AST 301
Introduction to Astronomy

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AST 301 (Lacy), course website

Topics for this week

How do we use the Hertzsprung-Russell diagram to make sense of the temperatures and luminosities of stars?

Describe the life stages of a low-mass star, like the Sun.

Use the HR diagram to show the evolution of a low-mass star graphically.

What happens inside of a star that makes it change from a main-sequence star into a red giant, then a planetary nebula and a white dwarf?

How do the life stages of a high-mass star differ, and why?

Describe the two types of supernovae

Temperature-Luminosity diagrams

Astronomers measure the temperatures and luminosities of many stars and plot them on a diagram called the Hertzsprung-Russell (or H-R) diagram.

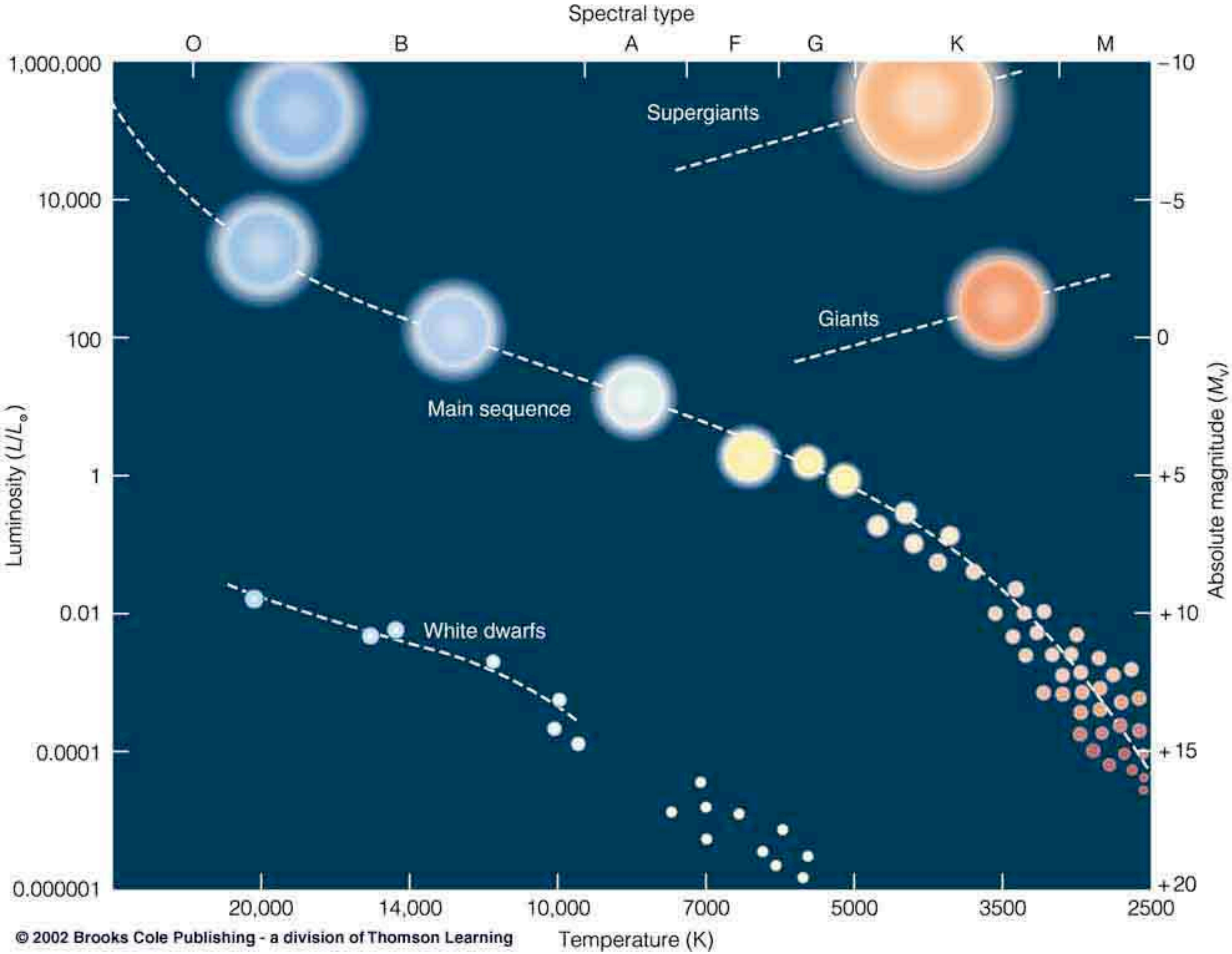
The horizontal axis is surface temperature and the vertical axis is luminosity.

