* comfortable -- in a dark cloud...suspended somehow in outer space.

A warm breeze is passing gently over you. In the distance you hear a sound vaguely like chalk against a blackboard. It mingles with phrases from some strange language, phrases like "epleurslaw" and "lipsis swee pingorb ts...libdical...libdical." The words are indistinct and dull, incredibly dull, but they pass, and as they do, the cloud parts and you see over the edge of a galaxy's vast spiral arm and into the endless chasm of intergalactic space beyond.

Somehow it all seems as it should.

You are above the disk of the galaxy, high above the plane, though not so high as the top of the bulge at the center. There stars of a million different colors are so densely packed together and so unspeakably brilliant that you turn away from the sloping bulge and the spiral arm. Even without the structures' intense glare, your eyes take a moment to adjust to the vast scatterings of stars dazzling as diamonds on a sea of black velvet.

The strange dry mist continues to clear. The breeze is growing quite distinct. It is coming from a particularly dark patch ahead of you.

A waiter you hadn't noticed puts a menu on the table. Odd, you think, that you hadn't noticed that table before. And there is something vaguely fishy about the waiter.

"Excuse me," you say. "Is that wind I feel?"

"Oui," the waiter responds, "It is the stellar wind. The large star nearby is very bright. It is blowing this dust away quite rapidly. You should be able to see them all in another moment -- the big one first and then the others. But," he adds, holding his finger in the air for emphasis, "even though you'll see it first, I can assure you that all the stars in the cluster formed at exactly the same instant, and are exactly the same distance from this spot."

"And what do you recommend?" you ask, picking up the menu. "I think you'll find everything interesting. The largest star changes the most from start to finish, of course, and can be quite dramatic. The smaller stars take longer to develop, but there are those who prefer the subtlety."

He turns, distracted by a faint glow at the center of the dark patch from where the wind is blowing. "Ah," he smiles, "here they are."

The bright patch quickly turns orange and yellow. Details of the edge of the cloud begin to show clearly as it passes. A second later a gap appears and, just as the waiter predicted, you see a brilliant blue white star. It is alone for a moment, then joined in rapid succession by five other stars. Actually, not all of them are equally

brilliant. There is a faint red one you almost miss, and the smaller ones in general are a bit harder to see against the glare of the bright ones.

"And already, they begin to change," he adds, almost wistfully.

"They are beautiful," you say. "But I wouldn't worry about these stars changing anytime soon." There is a quote you half remember. It is from Shakespeare, perhaps, and about stars being eternal, but all you can think of at the moment is "who would fardels bear to make his peace with a bare bodkin," so you let the matter drop and look at what's offered in this interstellar cafe.


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There is something odd about this menu, you think. Something very odd. Baffled, you turn to the waiter. "I'm sorry," you confess, "but I'm new to this. Where I come from, menus are very different. Can you tell me what I should do?"

The waiter smiles. "But of course," he answers, "I wouldn't know how to order a hamburger." Then he looks carefully at the menu. "It is never easy. There is a saying: 'Always start with blues and follow with reds.' But everyone has different tastes. Some prefer small stars while others insist that the larger they are the better they are. I think, if I were you, I'd start with the largest and work my way through all of them."

You hesitate. There are no prices on the menu.

"Of course," he adds, sensing your concern, "you are the guest of Chez Stella. There is no charge."

"Then I'll do as you suggest," you smile.

"A 60-solar-mass star, type O5. Plump and ripe. An excellent specimen! Pity they don't last long." And as he speaks you seem to zoom towards the brightest star until you can easily see its shape. An apple from thirty meters would appear to be about the same size. No other stars are visible.

"How long do they last?" you ask.

"Four million years, maybe less."

"I'm afraid that's more time than I have."

"That is what this is for," he smiles confidentially, and pulls an enormous golden stopwatch out of his pocket and holds it up so you can see the handsome, old-fashioned face. "With this watch, I can compress any star's entire existence -- from the moment it starts burning hydrogen to the instant it dies -- into exactly sixty seconds."

You nod, wondering where you could get a watch like that. It would have been very useful on the blind date you had last Friday.

The waiter raises the watch. "Ready?"

You turn to the star. It is hanging alone in black and empty space. "Yes," you say softly.

