AST 301
Introduction to Astronomy

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AST 301 (Lacy), course website

Topics for this week

Describe the Milky Way Galaxy

Describe the Standard Candle method of determining distances and how Cepheid variable stars are used as standard candles.

Describe how astronomers measure the distribution of mass in a galaxy and what they find.

Describe the various types of galaxies and how they differ from the Milky Way.

What is Hubble's law? How is it measured, and what does it tell us about the Universe?

Spiral Galaxy NGC 4414

Hubble Heritage

The Milky Way

A hazy band of light across the sky

Latin: Via Lactea, or Road of Milk

Astronomy: Galaxy

Galileo saw that it was made of many stars.

The stars form a band across the sky because they are in a flat distribution, like people in this room.

Could you determine the distribution of people in this room, and your position in that distribution from observations without leaving your seat?

Groups of four

Form a group of four students.

Choose one student as the discussion leader and one as the scribe.

Answer two questions:

1. What method could you use to map out the distribution of people in this room? You can invent measurement devices, but you cannot leave your seats.
2. What difficulties or biases in your results would you encounter?

I will ask several groups to report on their methods and expected difficulties.

Mapping out the Milky Way

William Herschel (early 1800s)

- Used two methods to map out the stars in the Milky Way
- star counting: more stars should be seen in the directions where the distribution extends farther
- star brightnesses: more distant stars should appear fainter (assuming all stars have the same luminosity)
- Concluded that we are near the center.

Why didn't Herschel use parallax to measure the distances to stars?

Doing the Math

The flux (or apparent brightness) of a star is the light power collected by a telescope divided by the collecting area of the telescope.

Flux depends on distance from the star because as the light goes away from the star it spreads out over a larger area.

$$F = \frac{L}{4\pi d^2}$$

If you can measure the flux, F, and can somehow figure out the luminosity, L, you can solve for the distance.

$$d = \sqrt{\frac{L}{4\pi F}}$$

Mapping out the Milky Way

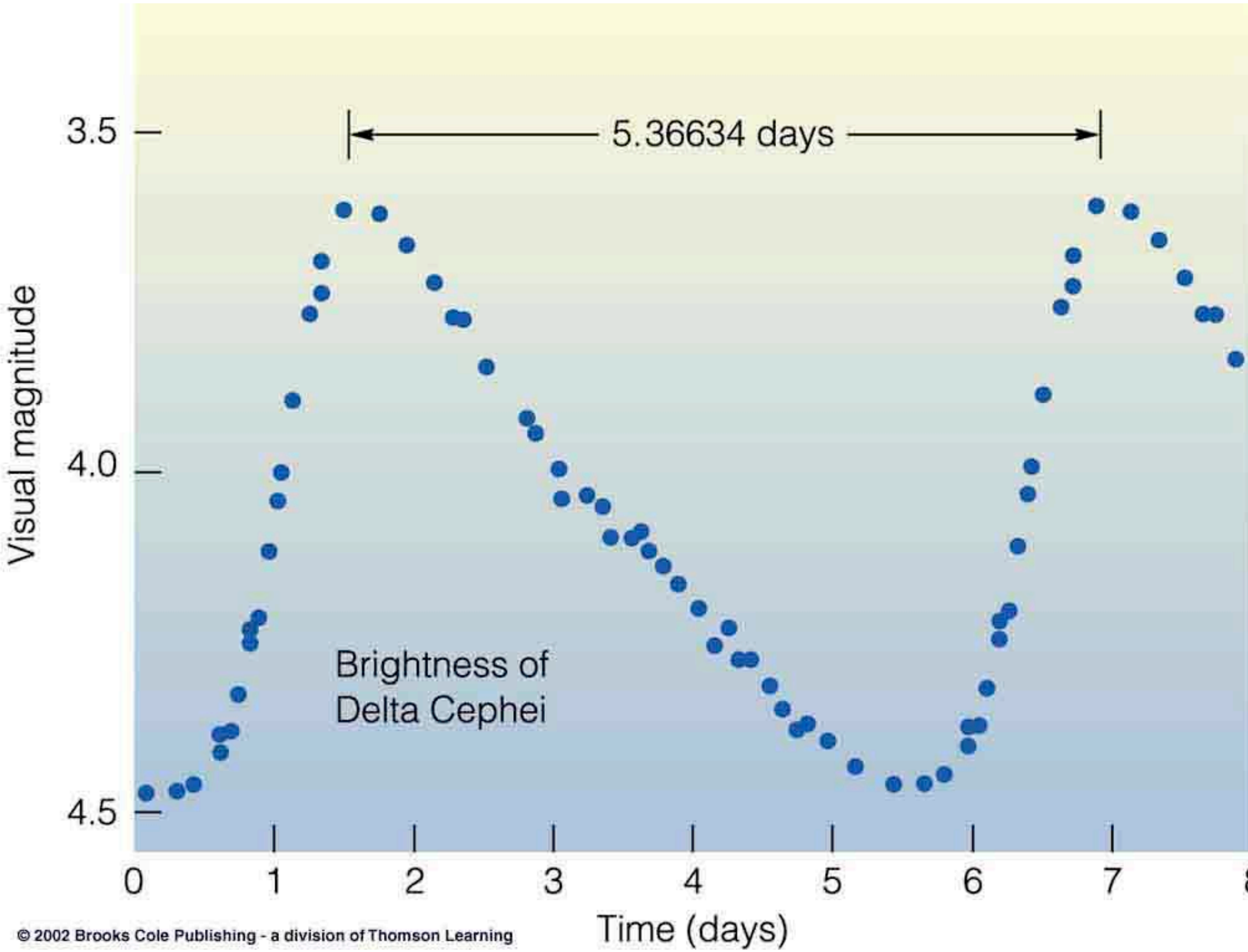
If we know how much light a star puts out (its luminosity) and we measure how bright it appears (its flux), we can calculate its distance.

