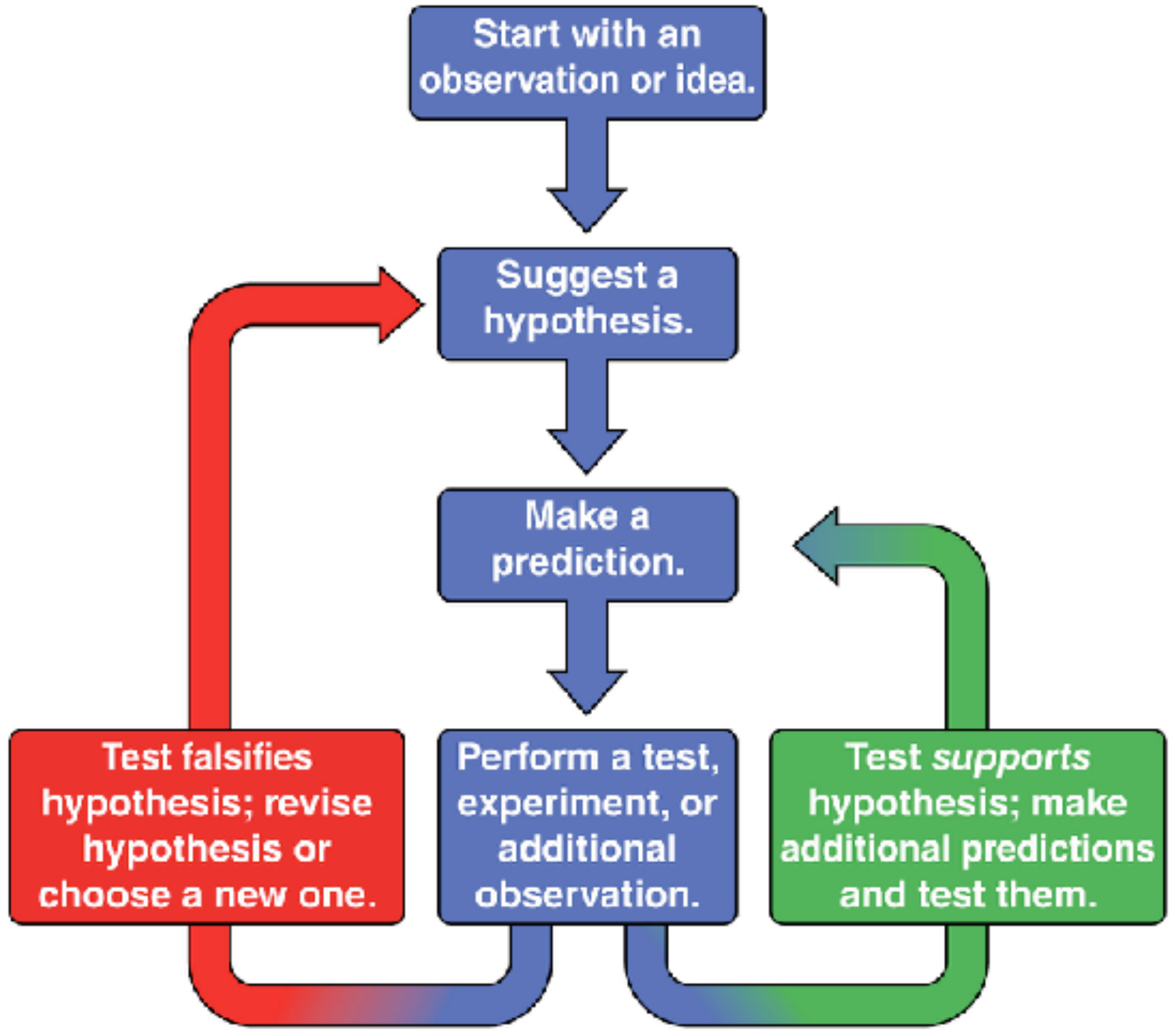
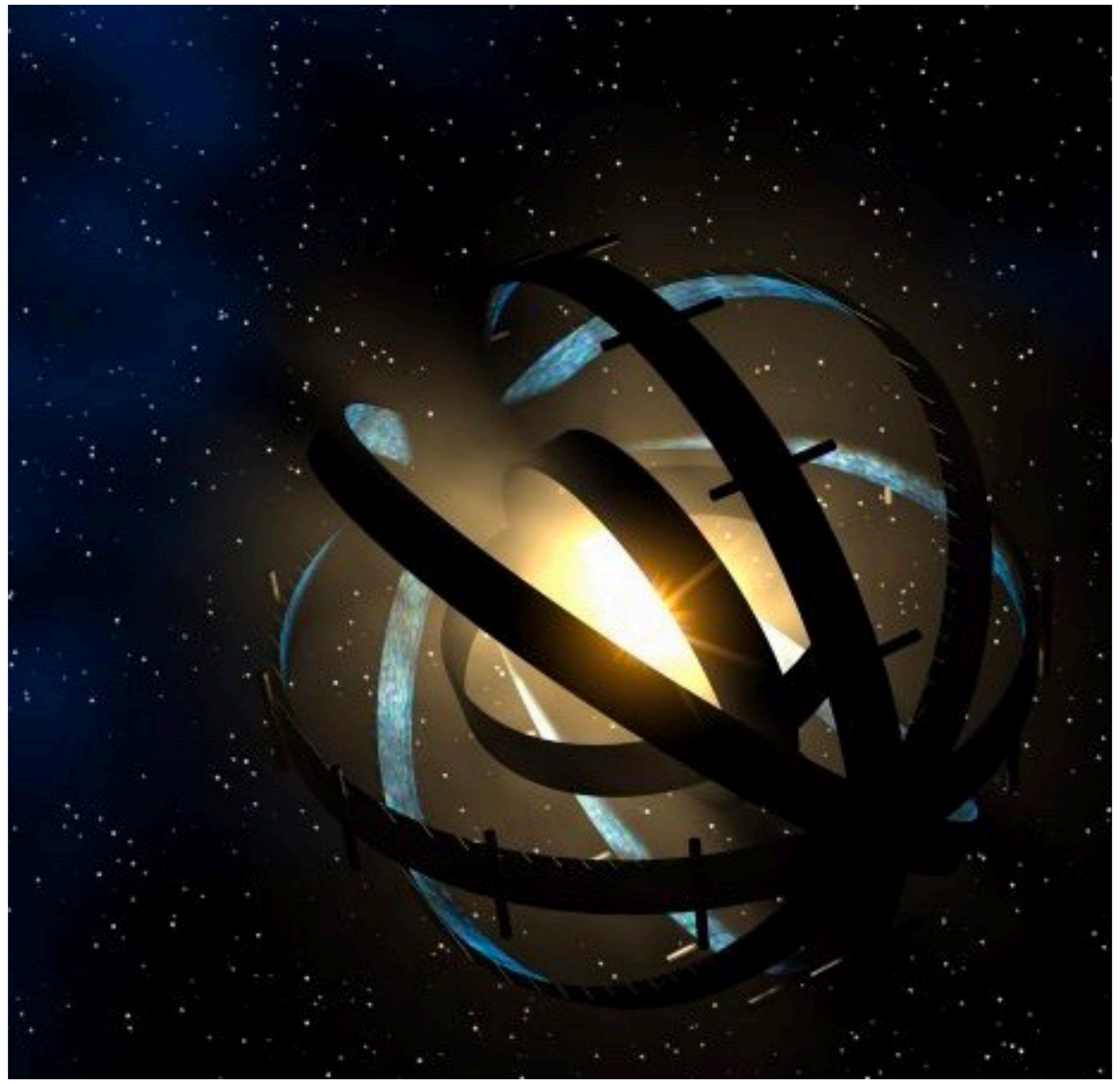
Final Exam Review



December 14th
10:30am
JFB 101 (this room)

Pick up midterms up front

TA-led review next Wednesday at usual office hours time/location: JFB 325, 3pm, Dec. 12th



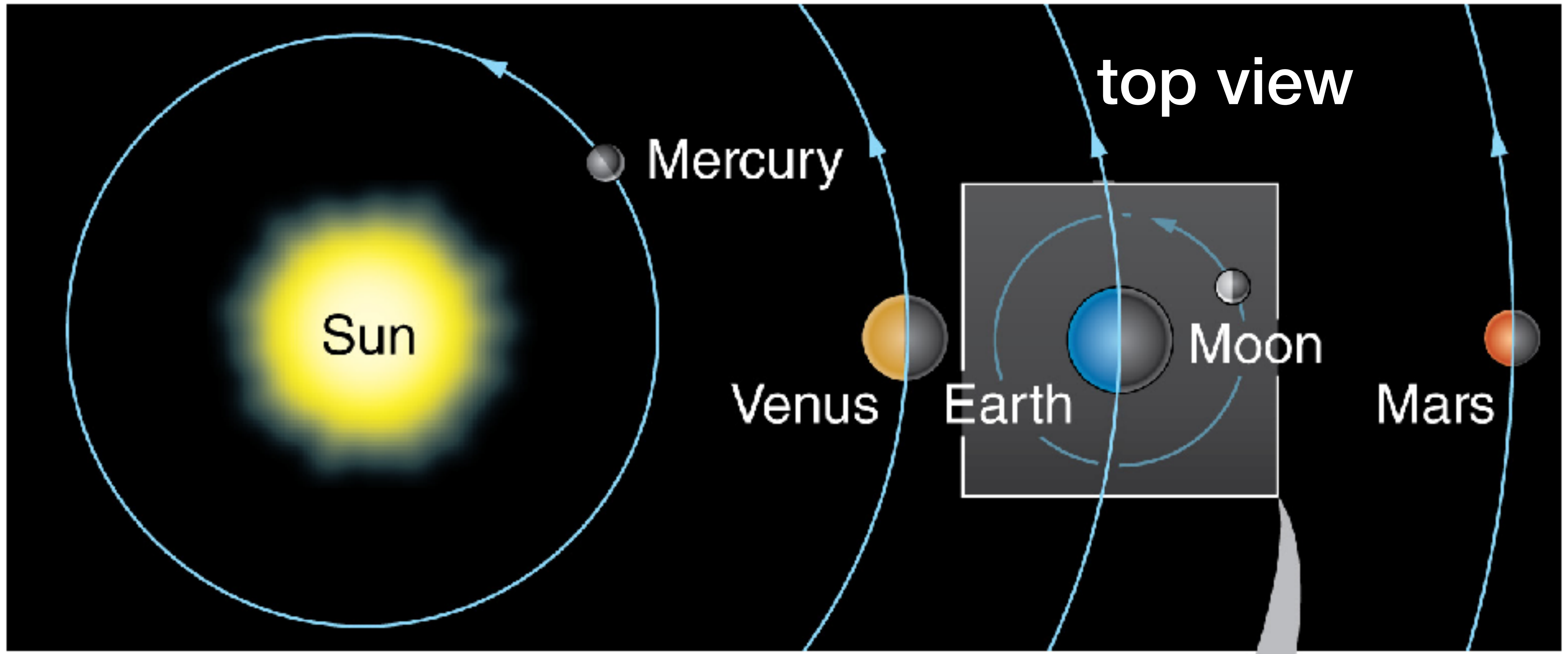
Exam Format

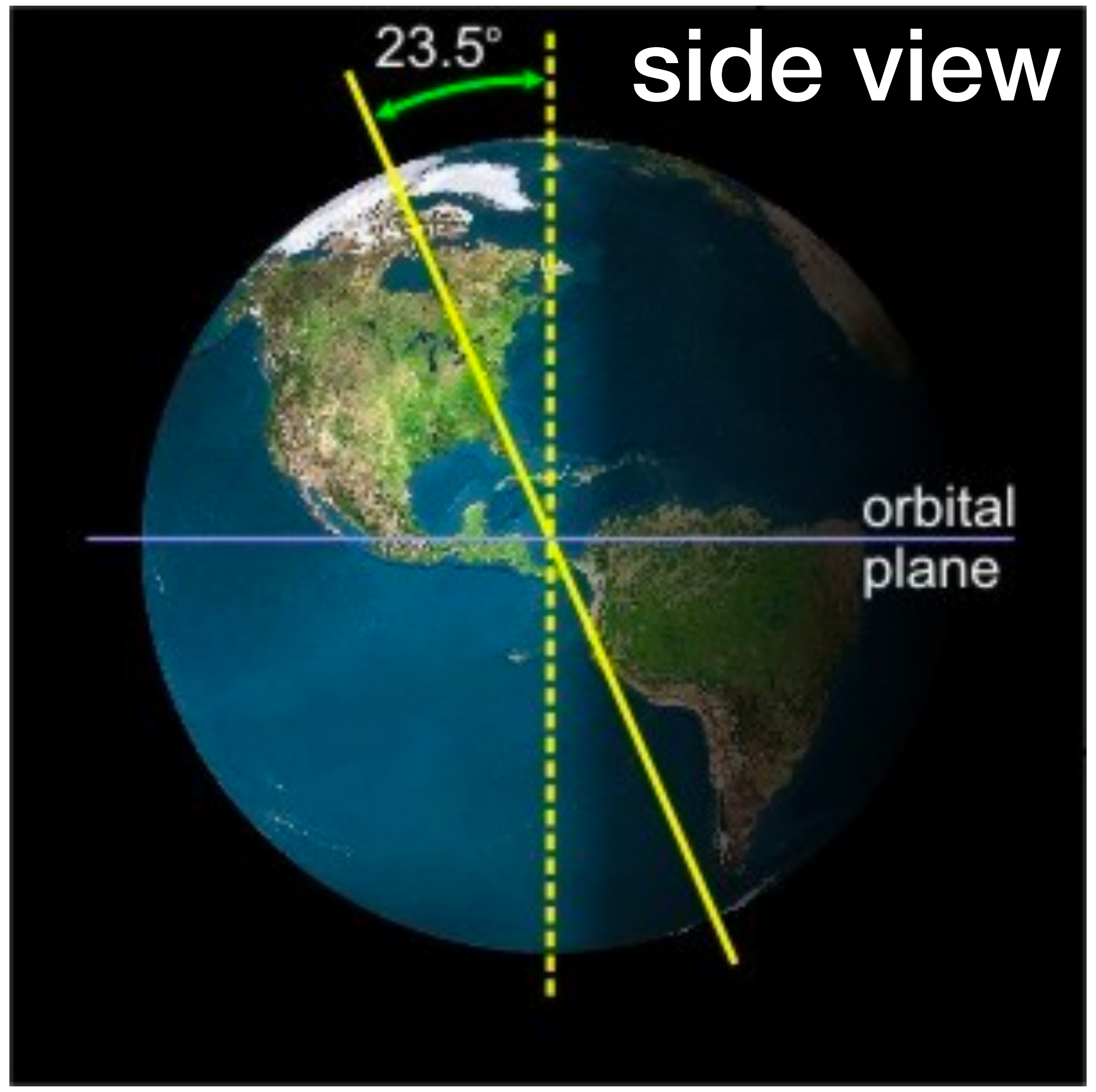
2hr time limit: 10:30am-12:30pm
counts 33% more toward your final grade than a midterm, so the exam will be roughly 33% longer (2hr should be plenty of time in other words)

