ESS 200
Notes: HR Diagrams, Doppler, and The Big Bang

Name: _____Key_____

Jets, etc.

**Part 1.** Hertzsprung-Russel Diagram

0. What is the point of an HR diagram? What is *luminosity*?

Brighter

Energy from Electromagnetic waves (similar to brightness)

Dimmer

our Sun (white medium-sized)

Supergiants

Giants

Main Sequence

White Dwarfs

red dwarfs

Luminosity (L_{sun}): 10^6, 10^4, 10^2, 1, 10^{-2}, 10^{-4}

Temperature (K): 40,000, 20,000, 10,000, 5,000, 2,500

Hotter ← → *Cooler*
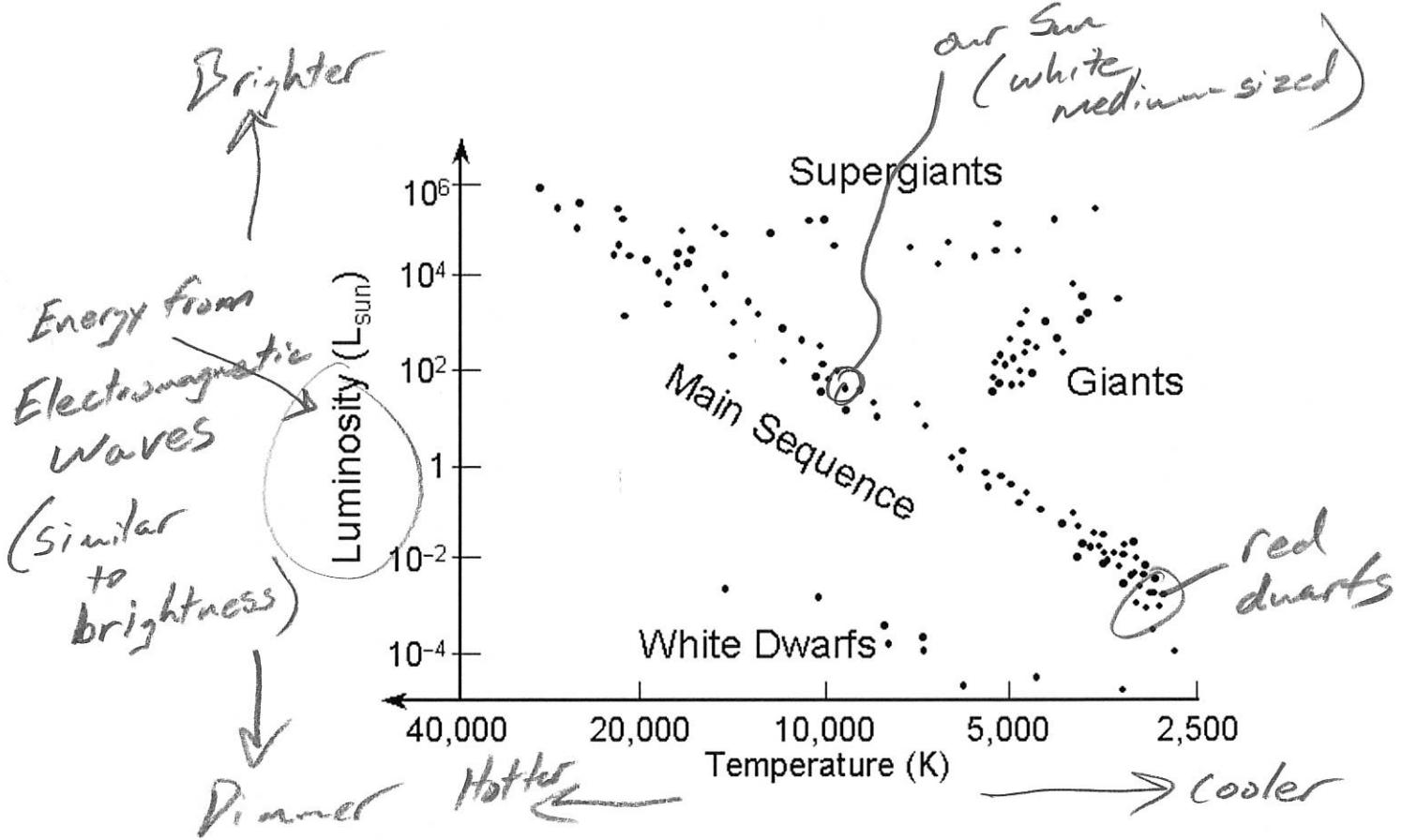
Part 2: The Doppler Effect:

1. Draw some sound waves that are being created by noisy people whose voices have different pitches.

Higher Pitch   Lower Pitch

waves more spread out
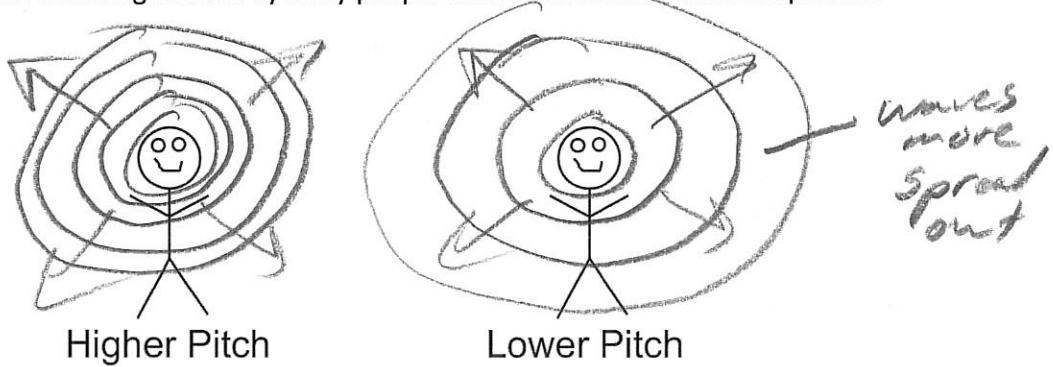
2. **Frequency** is the number of waves that reach a listener each second. The units are Hertz (Hz). 1Hz equals one wave per second.

3. When frequency is higher, pitch is (higher or lower).

4. Show what sound waves look like when they are created by the horn of a car that is moving to our right.
5. Which listener in the diagram will hear a higher frequency sound?

Low frequency

B will hear a higher Pitch

A
hears low pitch

High Frequency
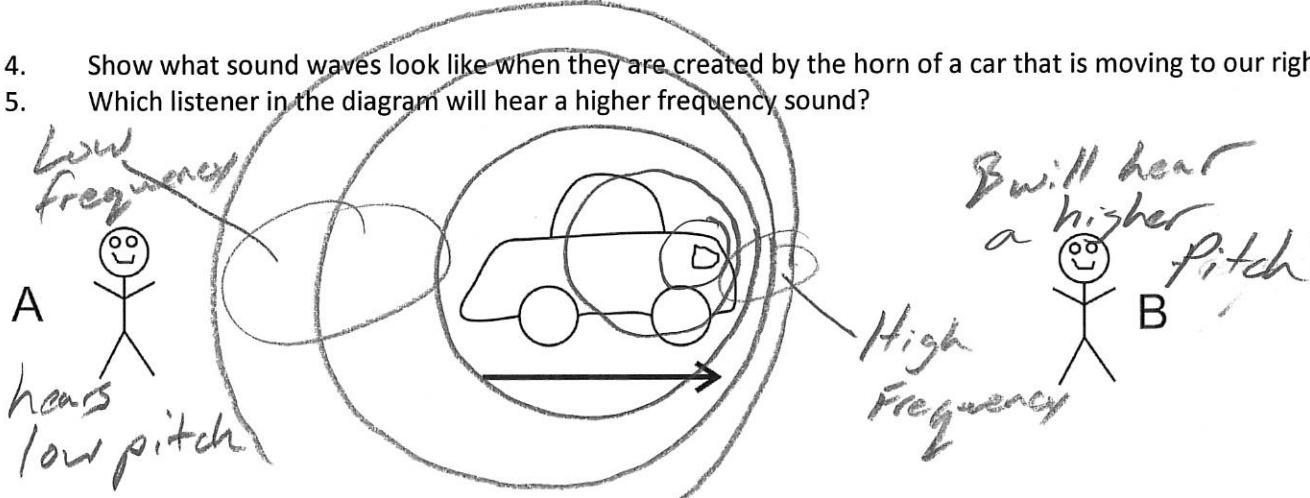
6. Show what sound waves look like when a car is honking its horn and traveling at the speed of sound.
7. Label a place where you would need to stand in order to hear a sonic boom.