This is referred to as the standard candle method of measuring the distance to a star.

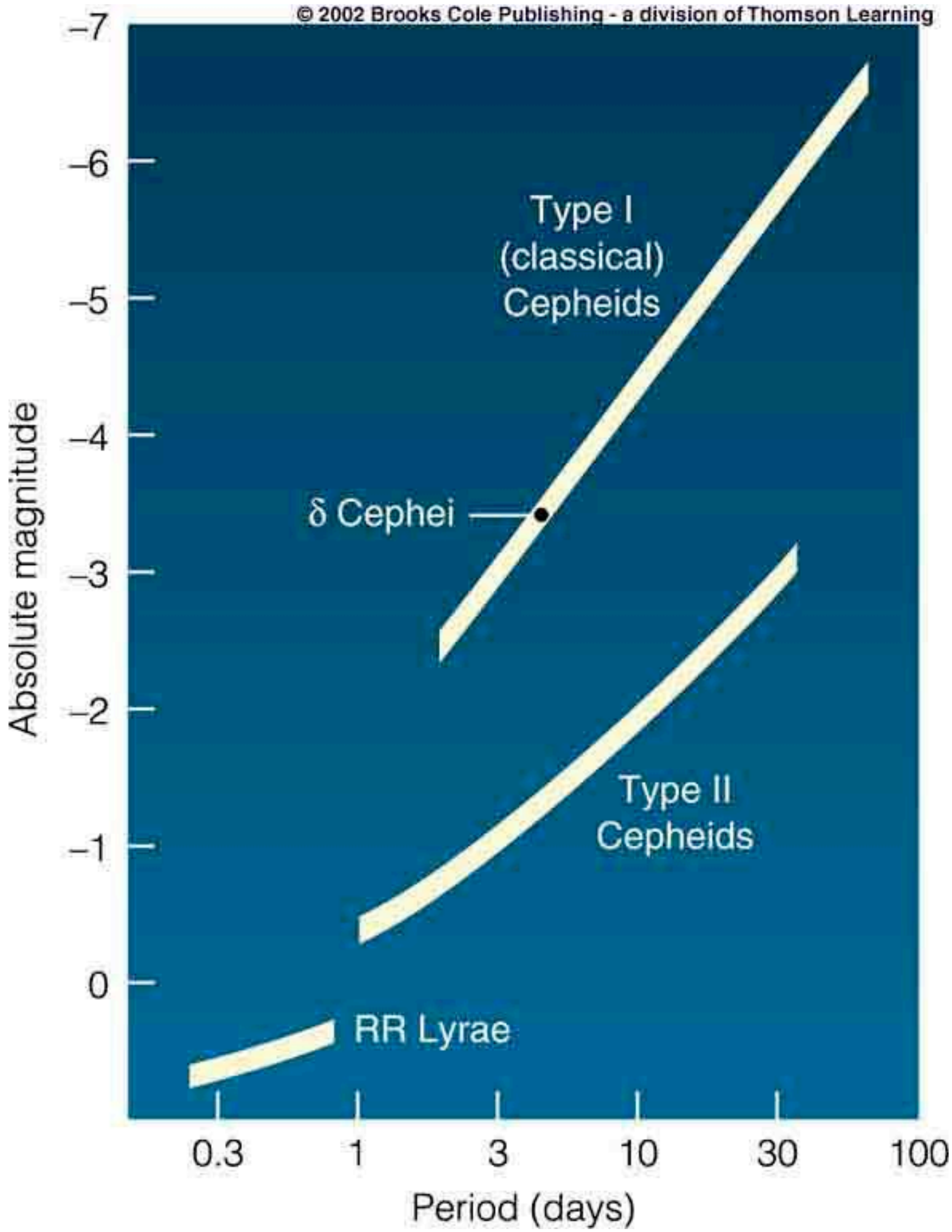
The problem is figuring out the luminosity of a star without first knowing its distance.