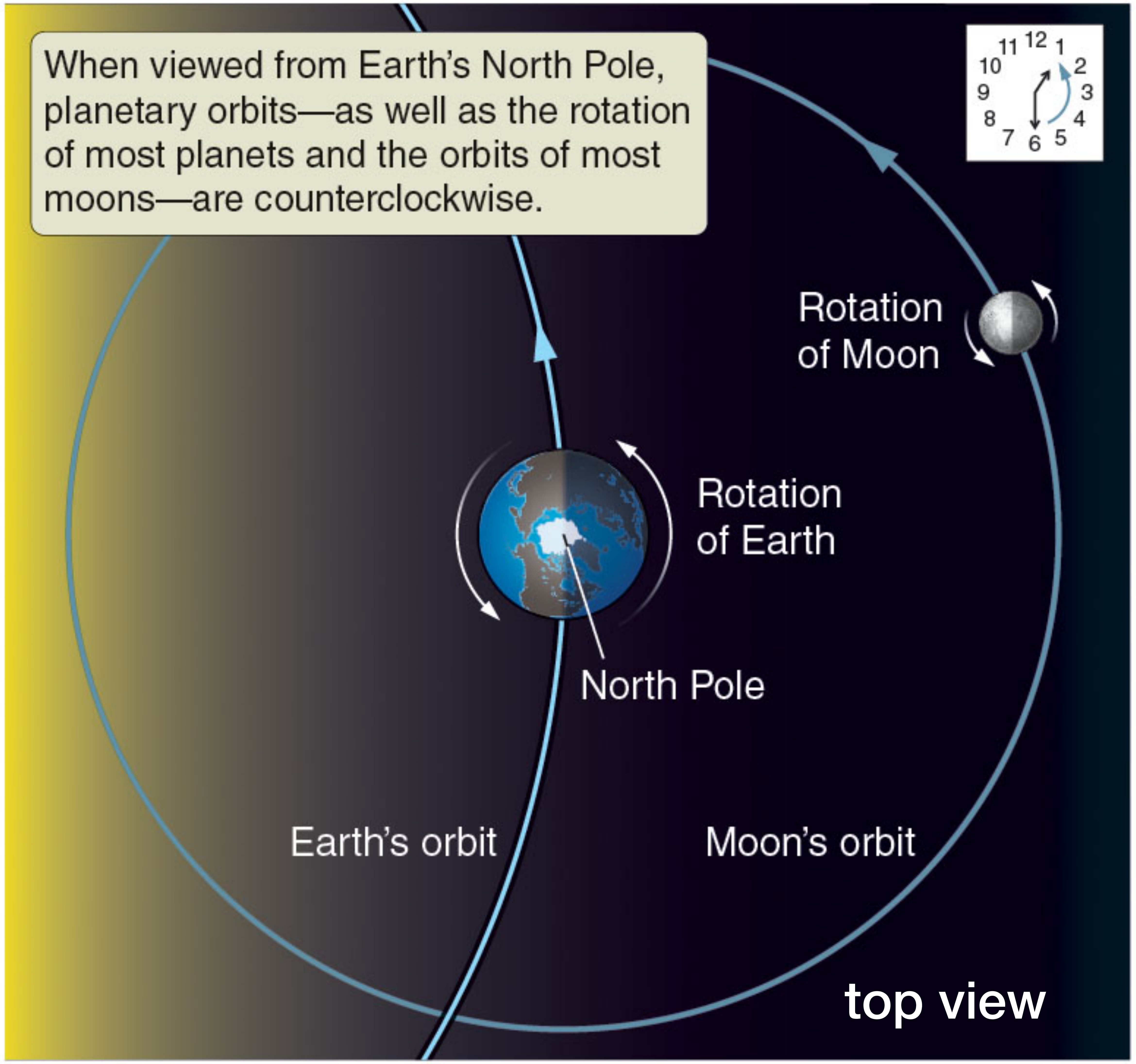
Multiple Choice Questions
60-75% of total score

Short Answer Questions
40-25% of total score
may require calculations, but calculators not needed (or allowed)