Each star is a dot on the diagram.

For historical reasons they plot temperatures increasing to the left (not right) and luminosities increasing upward.

They also sometimes plot colors instead of temperatures and absolute magnitudes instead of luminosities.

They find that stars cluster in 3 groups.


Spectral type
O
B
A
F
G
K
M
1,000,000
10,000
100
1
0.01
0.0001
0.000001
−10
−5
0
+5
+10
+15
+20
Supergiants
Giants
Main sequence
White dwarfs
Luminosity (L/L⊙)
Absolute magnitude (MV)
20,000
14,000
10,000
7000
5000
3500
2500
Temperature (K)

Star survey results

Many stars fall on a diagonal line running from the upper left (hot and luminous) to the lower right (cool and faint).

This group is called the main sequence.

The Sun is one of these stars.

But some fall in the upper right (cool and luminous) and some fall toward the bottom of the diagram (faint).

What can we say about the stars in the upper right?

What can we say about the stars toward the bottom?

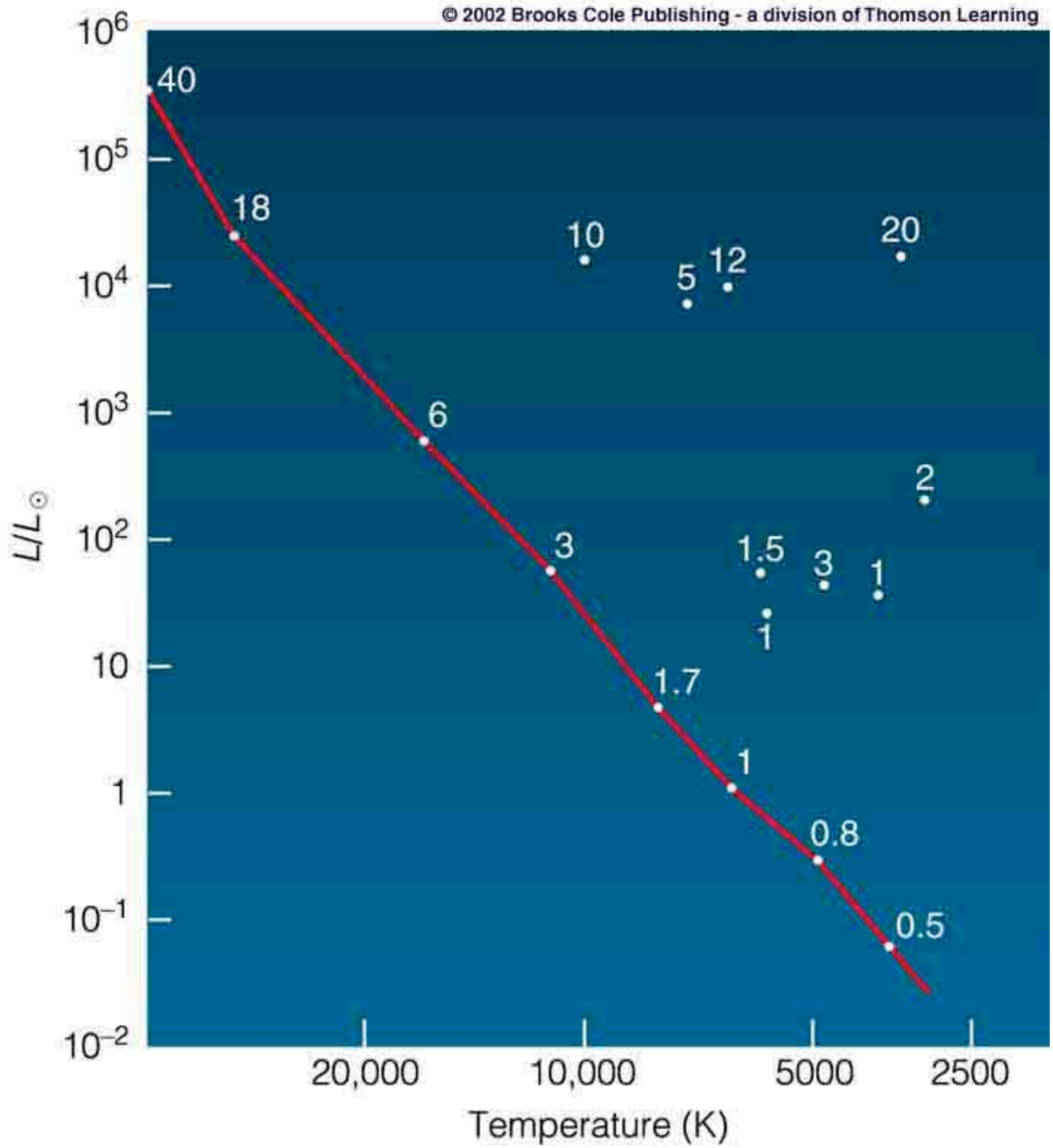
If all stars had the same size, what pattern would they make on the diagram?