Immediately you hear the "tock... tock... tock" of the stopwatch, and you gaze deep into the distant star. It is a brilliant blue, almost violet, like a blacklight at a party but more intense. From this distance it appears perfectly smooth. You blink. It dazzles and fascinates -- hard to look at but impossible to turn away from.

In spite of the waiter's claims, nothing seems to be changing. Maybe it grows a little brighter... maybe it turns a little less blue. It is definitely smoking. You hadn't noticed before, but it is giving off vast symmetric clouds of what looks like smoke or dust hanging in the space around the beautiful star.

Suddenly, after about 52 seconds, it reddens and inflates from the size of an apple to an enormous yellow-orange balloon eight meters in diameter. Then, just as suddenly, it collapses again into a hot blue core, leaving behind an expanding cloud of dust and gas. Something is clearly going on in the center, you think,

because it changes from orange to bluish white once or twice as it puffs larger and then collapses. It almost seems to be tearing itself apart.

The flash is so brilliant you could have seen it with your eyes closed. You blink, dazzled, and stare into empty space. You blink again and realize the star is gone. There is nothing left at all, except a vast, dense, and expanding cloud of dust or smoke.

"Is it gone?" you ask.

"In a sense, no," the waiter smiles. "About ten percent of its original mass is still there, trapped in a black hole. The rest has, as you see, been blown away by the supernova. It isn't a star any more. But, a lot of the material it has blown off will eventually mix with other dust and gas and eventually end up in another star - though probably not so large as this was." He pauses a moment, thinking. "Or it could end up as a planet, or in a person. After all, the oxygen in you came from a supernova like this one."

"The oxygen in me?" you start to ask, but he has already turned to the second star.

"This one has 25 solar masses and you'll see about seven million years of evolution in one minute." The dust and debris from the first star disappears and is replaced with a bluish white star about the size of a golf ball seen from thirty meters.

"Tock... tock... tock..." you hear as you concentrate. It eventually seems to get a little brighter and maybe a little bigger. It smokes some in those nice symmetric puffs you saw the first time. Then, in the last six seconds it too puffs up, until it is a deep-red sphere maybe eight meters across. "How much of it is getting blown into space?" you ask.

Before the waiter can answer, the star dies in a brilliant flash that is indistinguishable from the death of the first star.

You blink, dazzled into silence for a moment, but soon the questions come flooding back. "Was it doing the same thing the first one did? Was it changing color in the beginning? Did it get brighter? And was it getting bigger?" you try to ask all these questions and more, but the waiter doesn't seem to hear. He has already started the clock.

This one is twelve times as massive as the Sun and looks about three centimeters across from where you are. It remains unchanged for about ninety percent of its life. Suddenly it balloons into a deep-red ball more than five meters in diameter. Then, almost as if the balloon had popped, it collapses and turns blue for several seconds. Finally, it expands, turns red, and dies in a terrible flash.

"That little gleam left over is a neutron star," the waiter says, but before you can get a really good look, the debris disappears and is replaced by a new star. And the clock is already ticking.


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Everything is faster now. You try to stop him to ask questions but you have no chance. He's talking faster and faster and going through stars one after another.

Stars number 4, 5, and 6 behave a lot like the first three, though they are not as big or as bright. They still turn red and puff up at the end of their lives, but they don't get nearly as large. None of them die in a flash. Instead they create huge shells of gas and dust that slowly expand. All they leave behind are tiny white dwarfs with no fuel left to burn. These will hang endlessly in space to cool into dark lumps of matter.

"I don't understand," you ask when the last one is finished. "They seemed to change color, brightness, and size all at the same time. Are those things related?"

But there is no answer. You look around. The waiter is no longer there. You start to call out, but, looking around, you change your mind. The table is gone too, and the stars, and the warm wind. You are hot and it is very quiet. Something seems very familiar. You open your eyes and blink.

The classroom is empty. The clock shows 4:00 p.m.

"Rats!" You say to yourself. Your notebook is open and you can see in your own handwriting scribbles on Kepler and planet orbits and... That is where they stop. "I'll never learn any astronomy this way," you think as you begin to pack up your books to leave.