Seasons and Moon Phases: it's all just perspective

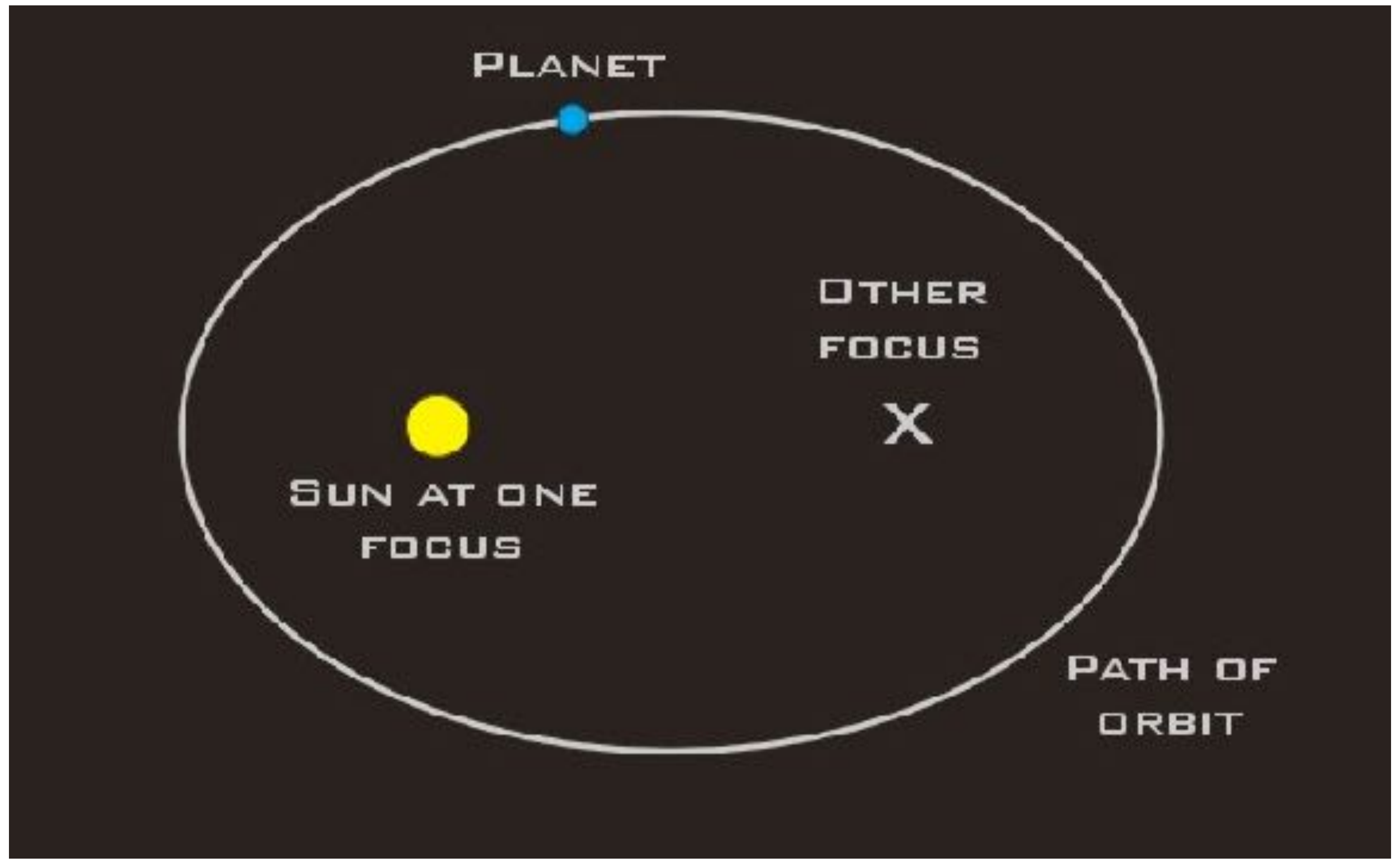




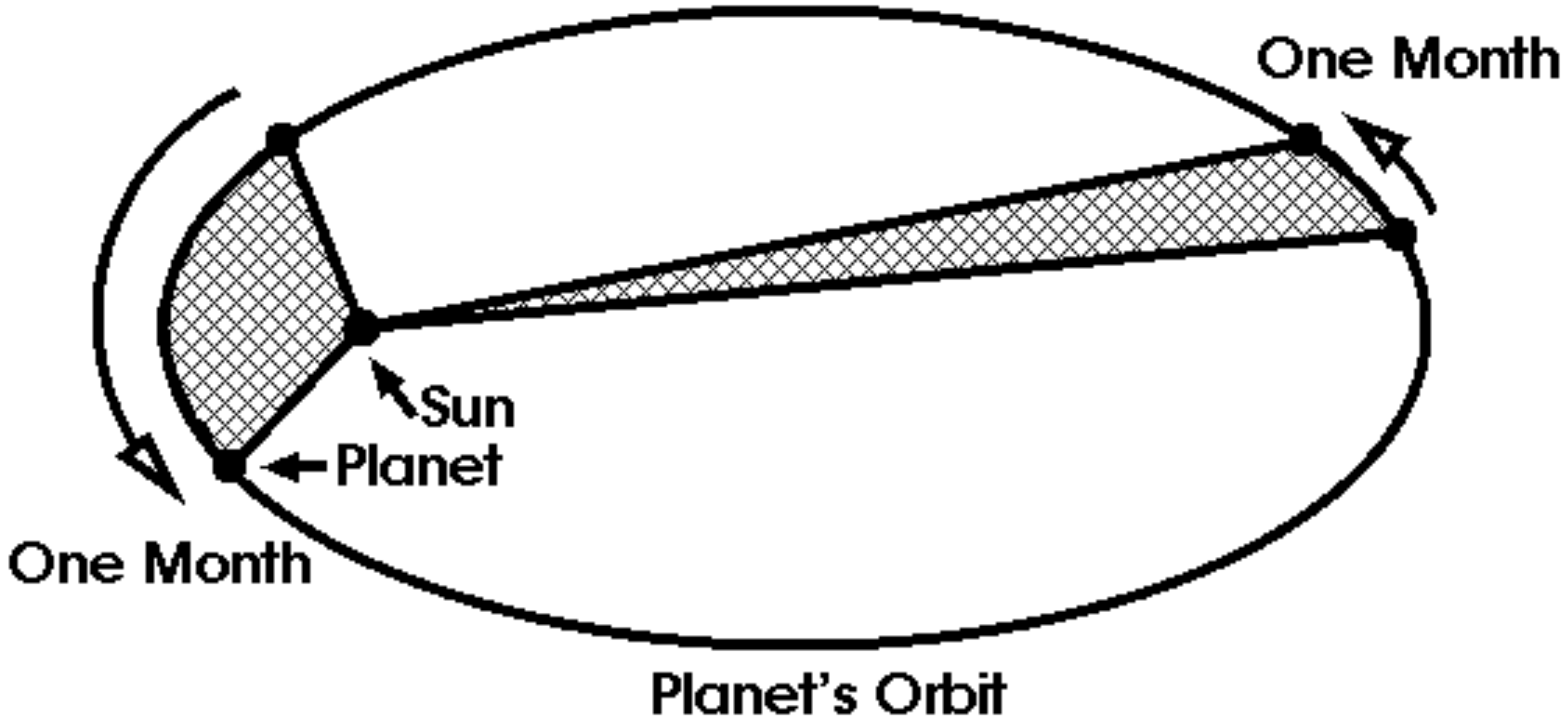


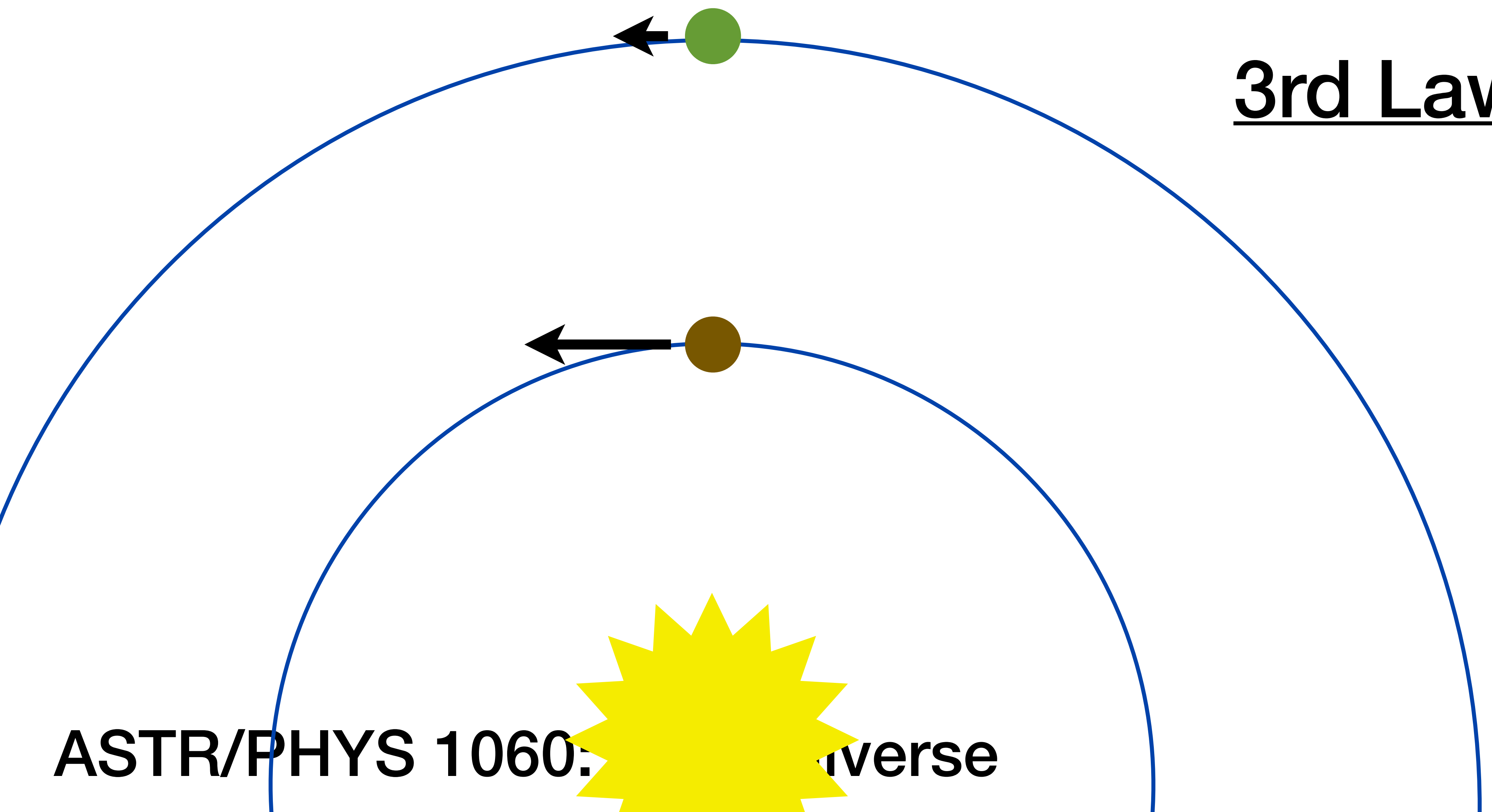
Kepler's 3 Laws

1st Law: Orbits are elliptical



2nd Law: equal areas in equal times





3rd Law: period depends on distance

(Period of Planet [in years])^2

=

(Average Distance of Planet from Star [in AU])^3

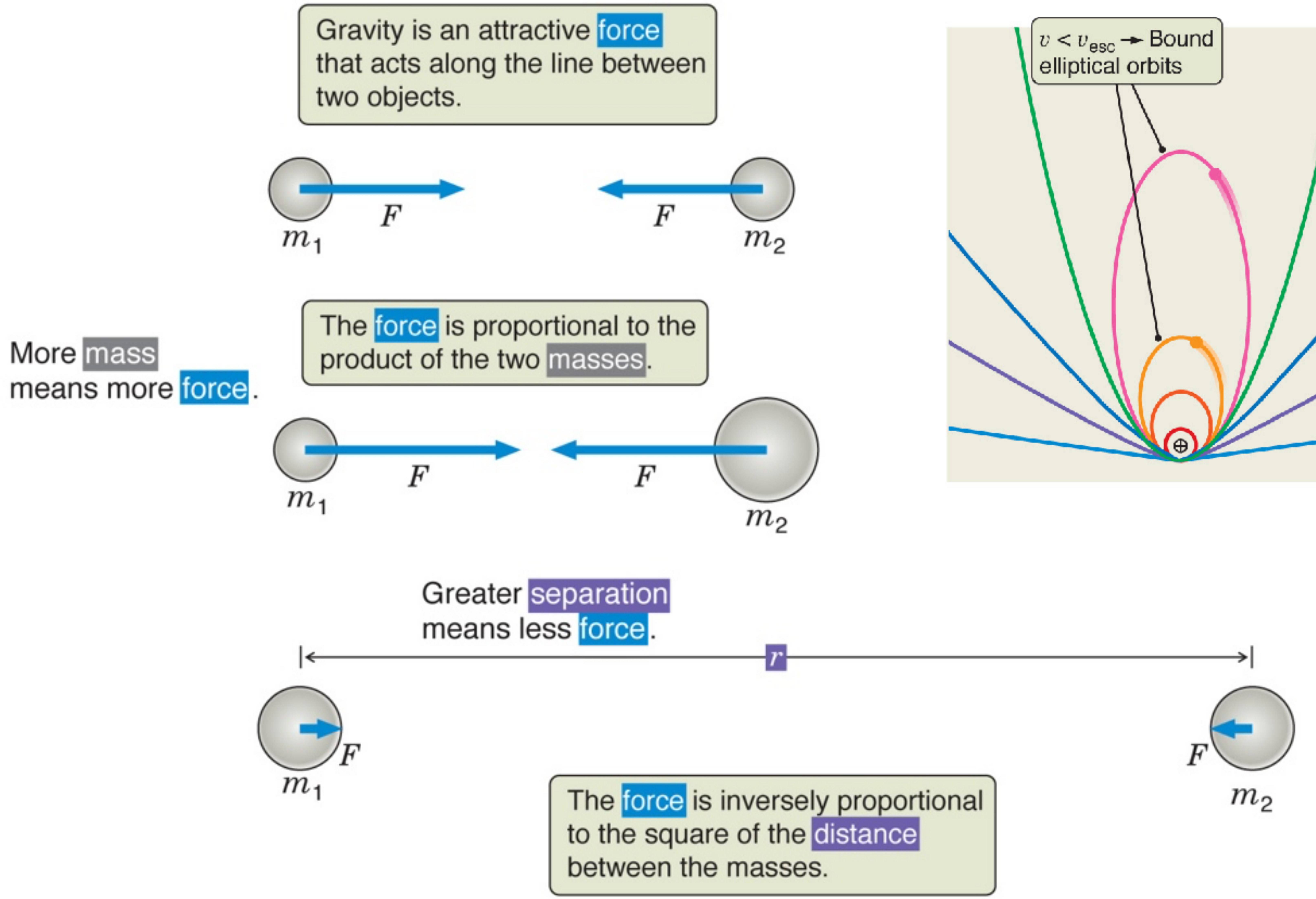
Newton's 3 Laws

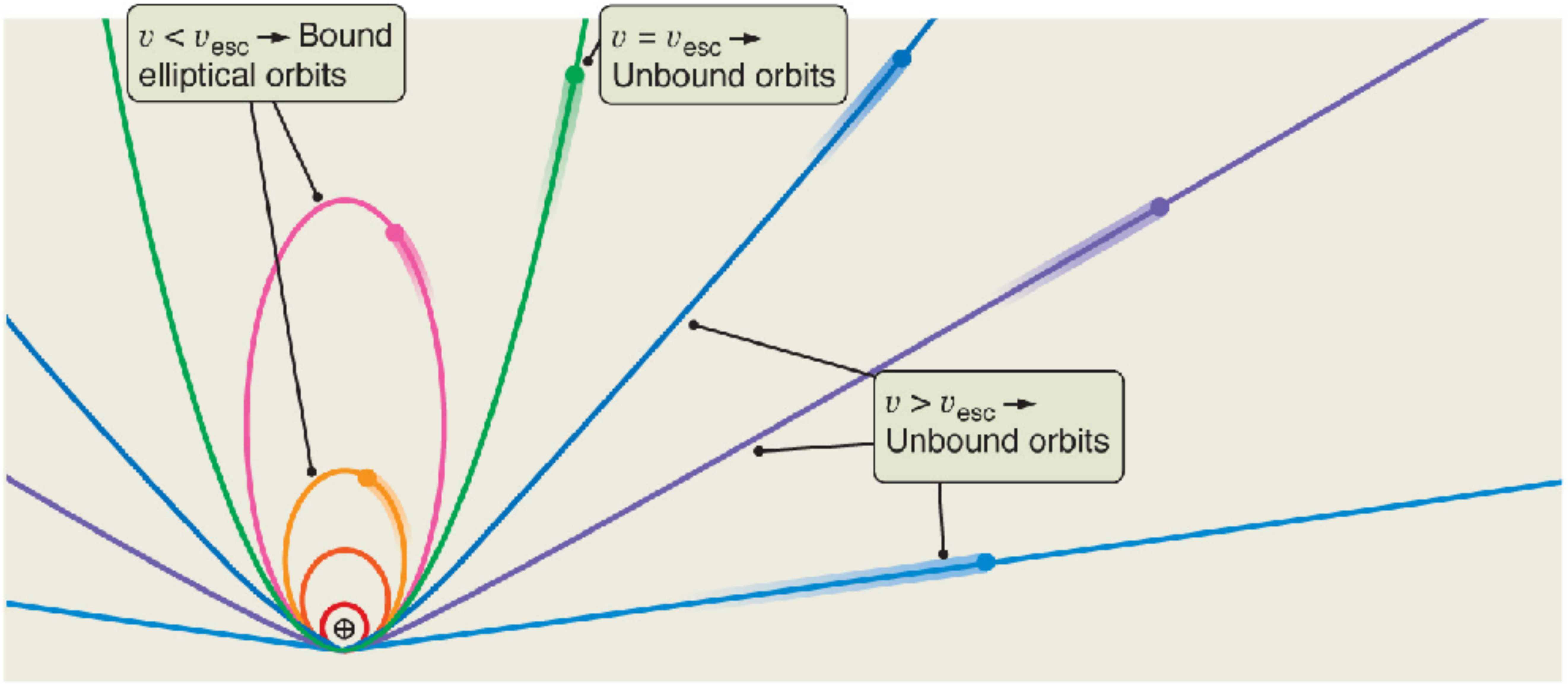
1) Law of Inertia: Objects at rest stay at rest, objects in motion stay in motion (Galileo figured this one out)

2) Motion is changed by unbalanced forces
acceleration = force / mass

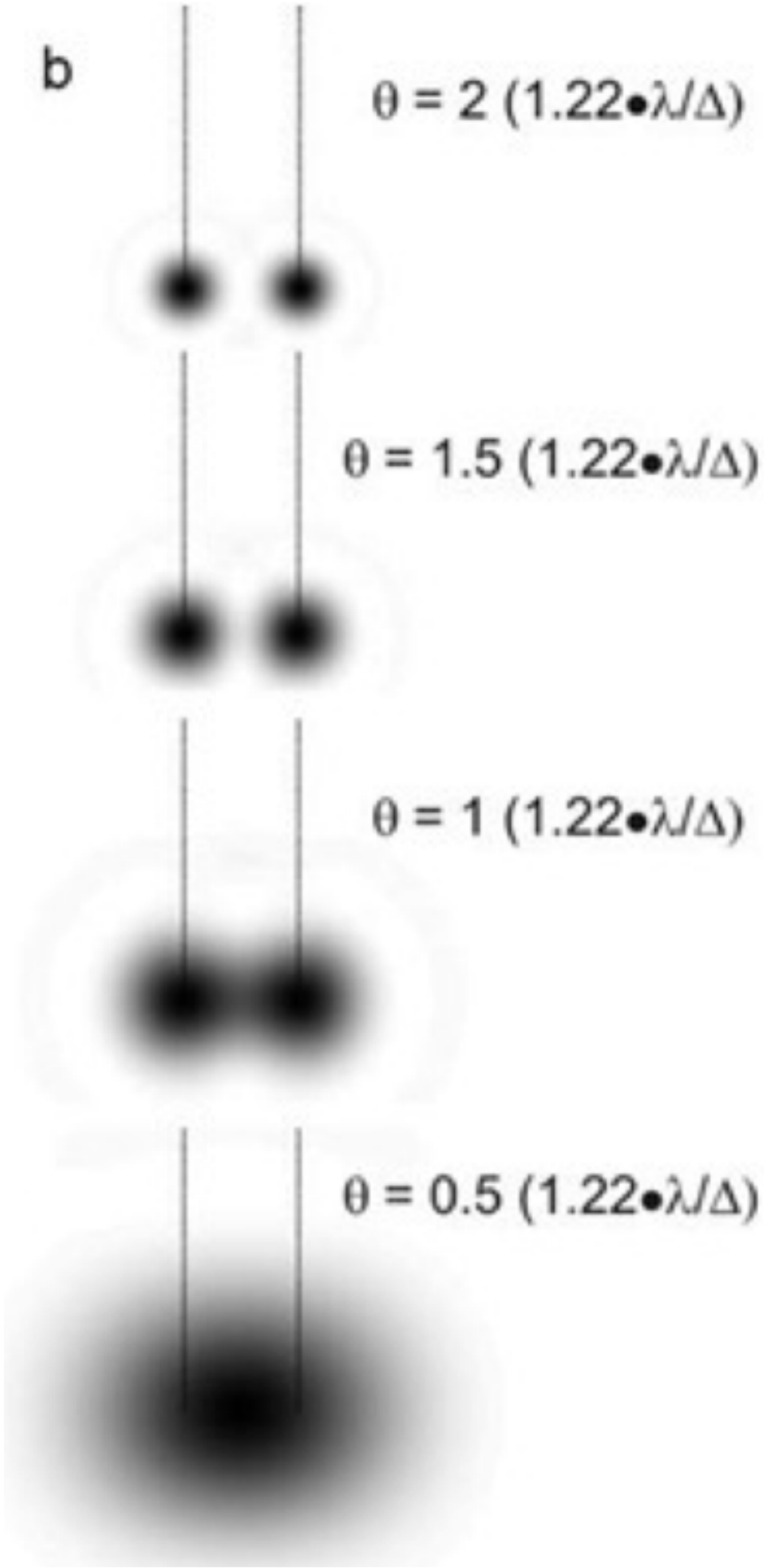
3) Forces always come in pairs and those pairs are always equal in strength but opposite in direction