Mass – Luminosity Diagram

We can plot the masses and luminosities of stars on a diagram like the H-R diagram.

Red giant and white dwarf stars follow no pattern, but main sequence stars fall along a line with luminosity increasing with mass.

Masses of stars on the H-R diagram



Groups of four

Choose a discussion leader and a scribe.

Read the graph:

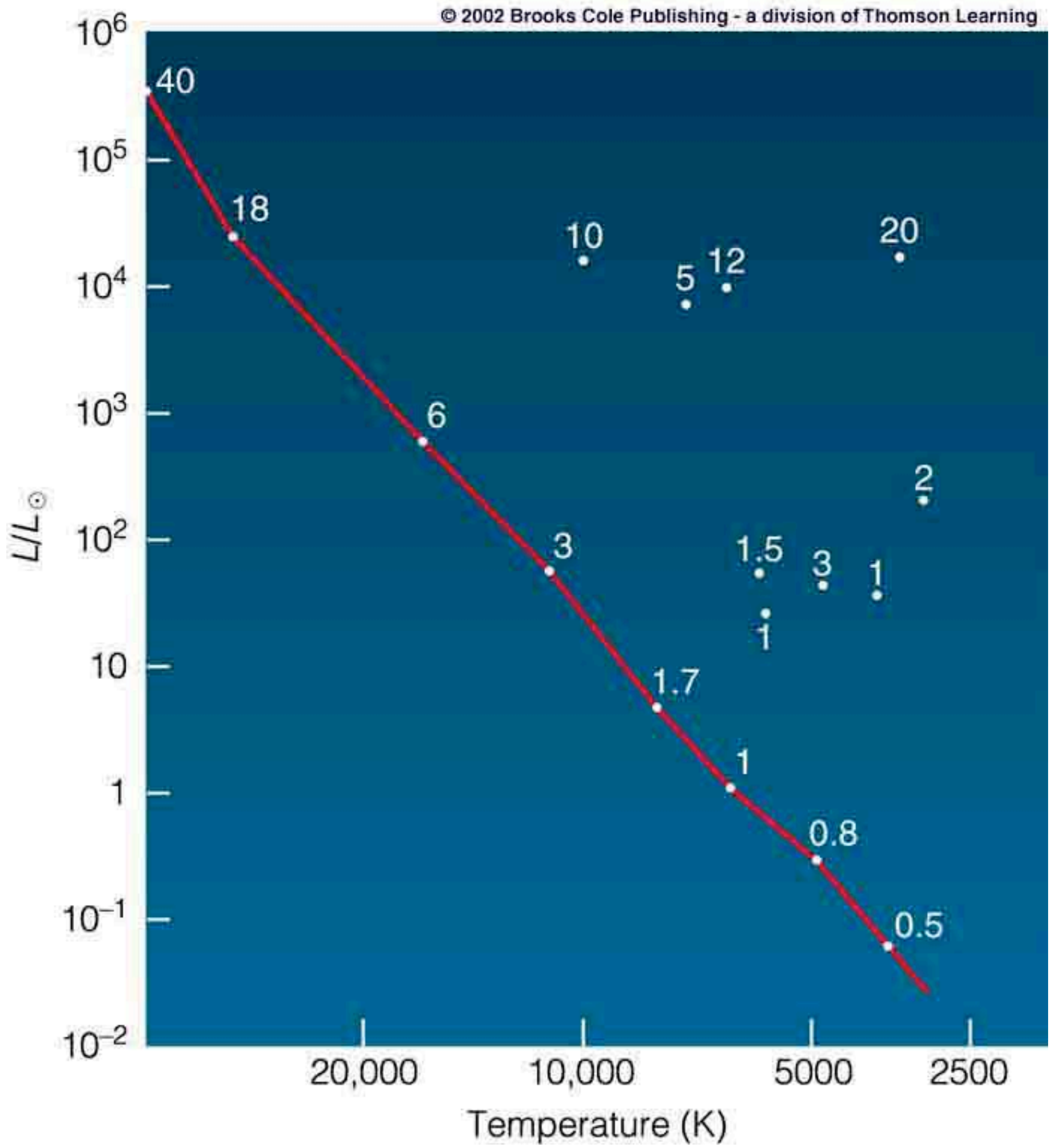
What is the luminosity in solar luminosities of the Sun?