Henrietta Leavitt (early 1900s)

- Studied variable stars in the Small Magellanic Cloud.
- Found that flux and period are proportional.
- Since all of her stars were about equally distant, this means that luminosity is proportional to the period of variation.



3.5
4.0
4.5
Visual magnitude
5.36634 days
Brightness of
Delta Cephei
0
1
2
3
4
5
6
7
8
Time (days)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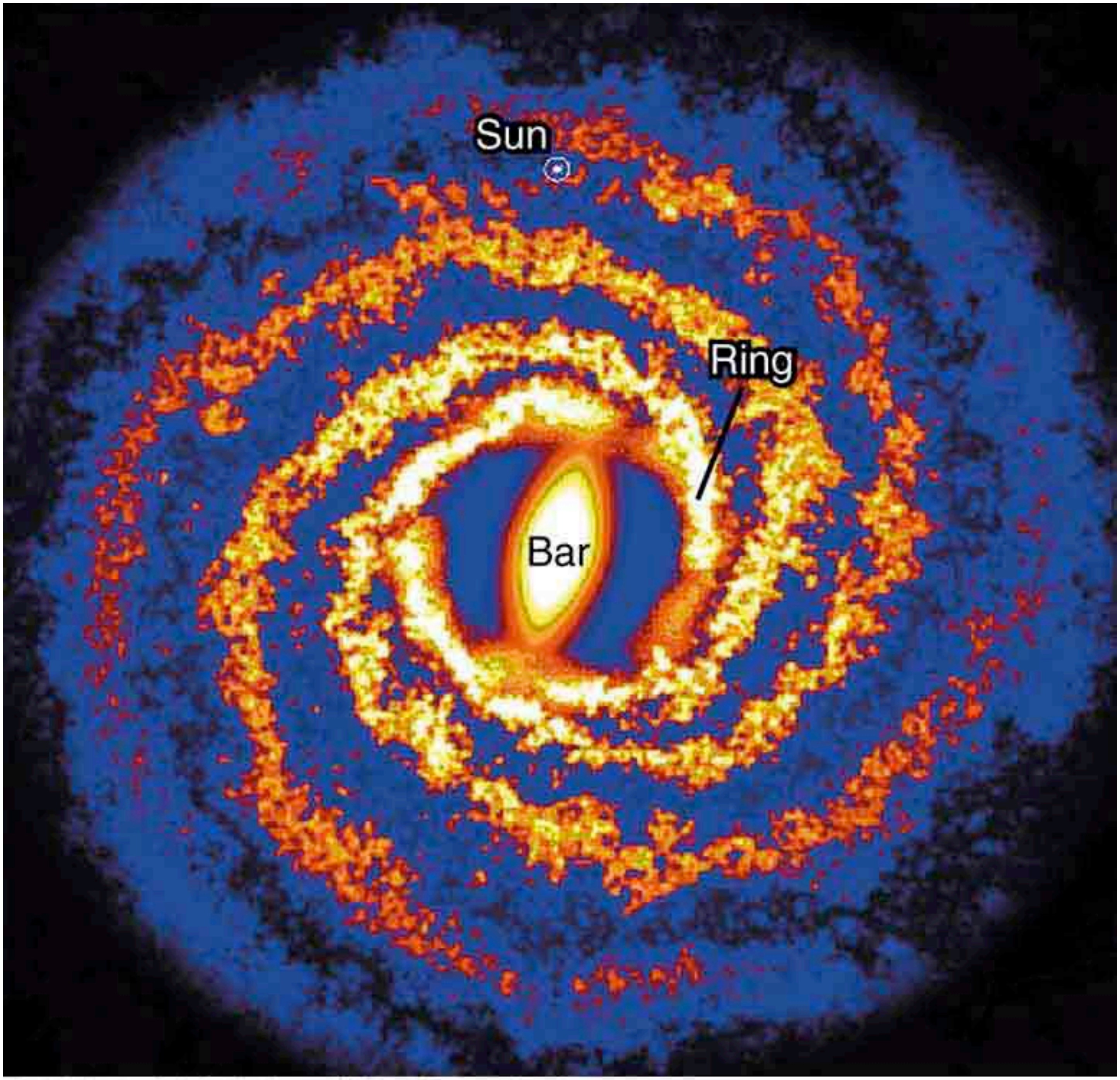
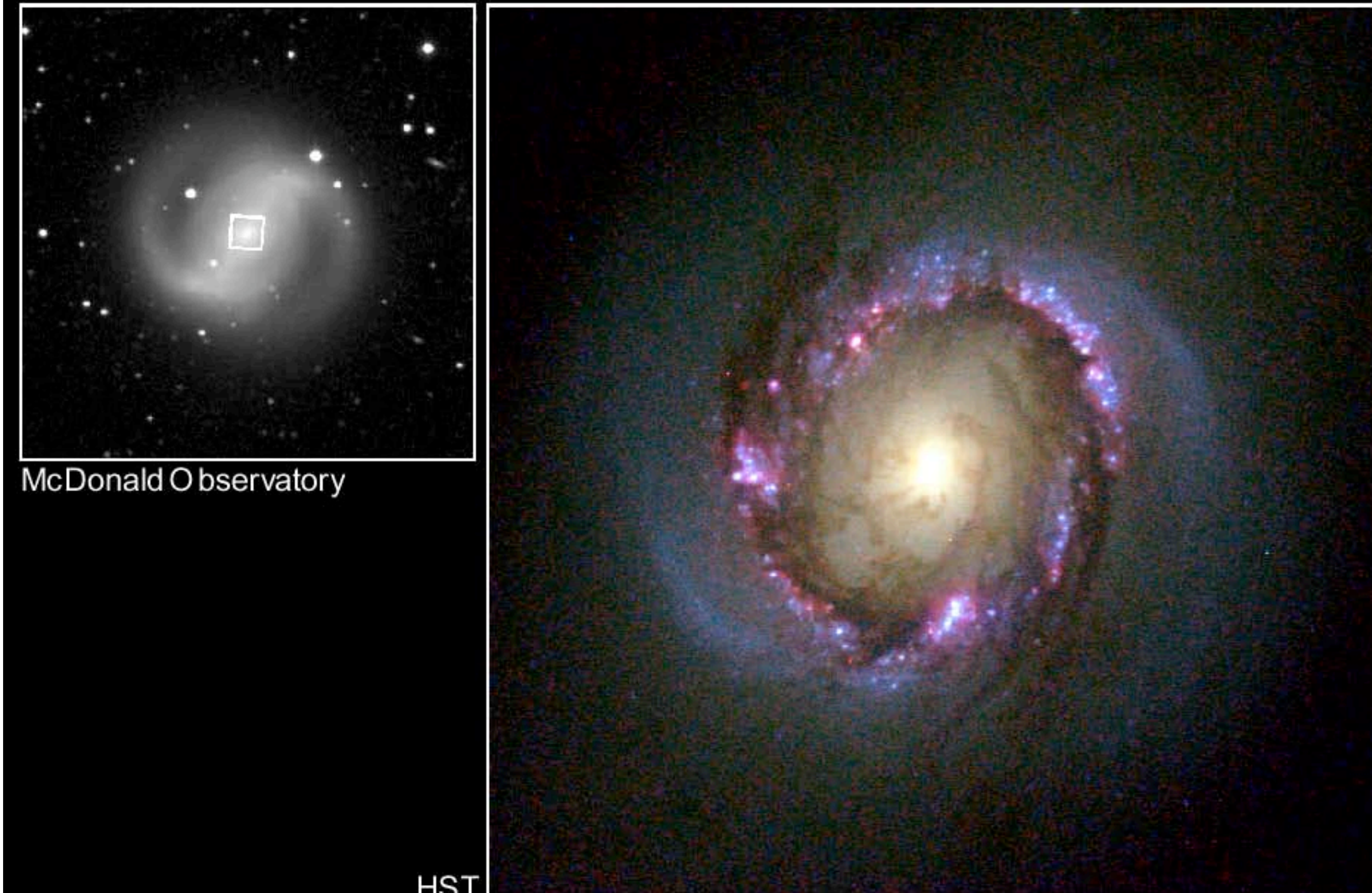
Absolute magnitude
–7
–6
–5
–4
–3
–2
–1
0
Type I
(classical)
Cepheids
δ Cephei
Type II
Cepheids
RR Lyrae
0.3
1
3
10
30
100
Period (days)