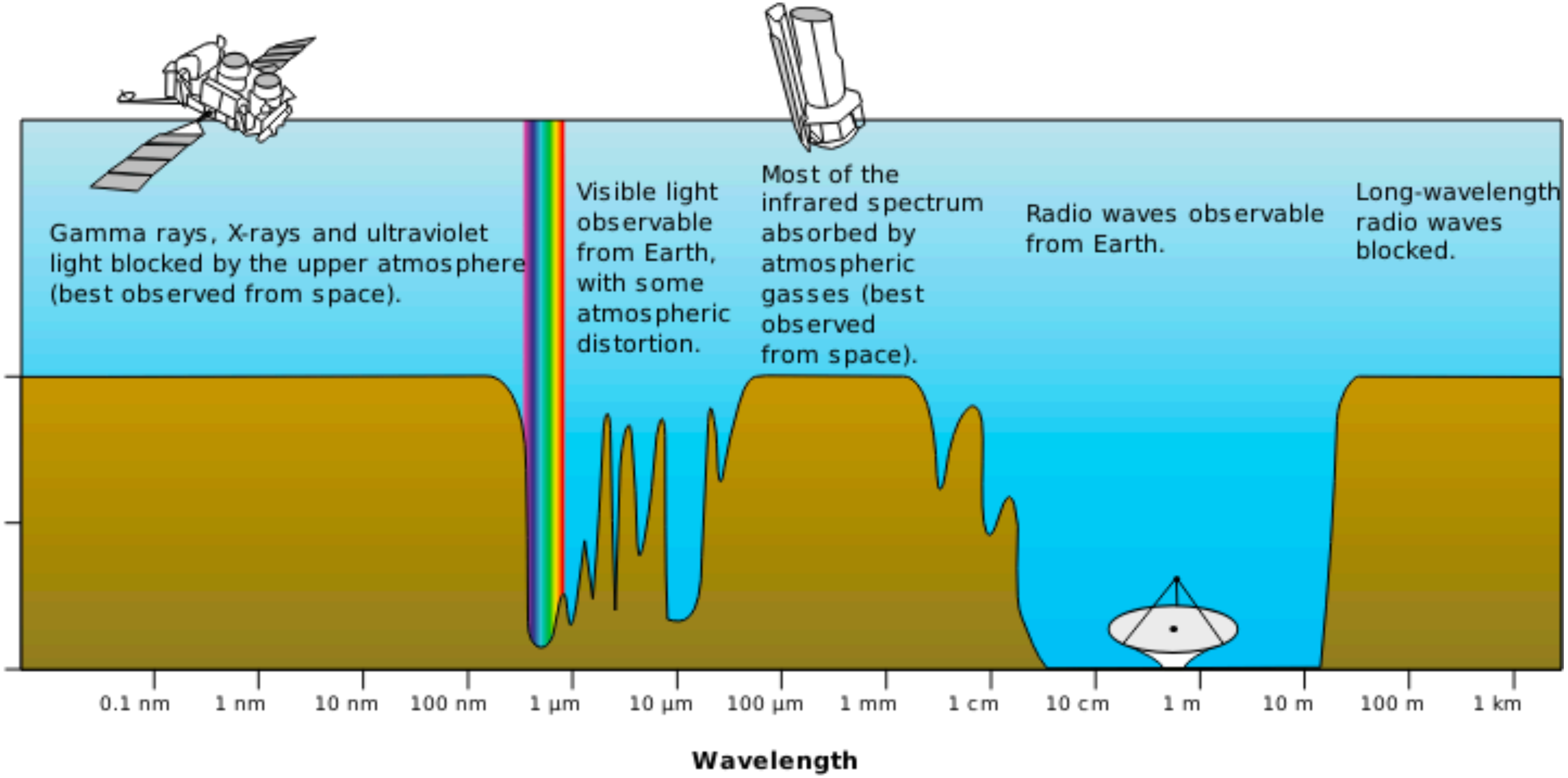
Newton's Universal Law of Gravitation: $F = G\frac{m_1 m_2}{r^2}$





Electromagnetic Spectrum



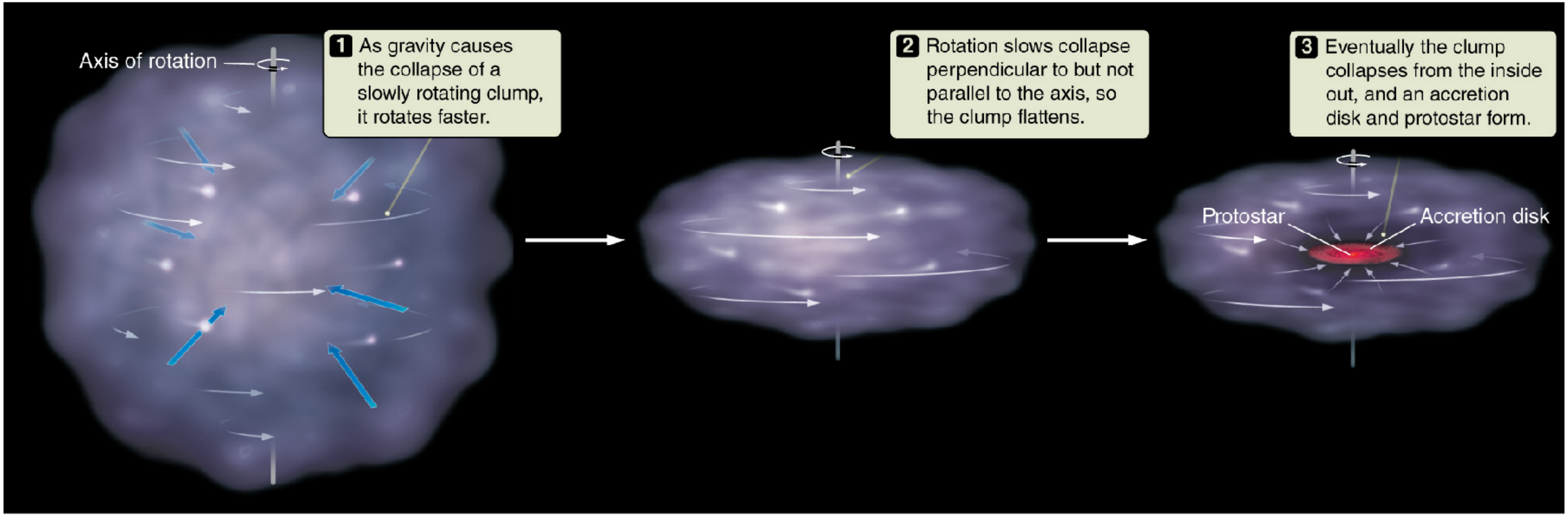


Telescopes

$$\text{angular resolution} = 206265 \text{ arcseconds} \frac{\text{wavelength}}{\text{telescope diameter}}$$

$$\longrightarrow \quad \theta \propto \frac{\lambda}{D}$$

Any small net spin of the collapsing cloud is amplified as it becomes smaller



Conservation of Angular Momentum: $L = m\ v\ r$

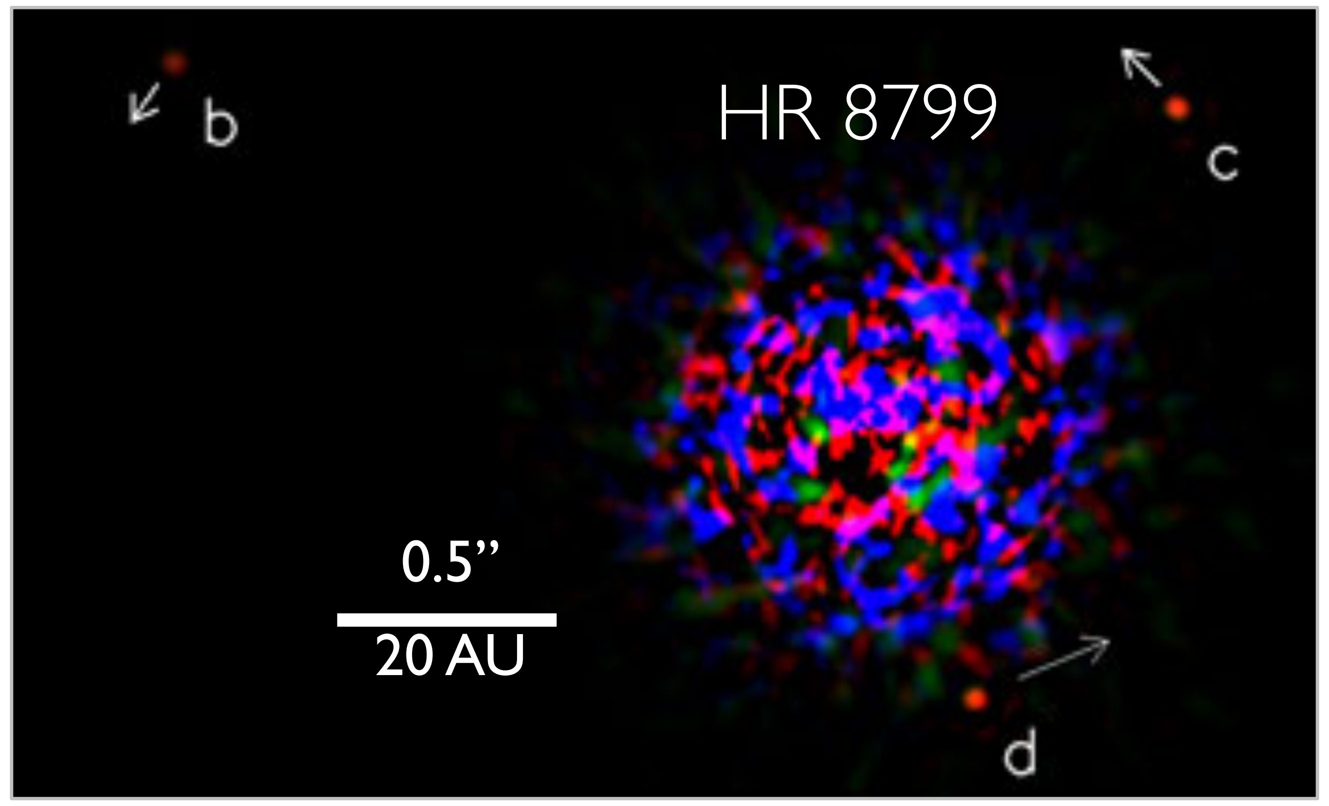
Mass Distribution in the Solar System

Sun
99.85%

Outer Planets
0.134%

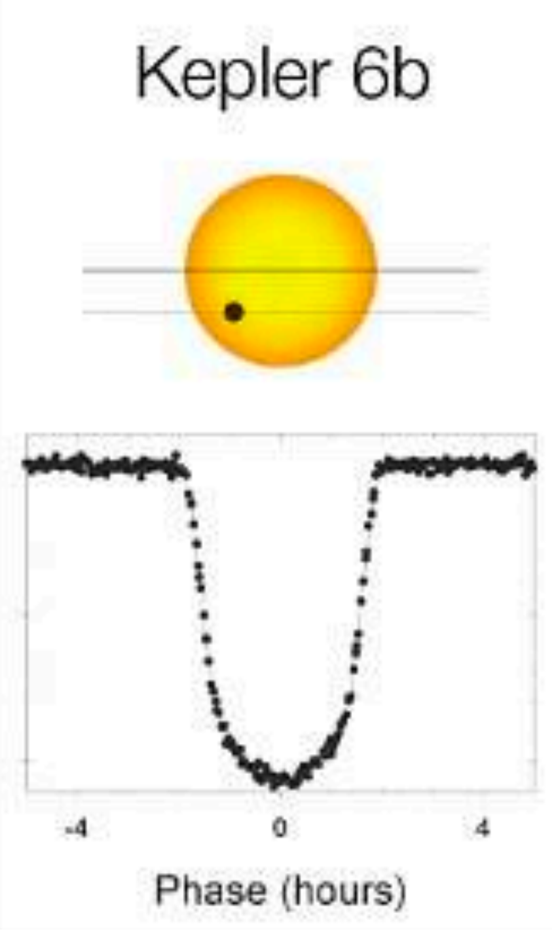
Terrestrial Planets
0.001%

How to find planets



Direct Imaging

- Detect them directly
  - Image the planet
  - Detect its atmosphere in a spectrum