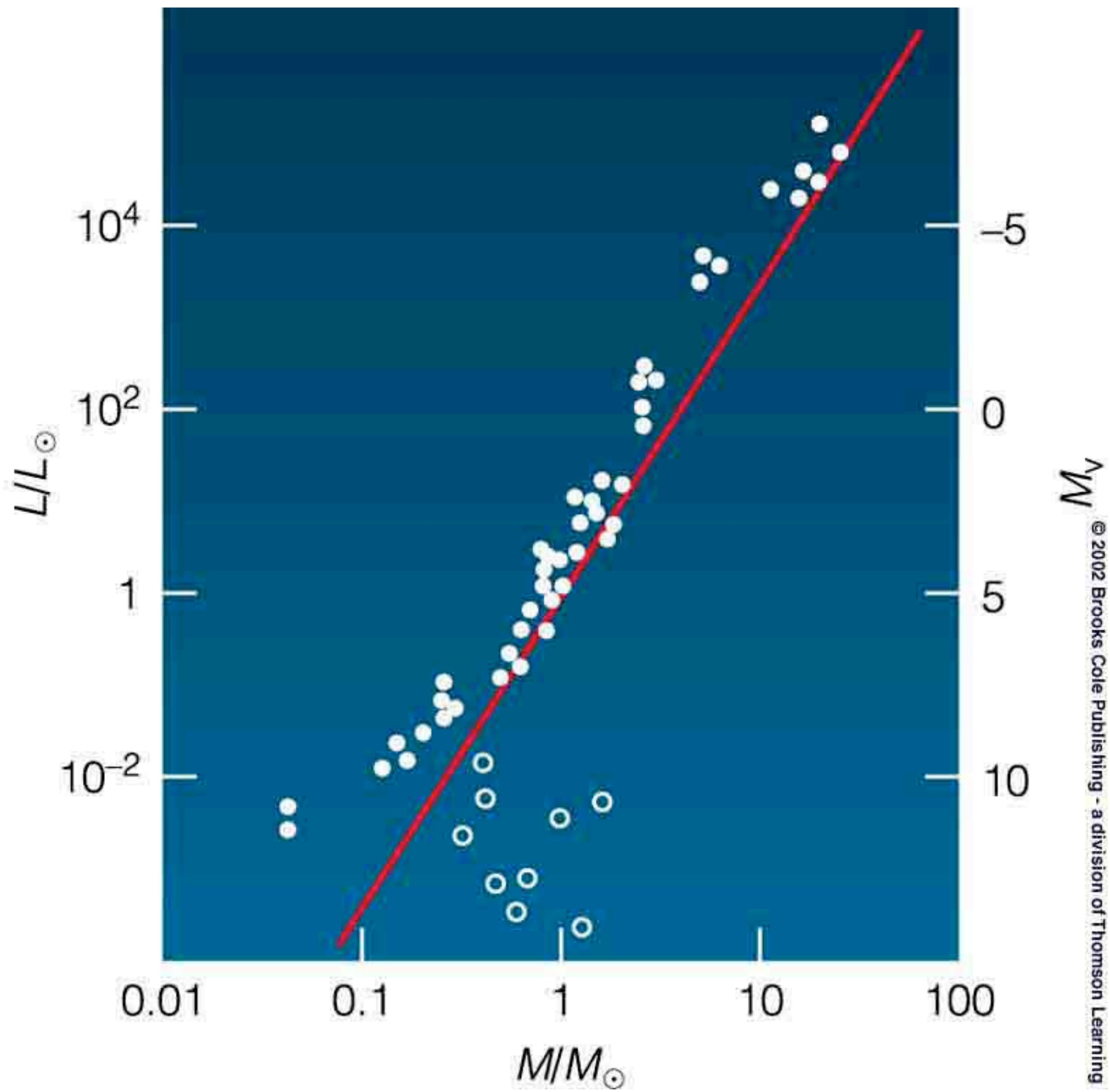
What is the luminosity of a 10 solar mass main sequence star? (Make an estimate.)