That is when you notice the menu. Tucked neatly beneath your notes is a familiar menu. On top it says "Chez Stella -- Serving the Stars for 15 Billion Years." On the left is a description of every star you saw. The right side is labeled "Tasting Notes." It contains three carefully drawn graphs labeled "Evolution of the Sun," "Evolution of a 25 Solar Mass Star," and "Temperature Changes in Six Stars." Attached is a note written in the waiter's neat hand.

*Bonjour -*

*I regret there was so little time to answer the many excellent questions you had. Some dreams are like that. I believe you'll find the answer to your and many other questions in the graphs given under "Tasting Notes." As you look them over, you may want to remember that the color of a star depends entirely on its temperature. The hotter a star is the bluer it looks, and the cooler it is the redder it looks.*

*A Bientot, M. Poisson*

*P.S. Should any other questions occur to you, remember you are always welcome at* Chez Stella.

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### References

The stellar models used here came from two separate sources. Both are available via the web from the Strasbourg (France) Data Center.

Schaller, G., et al. 1992, Astronomy and Astrophysics Supplements Series, vol. 96, pg. 269. (at URL vizier.u-strasbg.fr/cgi-bin/VizieR?-source=J/A+AS/96/269)

Charbonnel, C. et al, 1996, Astronomy and Astrophysics Supplements Series, vol. 115, pg. 339 (at URL vizier.u-strasbg.fr/cgi-bin/VizieR?-source=J/A+AS/115/339)


# Stellar Evolution (a la Chez Stella)

**Menu**

## BIENVENUE A CHEZ STELLA

(Serving the Stars for 15 Billion Years)

### Type O5

An extremely rare, deep-blue star with an explosive finish, this one begins life with sixty times the mass of the Sun and is a half million times brighter, but over the short course of its life, it loses more than eighty percent of its mass. It will become a supernova barely four million years after it starts burning. To put that in an Earthly perspective, humans split from chimpanzees only about five million years ago.

### Type O7

Another one for those who like it hot. This 25-solar-mass star is reminiscent of those peppery dishes from the southwest, but keep your eye on this one. It only lasts about seven million years (horses have been around longer) and can produce a black hole.

### Type B0

Light blue with nuances of white, a 12-solar-mass star lasts about eighteen million years (the Himalayas are less than ten million years old), but retains enough punch to keep its end exciting. Its supernova is indistinguishable from that of larger stars. Neutron-star aficionados take note: this star produces a nice one.

### Type B8

Brilliant white, a 3-solar-mass star lasts 440 million years, long enough to develop character. (The first plants crept onto Earth's continents about 420 million years ago.) It also has an interesting finish, producing a series of fascinating dust shells followed by a nice white dwarf.

### Type F0

Here is a slight variation on a familiar theme. Light yellow, it is only one and a half times the mass of the Sun, but what a difference that makes. It will live only three billion years, a third as long as the Sun.

### Type G4

This has to be everyone's favorite star. Deep yellow with orange undertones, this star lasts long enough to develop character, but its finish will be more than enough excitement for any of our descendants around to see it happen. It is the longevity champion of our sample. It will last about twelve billion years.