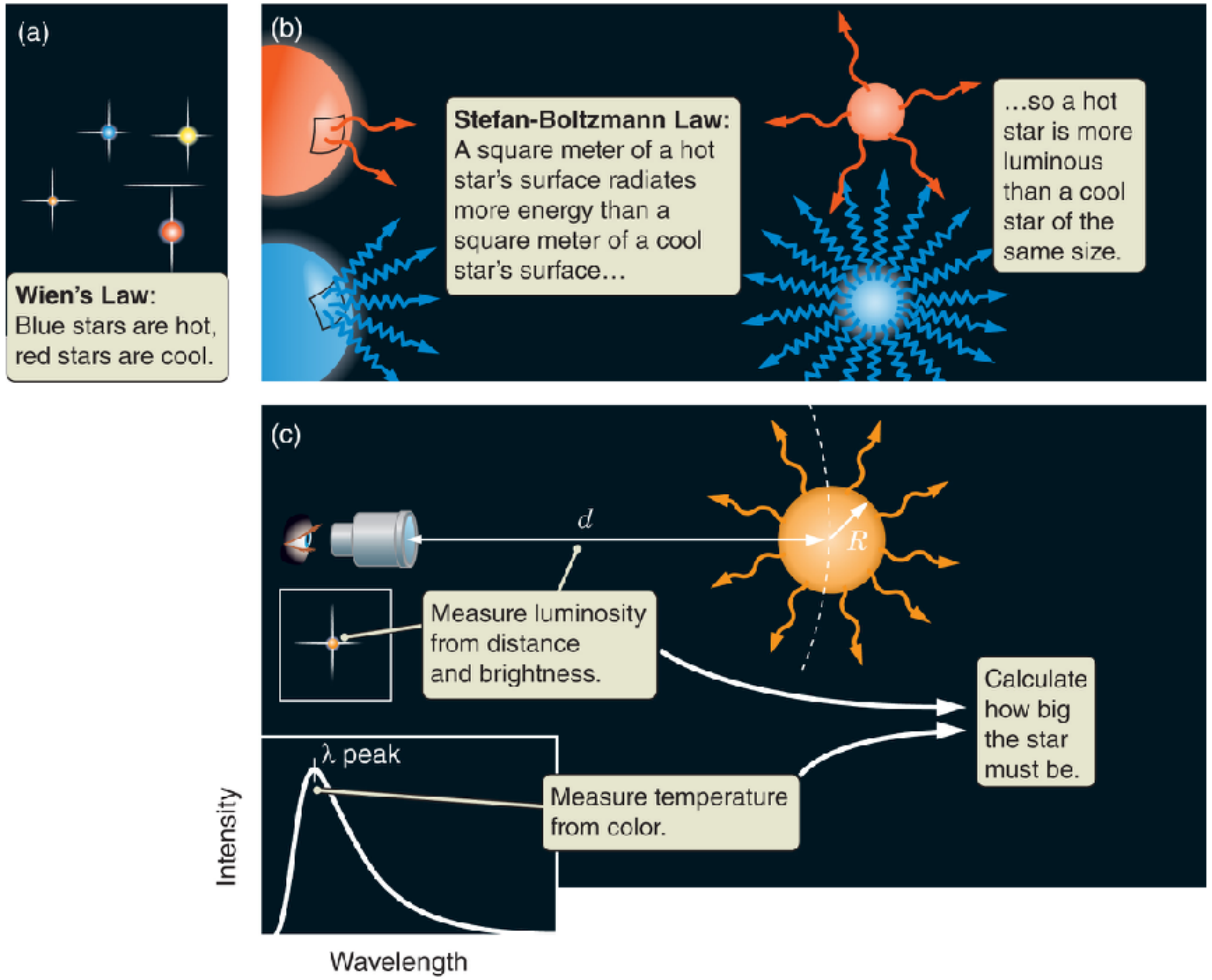
Transit Method

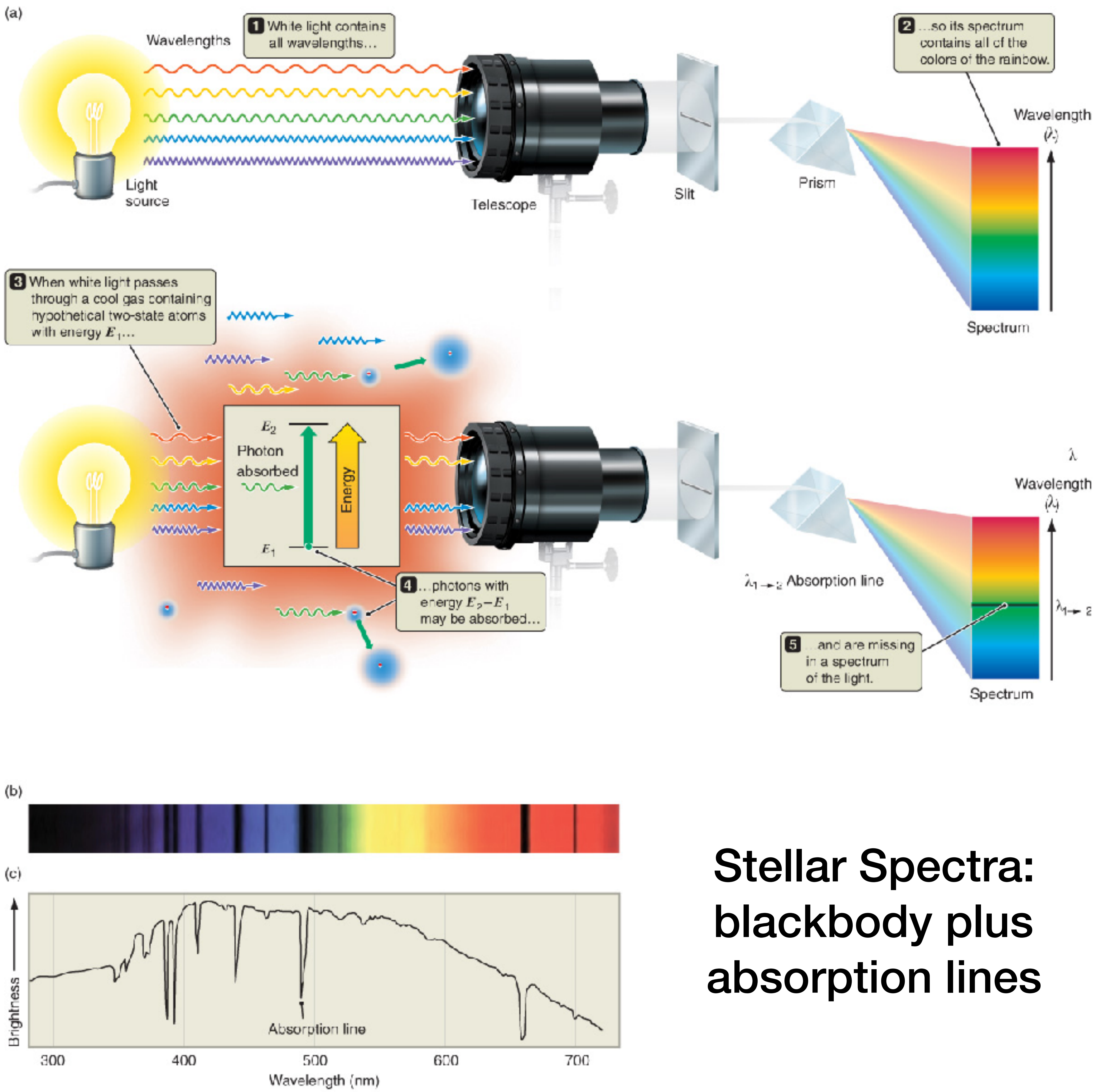
- Detect their influence on their star
  - Measure light blocked from the star when the planet eclipses it
  - Measure the star's motion due to the planet's gravity

$$\frac{\lambda_{observed} - \lambda_{emitted}}{\lambda_{emitted}} = \frac{v}{c}$$

Radial Velocity Method

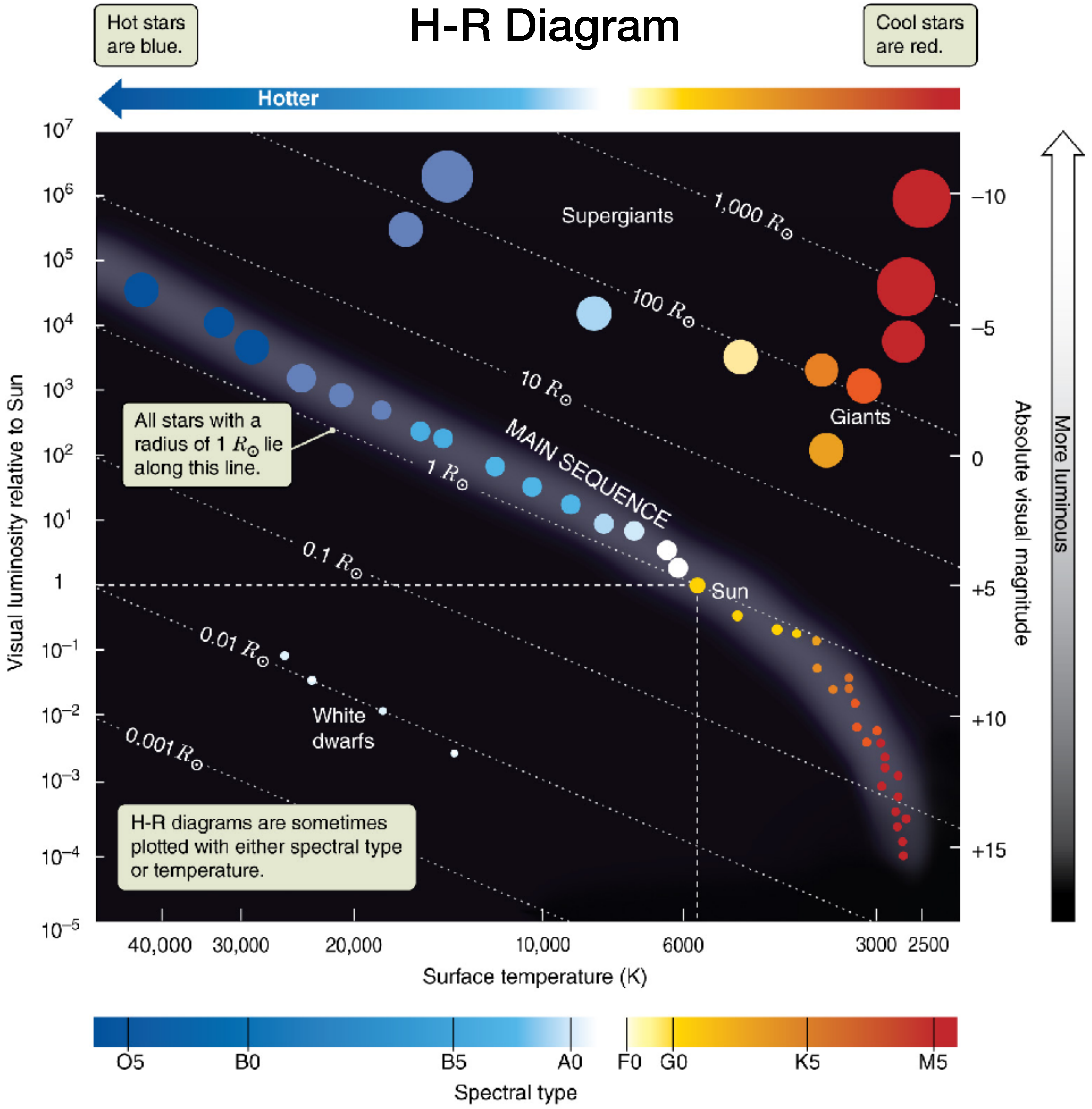
Luminosity depends on Temperature AND Size

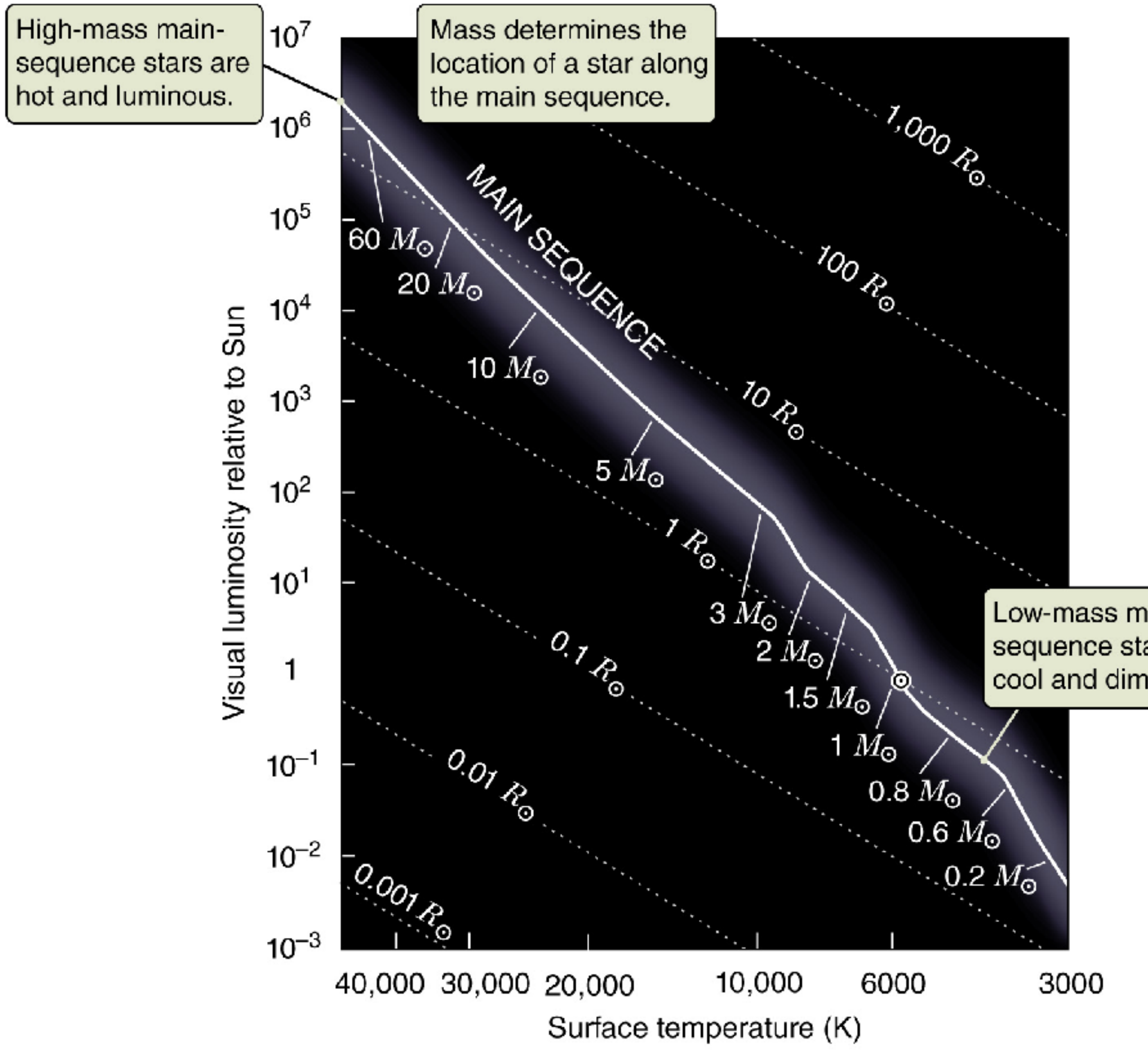




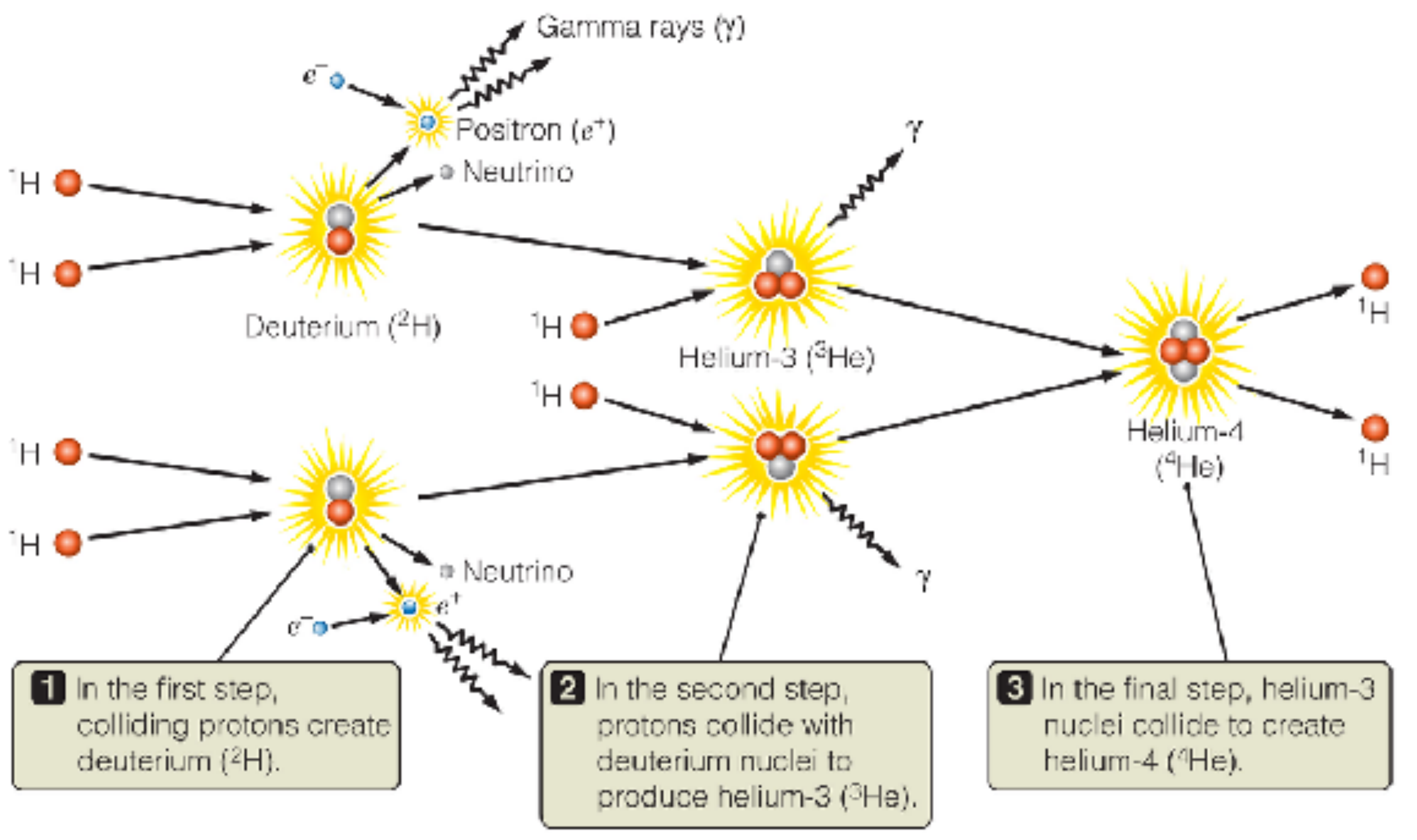
Stellar Spectra: blackbody plus absorption lines