What is the relation between mass and luminosity?

L α M^x

What is x? (Make an estimate.)





10^4
10^2
1
10^{-2}
$L/L_{\odot}$
–5
0
5
10
M_V
0.01
0.1
1
10
100
$M/M_{\odot}$
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Equilibrium in stars

Main-sequence stars are in equilibrium in two ways:

Hydrostatic equilibrium means that the pressure of the gas inside of a star (which tries to make it expand) balances the force of gravity (which pulls one side of the star toward the other, and so tries to make it contract).

The result is that the size of the star doesn't change.

Thermal equilibrium means that the loss of energy by radiation of light balances the generation of energy by nuclear fusion.

The result is that the temperature inside the star doesn't change.

Stable and unstable equilibrium

An equilibrium is stable if a small change in one of the balanced influences will change the situation by only a small amount.

For example, heating a balloon will make the pressure of the air in it increase. As a result, the balloon will begin to expand. But that will cause the pressure to drop, so it will stop expanding.

An equilibrium is unstable if a small change in one influence causes a large change in the situation.

A stick of dynamite is unstable.

Are stars stable or unstable?

What would happen if some gas were added to a star so its pressure increased?

It would be out of hydrostatic equilibrium and would expand.

But when a gas expands its pressure decreases, so after expanding a little bit it would again be in equilibrium.

What would happen to a star if the rate of nuclear fusion increased so it was generating energy faster than it was radiating it from its surface?

You would expect it to get hotter.

That would make it radiate more, but it would also make nuclear fusion go faster, and fusion would increase more than radiation, so the star would get even hotter.

Quiz

If a spaceship is orbiting the Sun and it is given more energy, what happens?

A. It goes into a smaller orbit in which it goes faster.

B. It goes into a smaller orbit in which it goes slower.

C. It goes into a bigger orbit and speeds up.

D. It goes into a bigger orbit and ends up going slower.

Quiz

If a spaceship is orbiting the Sun and it is given more energy, what happens?

Like a spaceship, the atoms in the Sun are held in by gravity, but don't fall to the center because they are moving.

If the atoms in the Sun were given more energy, the Sun would expand and the atoms would move more slowly.

Adding energy to the Sun would make it bigger and cooler.

Removing energy from the Sun would make it contract and heat up.

Thermal Equilibrium in Stars

Protostars are not in thermal equilibrium.

They lose energy by radiation from their surfaces, but they aren't hot enough inside to ignite nuclear fusion to replace the lost energy.

As a result, they contract and heat up.

Once they are hot enough inside (about 10^7 K) fusion can replace the energy they are losing.

They are then in a stable thermal equilibrium; if fusion slowed down, they would contract and heat up causing fusion to speed back up until it balances the energy they are losing.

Because of this stable equilibrium, the Sun will hardly change for 10^{10} years, until it uses up all of the hydrogen in its core.

Quiz

If a star (or a part of a star) radiates more energy than it generates, it will …

A. contract and heat up

B. contract and cool off

C. expand and heat up

D. expand and cool off

Becoming a Red Giant

(The complete explanation for how a main-sequence star becomes a red giant is complicated, and I'm not really giving you the whole story. But the conclusion is right. Don't worry if you don't follow all of the explanation.)

When all of the hydrogen in the core of a main-sequence star is all turned into helium, fusion will stop in the core, and the core will contract and heat up.

Fusion will continue in a shell around the helium core, and will generate more energy than fusion in the core did.

The extra energy going out from the core+shell will make the envelope expand and cool off.

Red Giants

When the Sun becomes a red giant, its radius will increase to about ½ AU, and it will become more than 100 times more luminous than it is now.

Life will not be pleasant on Earth.

The core of the Sun will be mostly helium, and will continue to contract and heat up.

When the temperature in the core reaches about 10^8 K (about 1 million years after the Sun leaves the main sequence), helium will begin to fuse to make carbon.

A Red Giant with helium fusion

When helium fusion starts generating energy in the core of a red giant, the core expands and hydrogen fusion in the shell around the core slows down.

As a result, less total energy is being generated, and the envelope contracts and warms up some.

But pretty soon all of the helium in the core is converted into carbon and fusion stops again in the core.

Then the core again contracts, surrounded by two shells, one with He → C fusion, and one with H → He fusion.

The envelope again expands and cools off.

Display stellar evolution with the HR diagram