Sonic boom where waves "pile up"
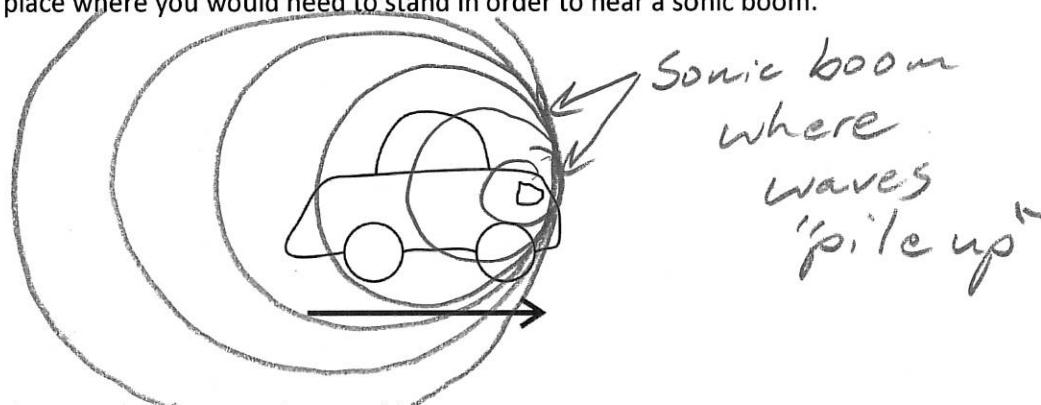
8. Draw light waves leaving a stationary white star

sees white

Sees white

A

B
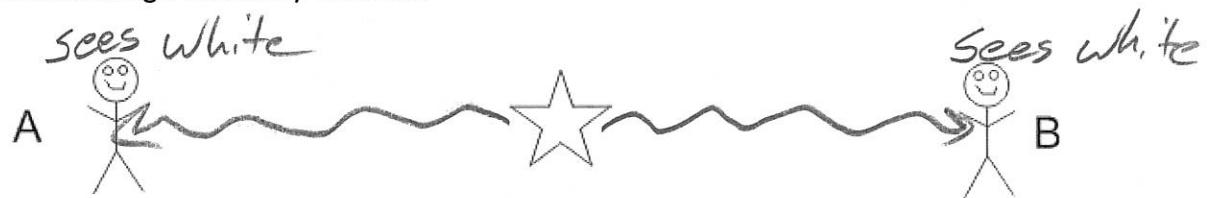
9. Draw light waves leaving a white star that is moving to the left.
10. Label the person who sees a slightly bluer version of the star. Label the person who sees a slightly redder

waves compressed

Waves stretched

A

B

Sees bluer light

Sees redder light
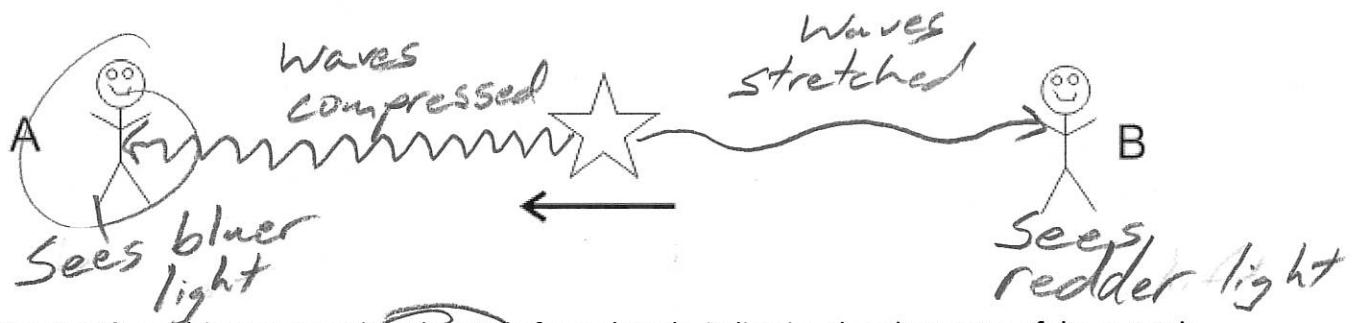
11. A **red shift** is a (shortening or lengthening) of wavelengths indicating that the source of the waves is getting (closer to or farther from) the observer. A **blue shift** is a (shortening or lengthening) of wavelengths indicating that the source of the waves is getting (closer to or farther from) the observer.