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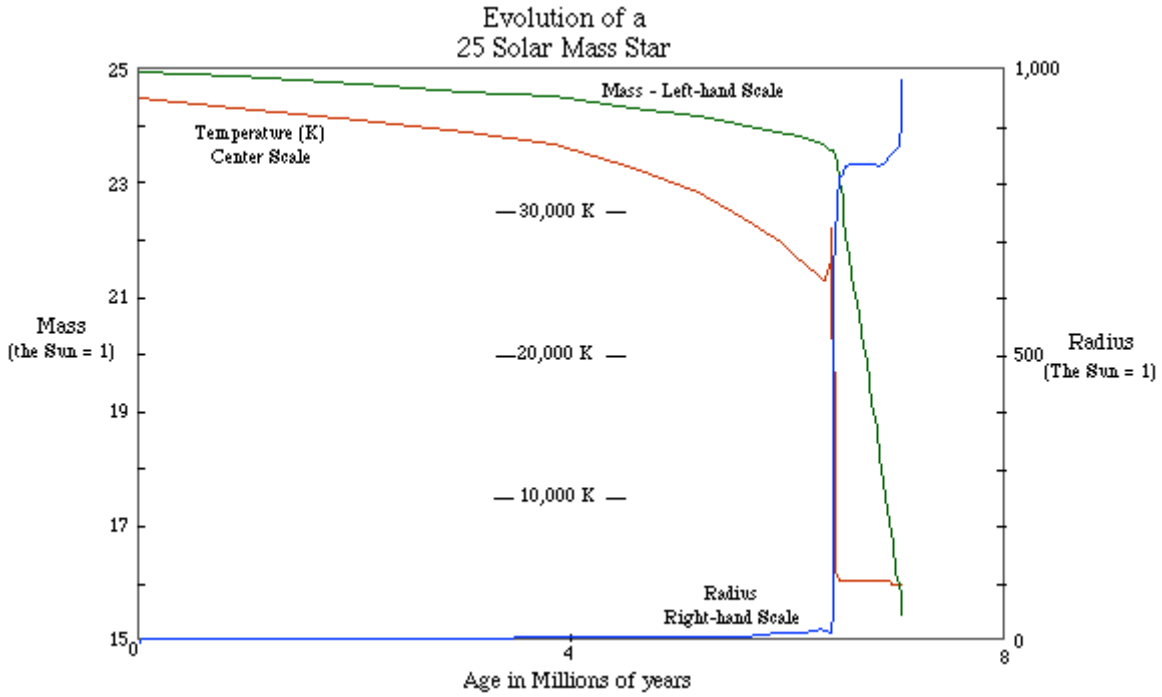
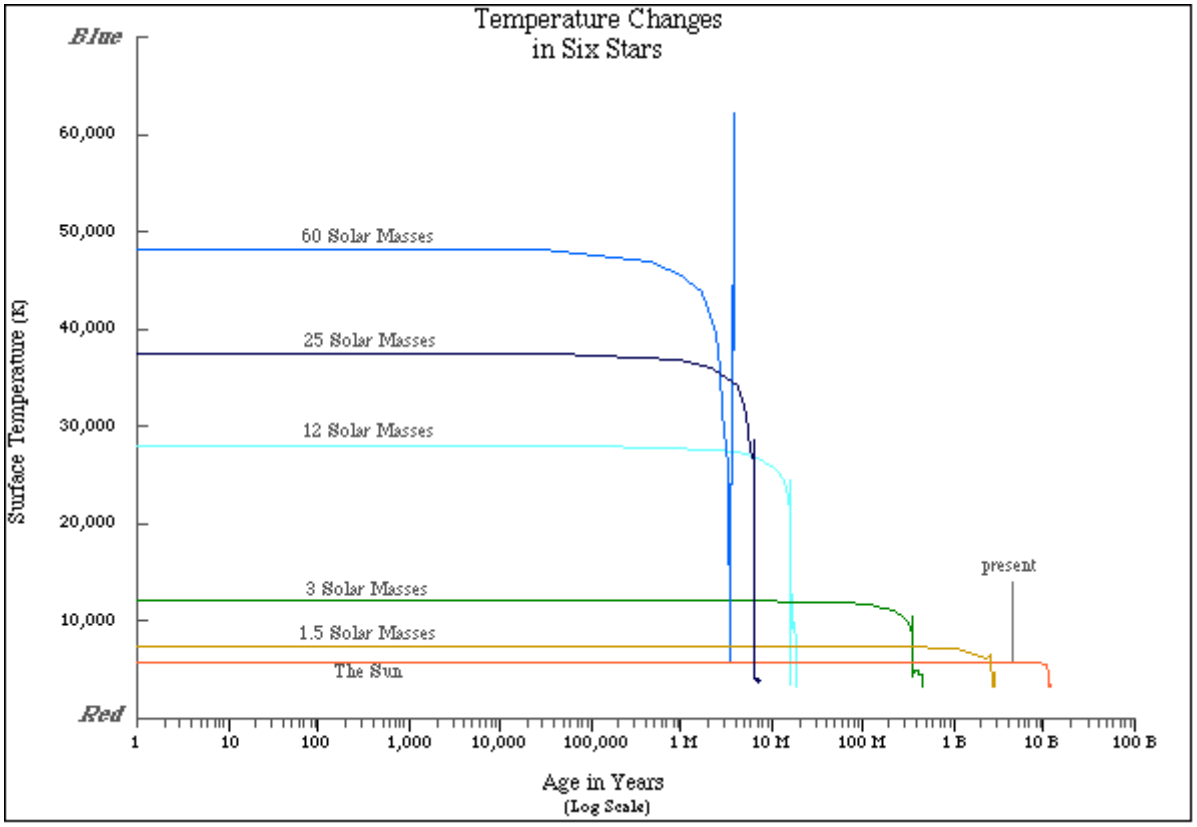
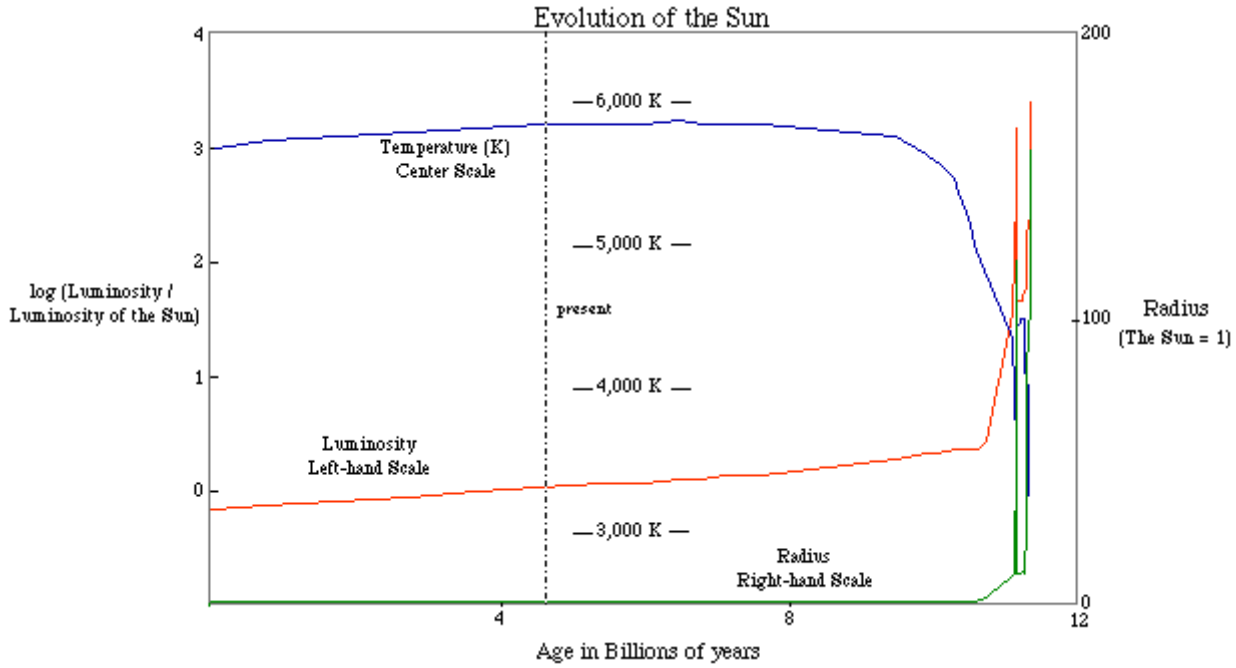
### Tasting Notes

*Plots courtesy of the author, Michael Chabin*




Temperature Changes
in Six Stars
Blue
Red
Surface Temperature (K)
60,000
50,000
40,000
30,000
20,000
10,000
60 Solar Masses
25 Solar Masses
12 Solar Masses
3 Solar Masses
1.5 Solar Masses
The Sun
present
1
10
100
1,000
10,000
100,000
1 M
10 M
100 M
1 B
10 B
100 B
Age in Years
(Log Scale)


Evolution of the Sun
log (Luminosity /
Luminosity of the Sun)
4
3
2
1
0
6,000 K
5,000 K
4,000 K
3,000 K
present
Temperature (K)
Center Scale
Luminosity
Left-hand Scale
Radius
Right-hand Scale
200
100
0
Radius
(The Sun = 1)
4
8
12
Age in Billions of years