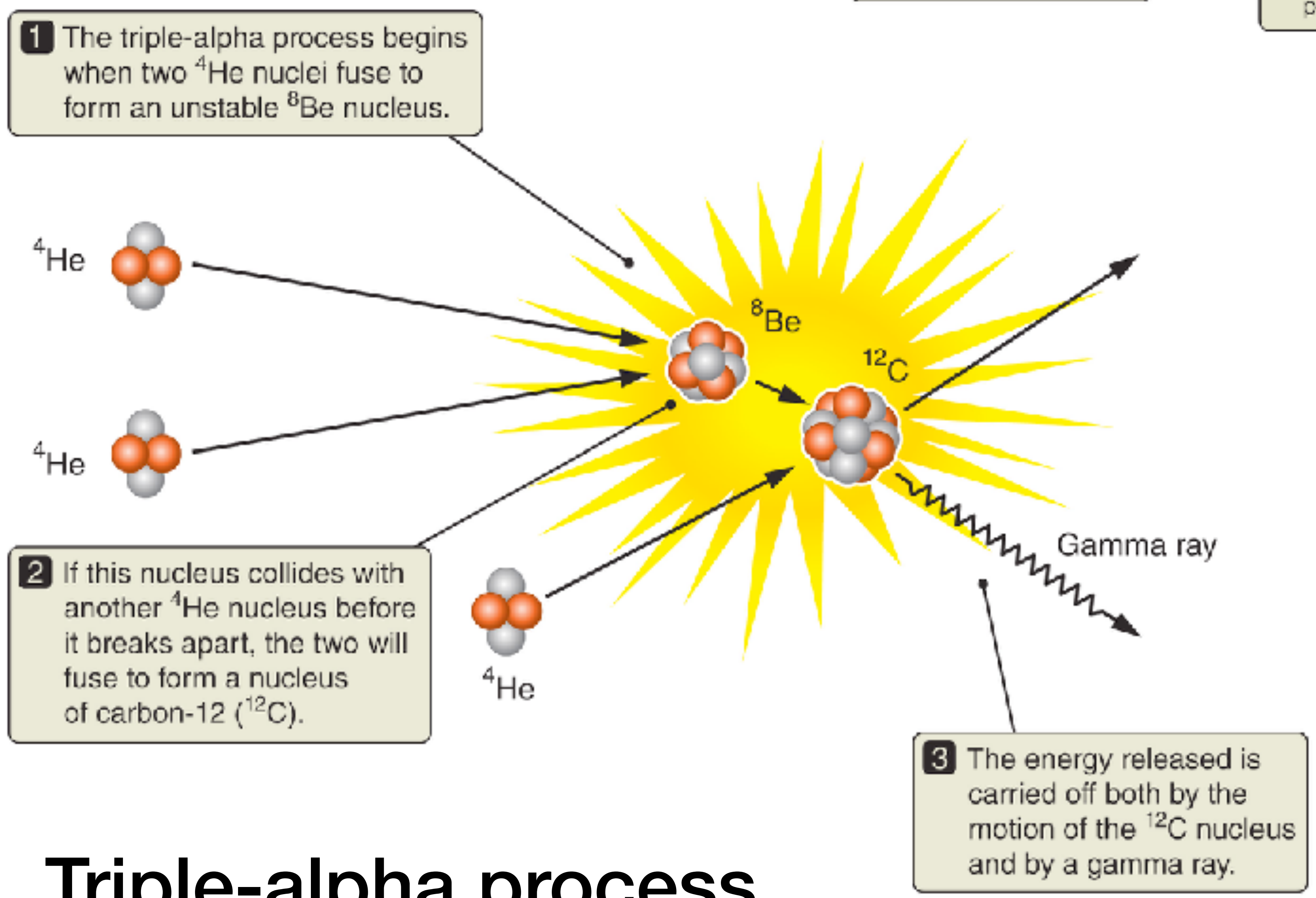
H-R Diagram


Hot stars are blue.
Cool stars are red.
Hotter
Supergiants
Giants
MAIN SEQUENCE
White dwarfs
Sun
1,000 $R_\odot$
100 $R_\odot$
10 $R_\odot$
1 $R_\odot$
0.1 $R_\odot$
0.01 $R_\odot$
0.001 $R_\odot$
All stars with a radius of 1 $R_\odot$ lie along this line.
H-R diagrams are sometimes plotted with either spectral type or temperature.
Visual luminosity relative to Sun
10^7
10^6
10^5
10^4
10^3
10^2
10^1
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
Absolute visual magnitude
−10
−5
0
+5
+10
+15
More luminous
40,000 30,000 20,000 10,000 6000 3000 2500
Surface temperature (K)
O5 B0 B5 A0 F0 G0 K5 M5
Spectral type

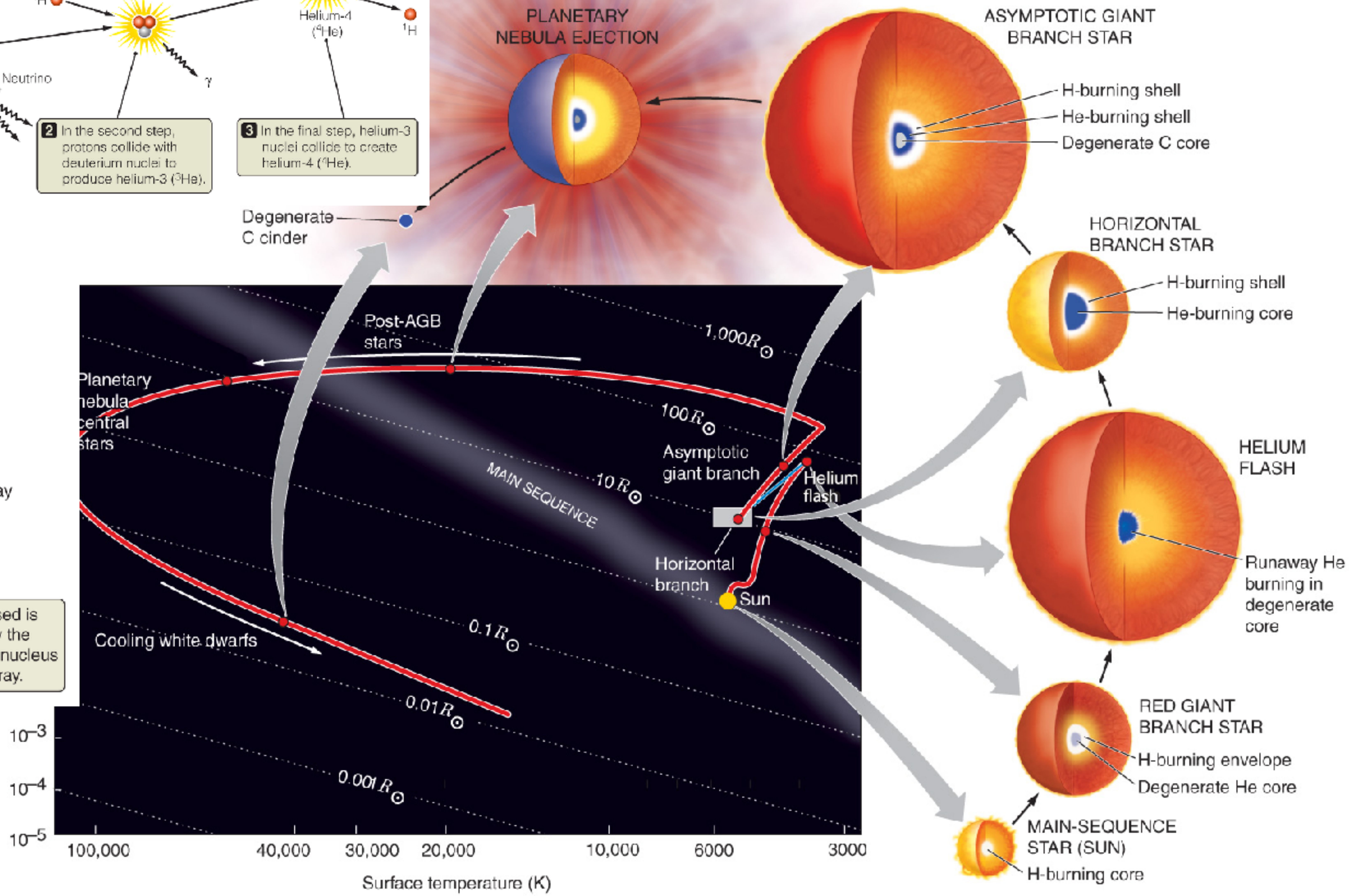

High-mass main-sequence stars are hot and luminous.
Mass determines the location of a star along the main sequence.
Low-mass m sequence sta cool and dim
MAIN SEQUENCE
60 $M_\odot$
20 $M_\odot$
10 $M_\odot$
5 $M_\odot$
3 $M_\odot$
2 $M_\odot$
1.5 $M_\odot$
1 $M_\odot$
0.8 $M_\odot$
0.6 $M_\odot$
0.2 $M_\odot$
1,000 $R_\odot$
100 $R_\odot$
10 $R_\odot$
1 $R_\odot$
0.1 $R_\odot$
0.01 $R_\odot$
0.001 $R_\odot$
Visual luminosity relative to Sun
10^7
10^6
10^5
10^4
10^3
10^2
10^1
1
10^{-1}
10^{-2}
10^{-3}
40,000 30,000 20,000 10,000 6000 3000
Surface temperature (K)

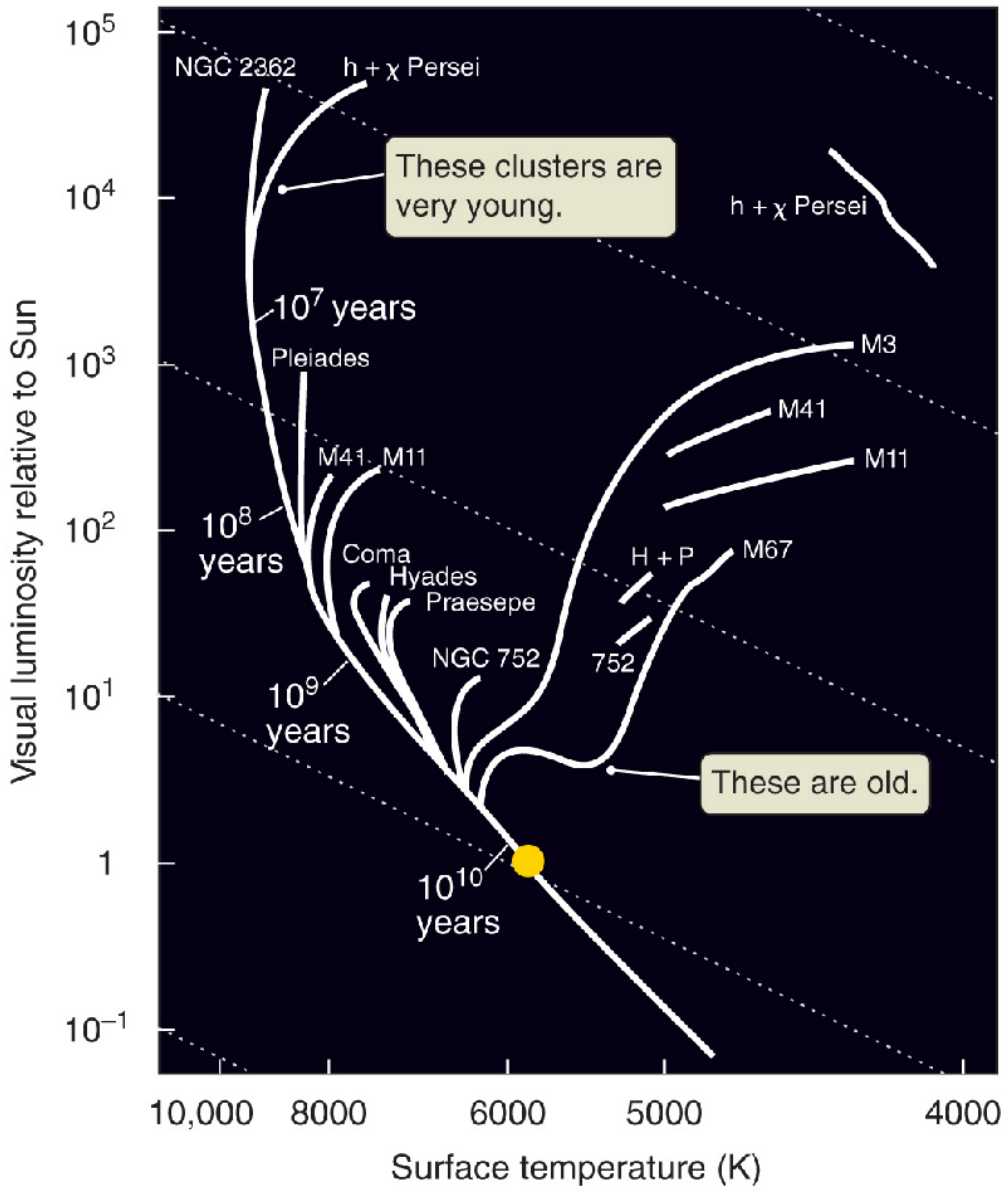
proton-proton chain burns H —> He, releasing neutrinos and positrons (gamma rays)