Part 3: The Big Bang

12. How long ago did the Big Bang occur? (i.e. what is the age of the universe)

13.8 billion years ago

or round to 1×10^{-34} m

13. How big was the Universe at the first moment of the Big Bang?

Smaller than a Planck Length (1.6×10^{-35} m)

14. Big Bang Timeline:

a. What happened during the first few seconds after the Big Bang?

- The Universe expanded rapidly
- Hydrogen an helium formed

b. What was the temperature of the Universe in the first few seconds?

10^{32} degrees Kelvin (to convert to Celsius, add $273°$)

c. What did space look like up to 380,000 years after the Big Bang?

It would have glowed like a red star, but it was opaque, so no light could travel through it, so it couldn't be "seen" $3000°K$

d. What happened about 380,000 years after the Big Bang?

Space turned from opaque to transparent. Light began to travel through the Universe

e. When did the first stars and galaxies form?

≈ 1 Billion years after the Big Bang

15. When we look out into space, we are looking back into time. As we look farther away, we look further back in time. Describe the most distant thing we can see. How old is its image?

We can see parts of the universe back when they were still glowing and opaque.

16. The most distant objects in the Universe are not where they appear to be. Where are they? Explain why.

This is called the "surface of last scatter."

Originally, this surface was $3000°K$ and red. However, since it is moving away from us at/near the speed of light, its waves have red shifted to microwaves at only $273°K$,

17. List and explain two pieces of evidence for the Big Bang.

① Cosmic Microwave Background Radiation (CMBR)
— This is the heat left over from the Big Bang. It is what we see when we look deep into space (and into the past) to near the time of the Big Bang

② Hubbles Law
— Edwin Hubble showed that all* galaxies move away from us, and that farther galaxies move faster -- So the universe is expanding

Hubble's Law

18. What is the significance of the graph on the right?

Galaxies on the top right are farthest away, and they are moving away fastest

$$v = H_0 d$$
$$H_0 = 71 \text{ km/s/Mpc}$$

v, the recession velocity in km/s

d, the distance to a galaxy in Mpc

19. Describe how Edwin Hubble created this graph.

He compared galaxies' distances to their red shifts
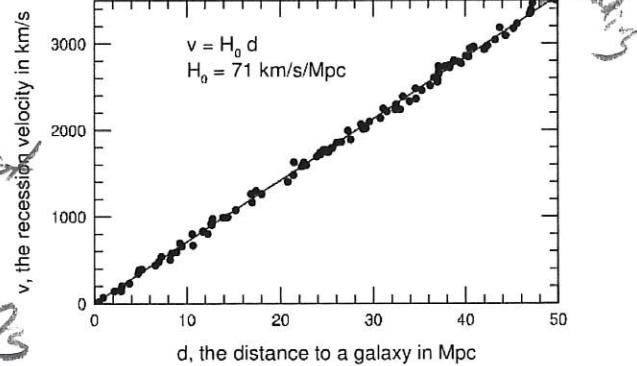
20. What are the two diagrams below supposed to show, and how are they related to one another?

The top diagram shows that, as we look into space, and back in time our view is blocked by a glowing, opaque "wall" that existed 388,00 years after the Big Bang.

The bottom diagram shows what this "wall" of light looks like from Earth through a microwave telescope. The "wall" is the "CMBR.

"wall"

Big Bang
TIME
0
TEMP
∞
End of Inflation
10¹⁴ K
Formation of D & He
10¹⁰ K
CMB Spectrum Fixed
10⁵ K
Radiation = Matter Energy
10 000 K
CMB Last Scattering
3000 K

PRESENT
13.7 Billion Years
after the Big Bang

The cosmic microwave background Radiation's "surface of last scatter" is analogous to the light coming through the clouds to our eye on a cloudy day.

"wall"

We can only see the surface of the cloud where light was last scattered