Our place in the Milky Way

Harlow Shapley (about 1920)

- Determined the constant of proportionality between period of variation and luminosity, so the luminosity of a Cepheid variable star could be determined from its period.
- Then he could use Cepheid variables as standard candles.
- He mapped out the distribution of globular clusters.
- He found that they formed a distribution centered some distance from us in the direction of Sagittarius.
- He concluded that we are not at the center of the Milky Way and that the Milky Way is more than 10,000 ly across.


Sun
Ring
Bar



Galaxy NGC 4314 • Nuclear-Ring
Hubble Space Telescope • Wide Field Planetary Camera 2

PRC98-21 • June 11, 1998 • ST ScI OPO • G. F. Benedict (University of Texas) and NASA

Distribution of Mass in the Milky Way

At least for other galaxies, we can measure the distribution of luminous matter by simply taking a picture.

But is that a fair sample of all of the matter in a galaxy?

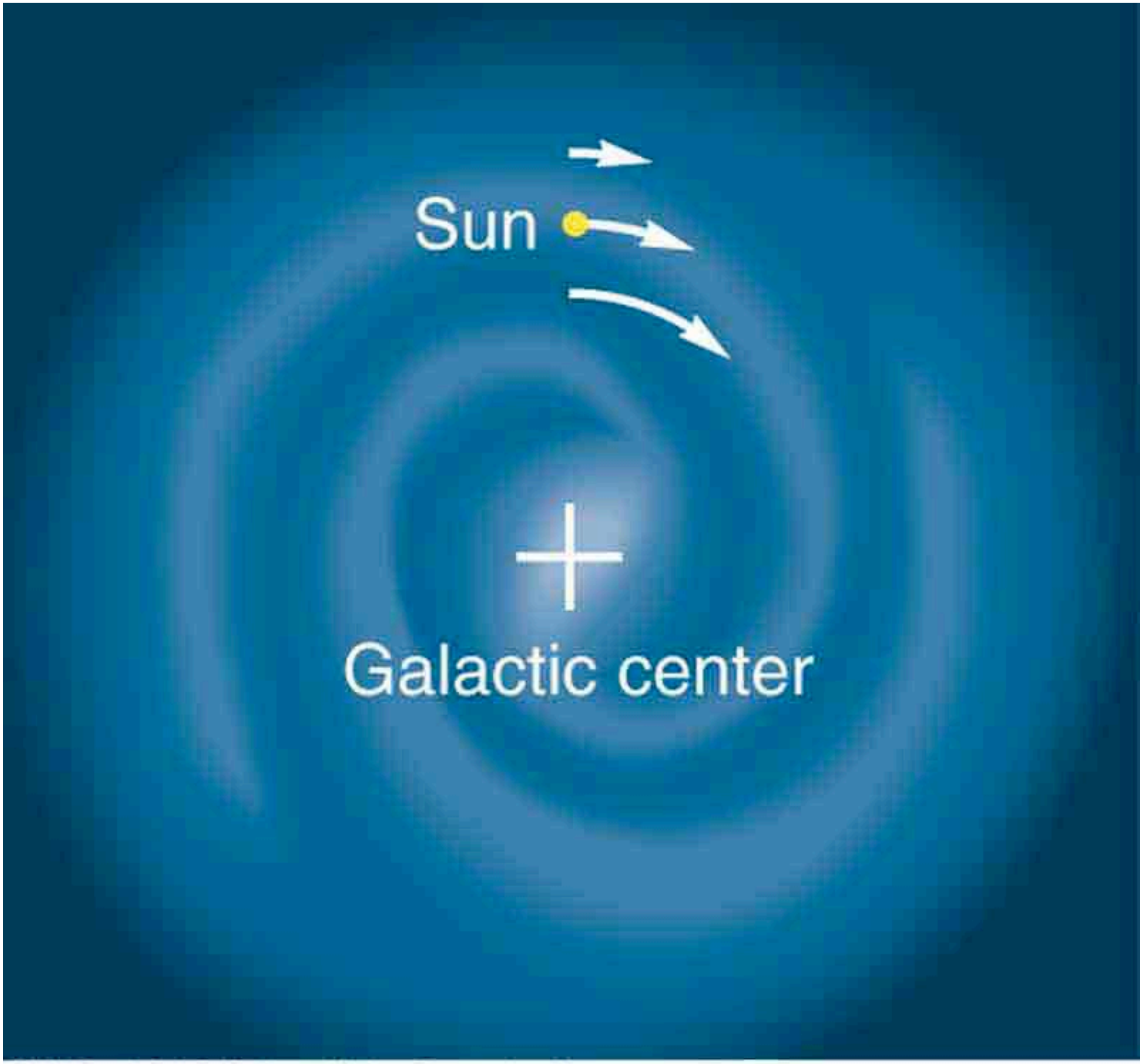
Some stars emit much more light than others.