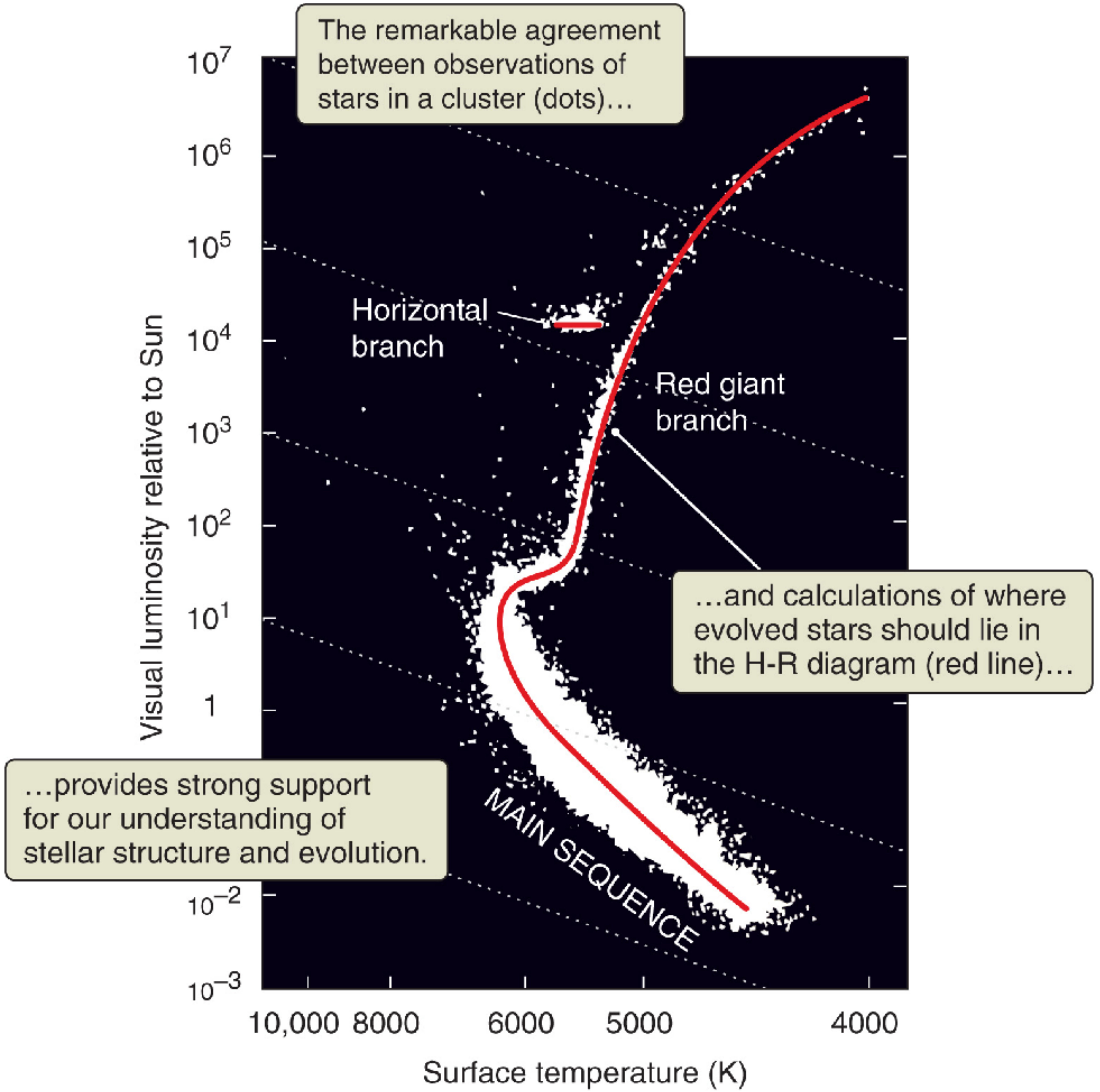


Triple-alpha process, burns He —> C in Horizontal Branch phase



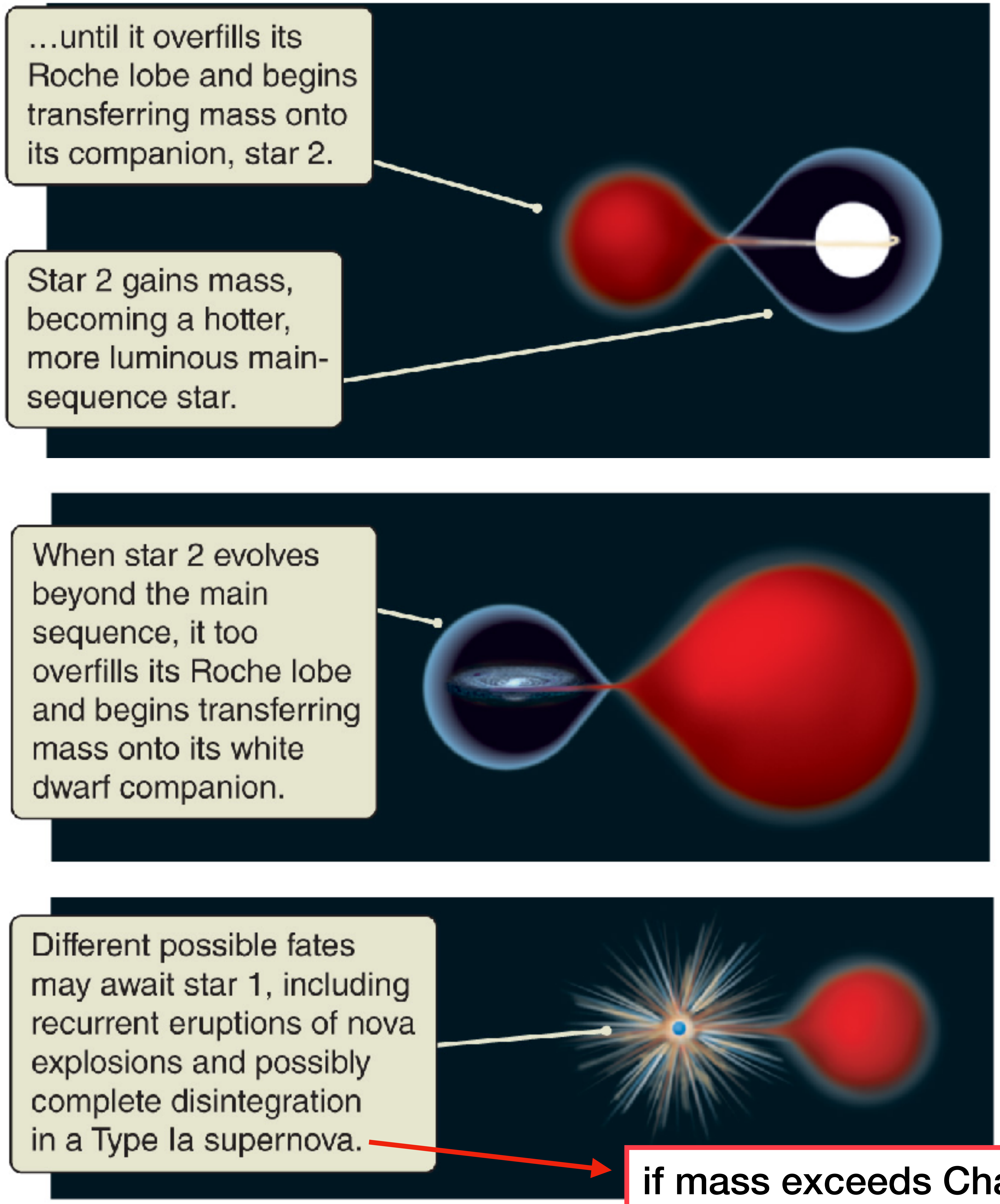


NGC 2362
h + χ Persei
These clusters are very young.
h + χ Persei
10^7 years
Pleiades
M3
M41
M41, M11
M11
10^8 years
Coma
Hyades
Praesepe
H + P
M67
NGC 752
752
10^9 years
These are old.
10^{10} years
10^5
10^4
10^3
10^2
10^1
1
10^{-1}
Visual luminosity relative to Sun
10,000
8000
6000
5000
4000
Surface temperature (K)

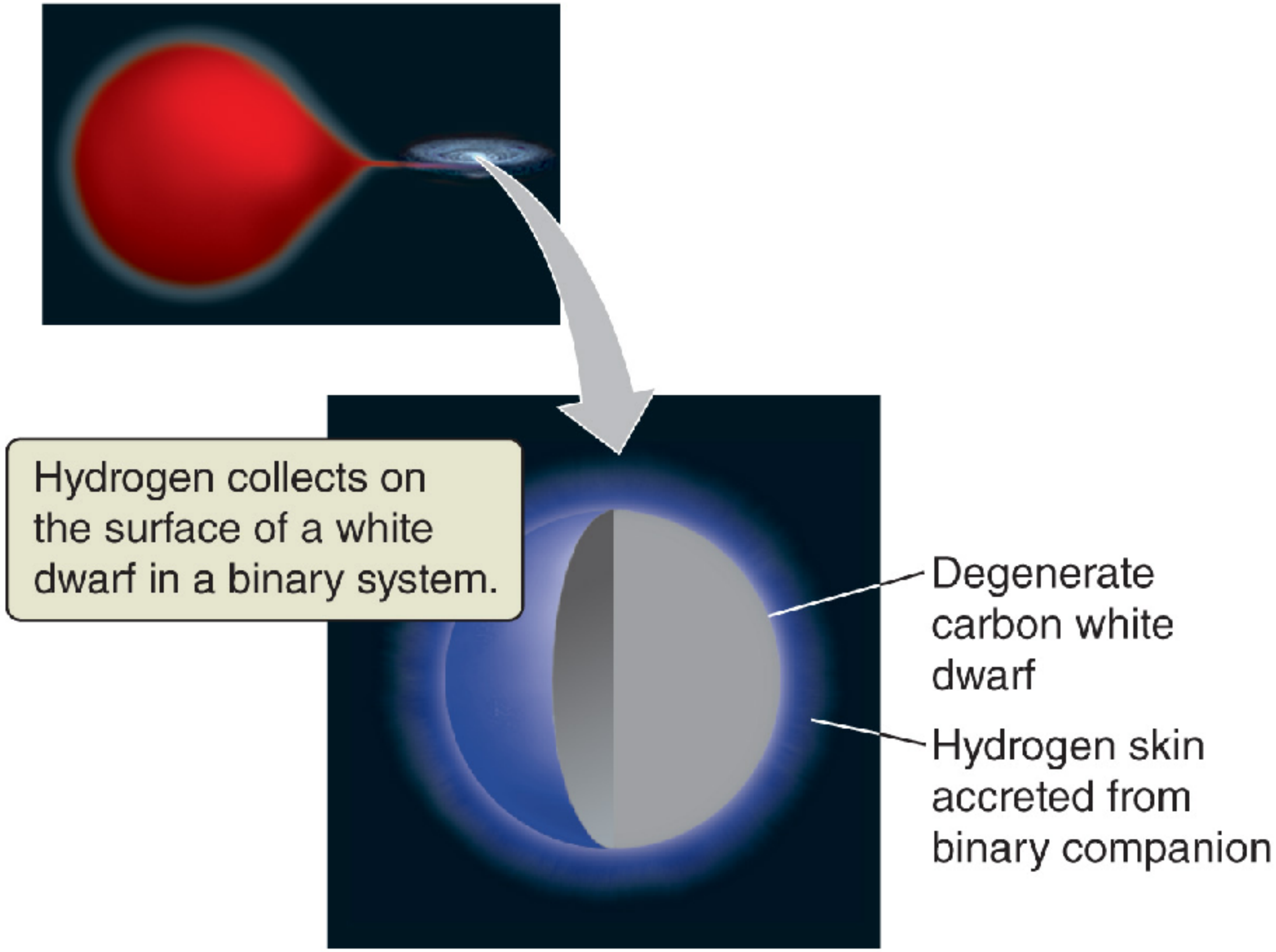


The remarkable agreement between observations of stars in a cluster (dots)…
Horizontal branch
Red giant branch
…and calculations of where evolved stars should lie in the H-R diagram (red line)…
…provides strong support for our understanding of stellar structure and evolution.
MAIN SEQUENCE
10^7
10^6
10^5
10^4
10^3
10^2
10^1
1
10^{-2}
10^{-3}
Visual luminosity relative to Sun
10,000
8000
6000
5000
4000
Surface temperature (K)