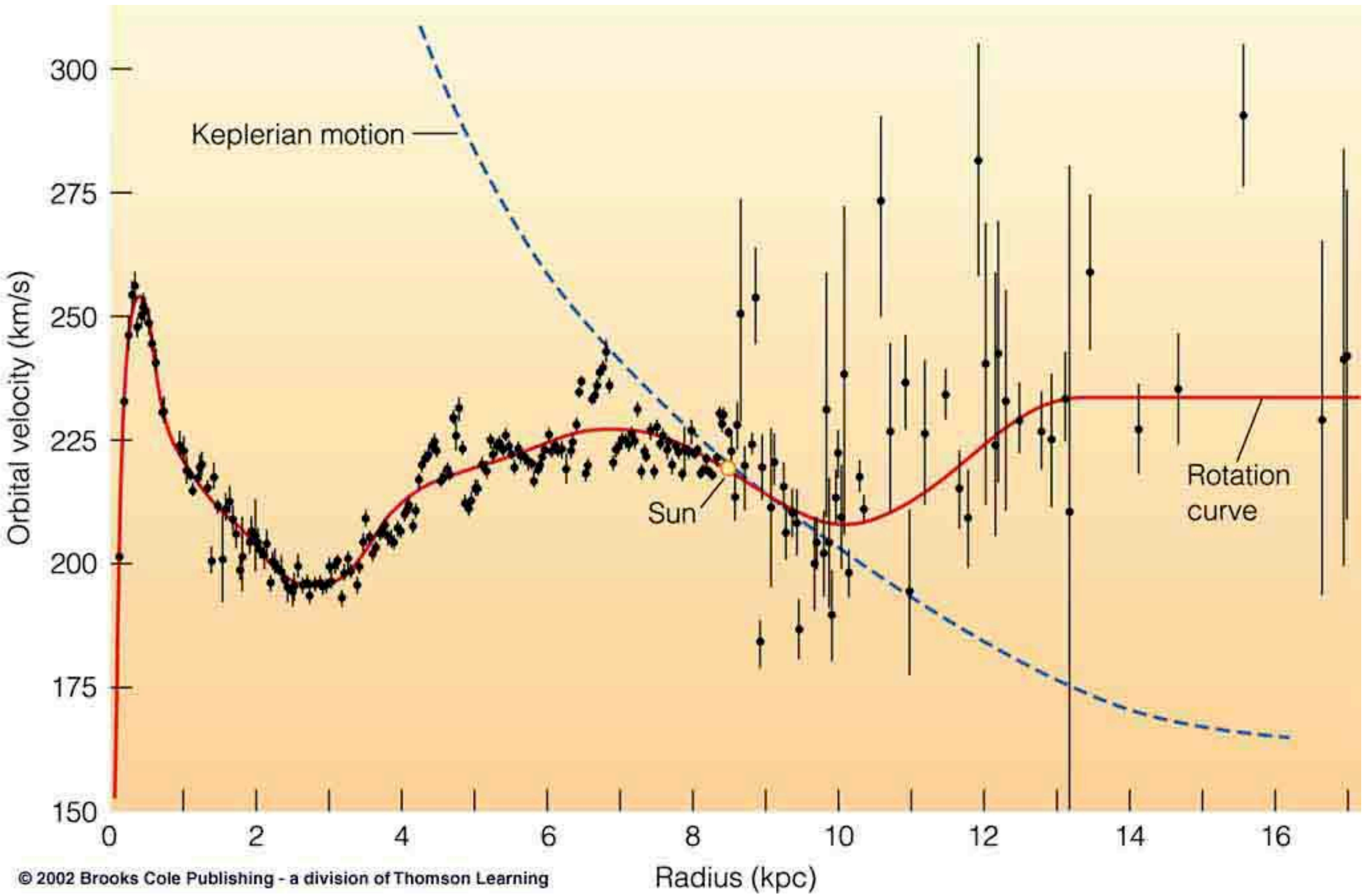
We can measure the distribution of mass in a galaxy by observing how fast stars orbit in the galaxy.

They orbit around whatever is inside of their orbits – black holes, stars, gas, dust, ???

We can use Kepler's 3rd law to determine the mass of whatever is inside of their orbits.

M(inside orbit) = a^3 / P^2


Sun
Galactic center


Keplerian motion
Sun
Rotation curve
Orbital velocity (km/s)
300
275
250
225
200
175
150
0
2
4
6
8
10
12
14
16
Radius (kpc)

Orbital speeds and mass

All stars seem to orbit around the center of the Milky Way with speeds of 200-250 km/s.

Kepler's 3rd law then tells us

$$v_{orbital} = \sqrt{\frac{GM_{inside\_orbit}}{r_{orbit}}}$$

or

$$M_{inside\_orbit} = \frac{v_{orbital}^2 r_{orbit}}{G}$$

so if the orbital speed is approximately constant,

$$M_{inside\_orbit} \propto r_{orbit}$$

There is mass where we see almost no stars

We conclude that $M_{\text{inside of radius r}} \alpha$ r.

This means that there is as much mass between 11 and 12 kiloparsecs from the center as there is between 1 and 2 kpc.

This is surprising because there is much more light coming from the stars between 1 and 2 kpc from the center.

The amount of mass we calculate is also surprising.

It is several times more than the mass we calculate of the stars we can see.

Most of the mass in the Milky Way must be dark.

On homework you will see the evidence for a different kind of dark matter in the central parsec of the Milky Way.