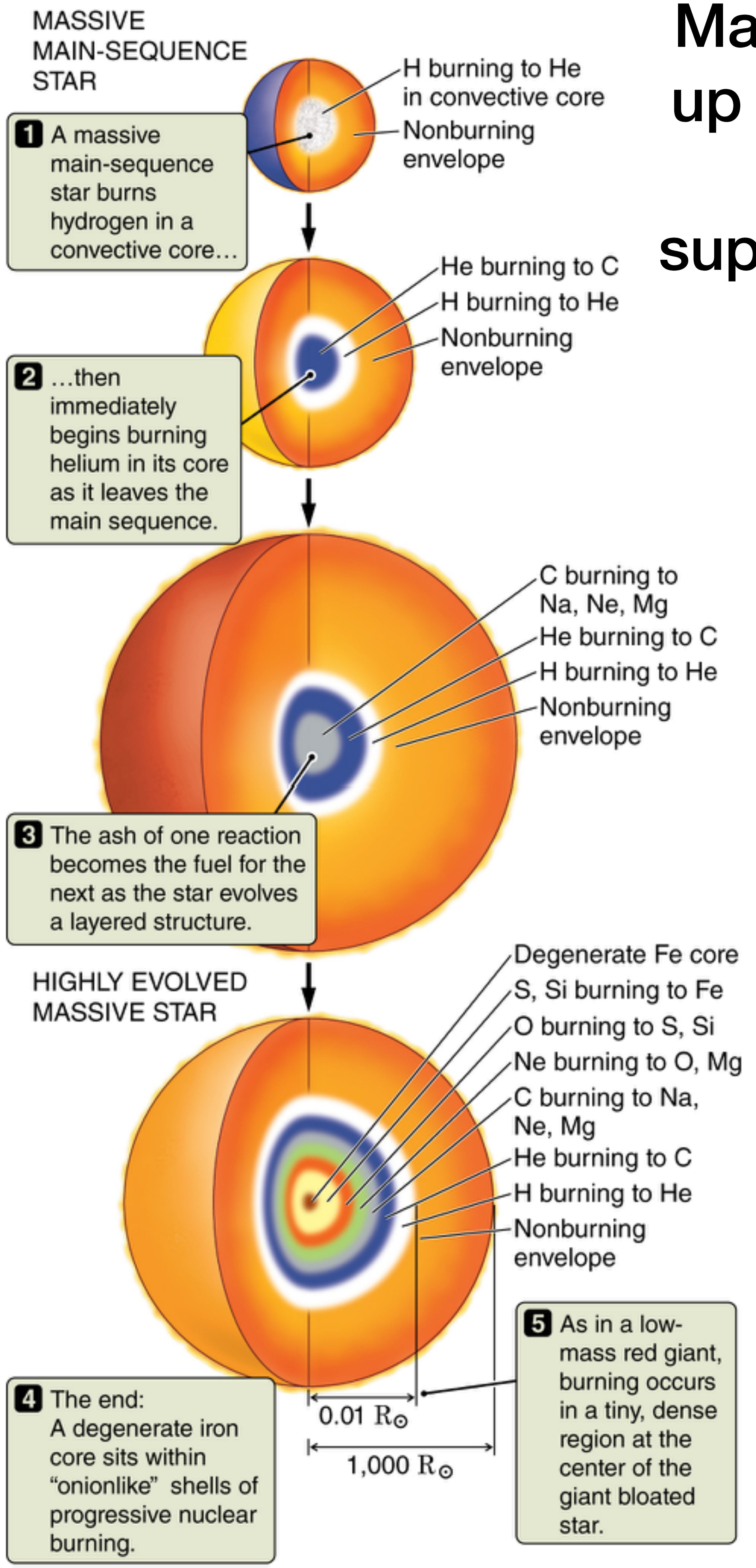
White Dwarf <—> electron degeneracy pressure

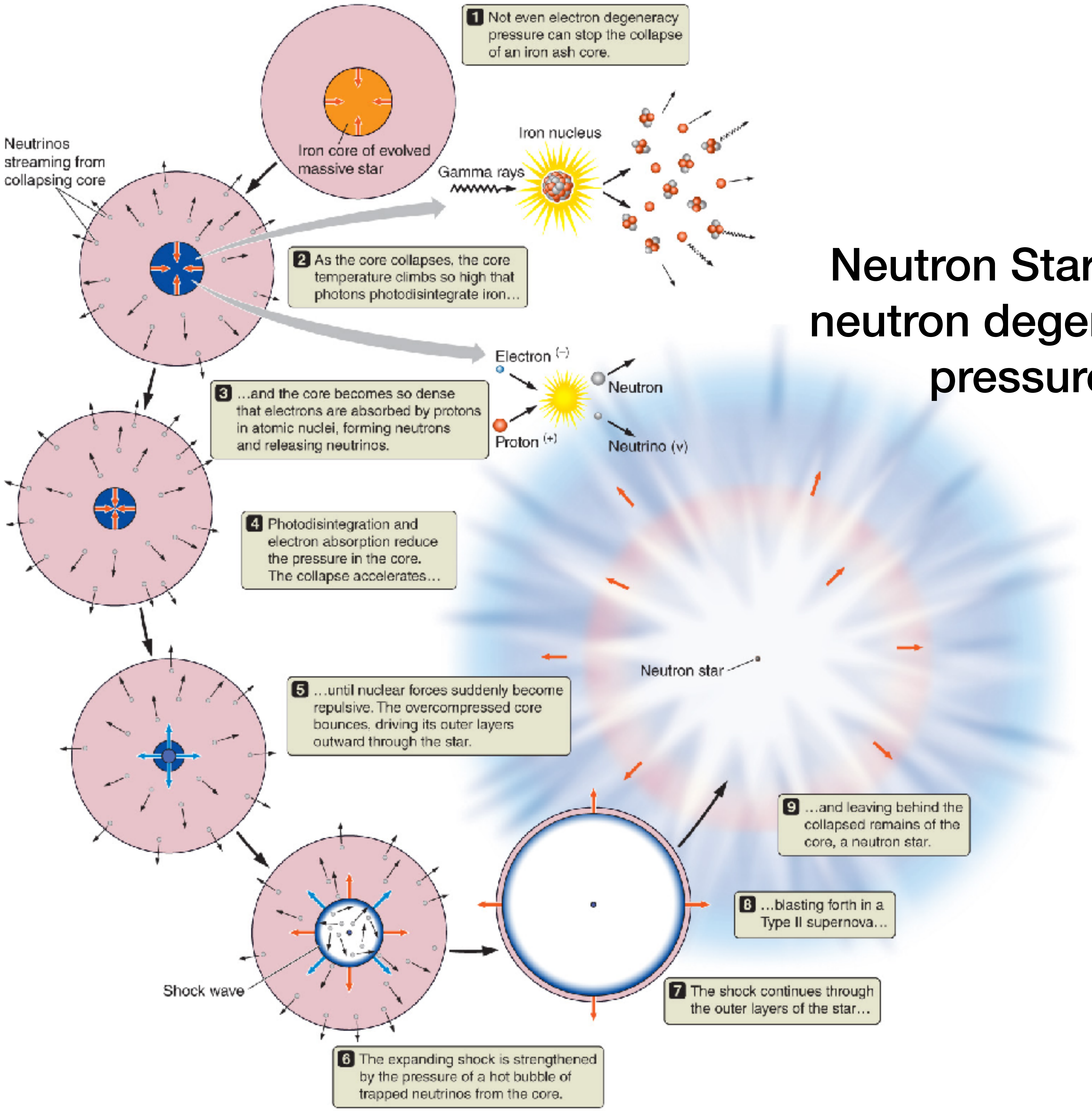


if mass exceeds Chandrasekhar limit (1.4 M_{sun})

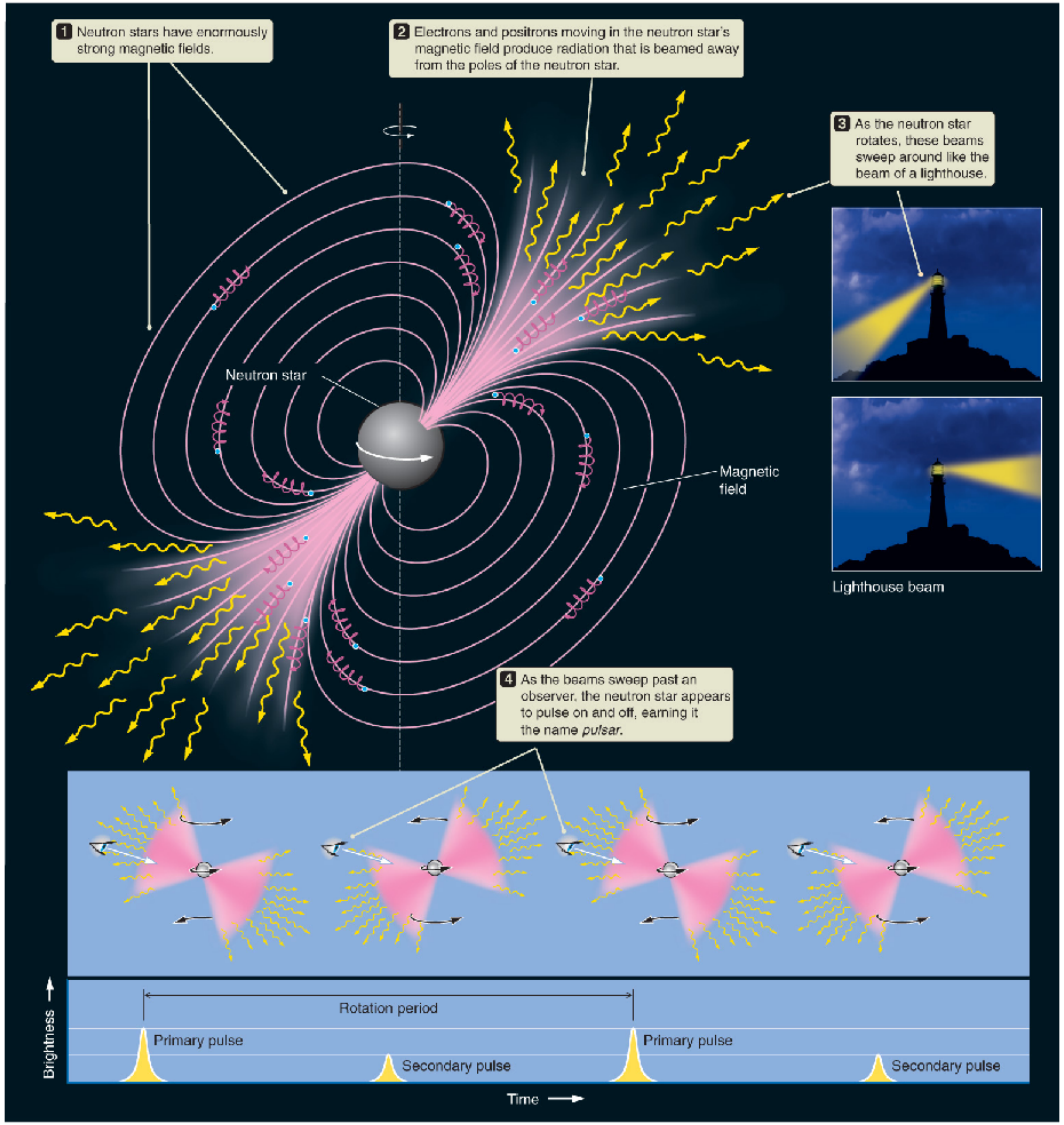


Massive stars burn up to Fe (iron) in its core, then go supernovae (Type II)





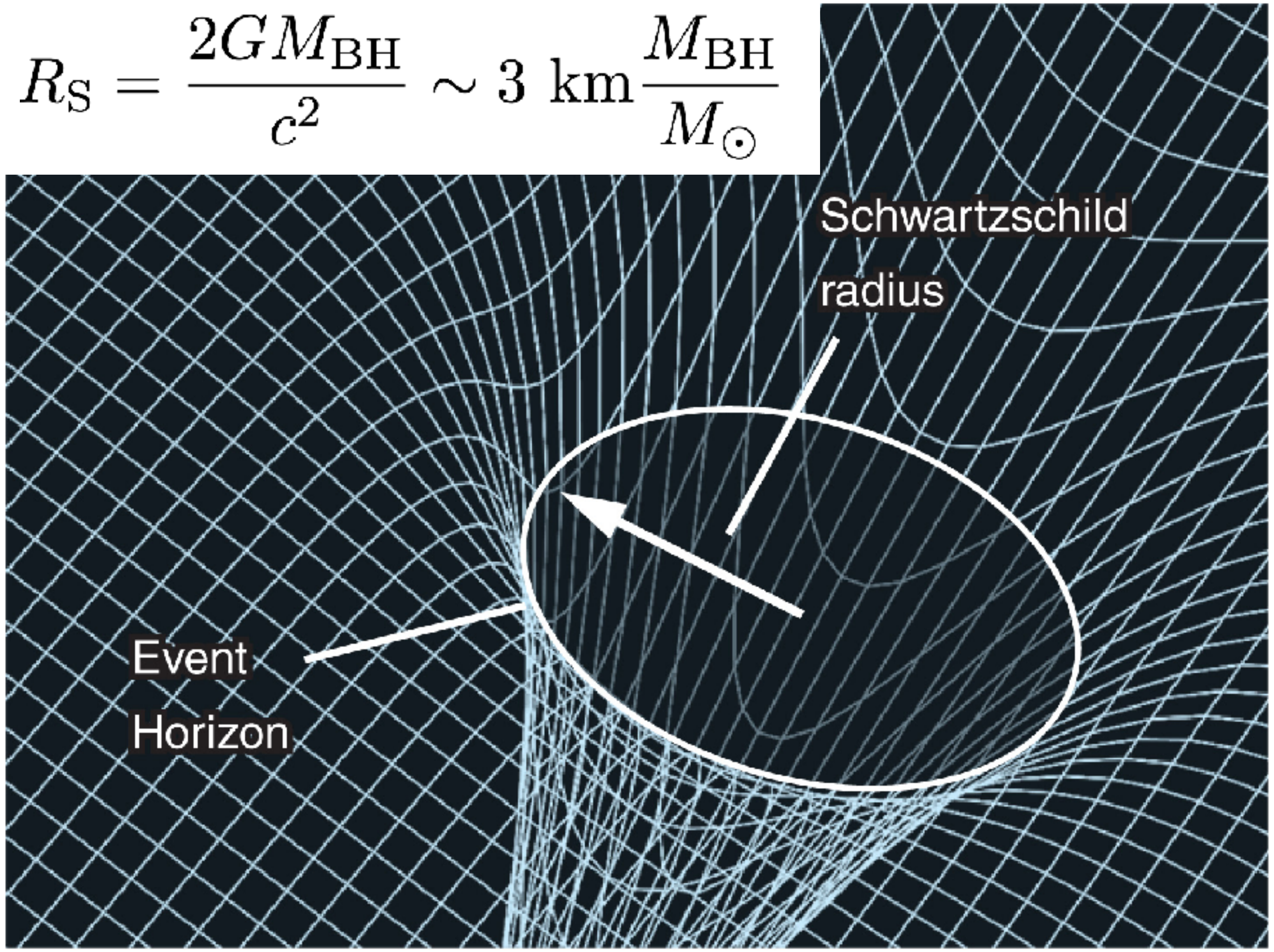
Neutron Star <—> neutron degeneracy pressure

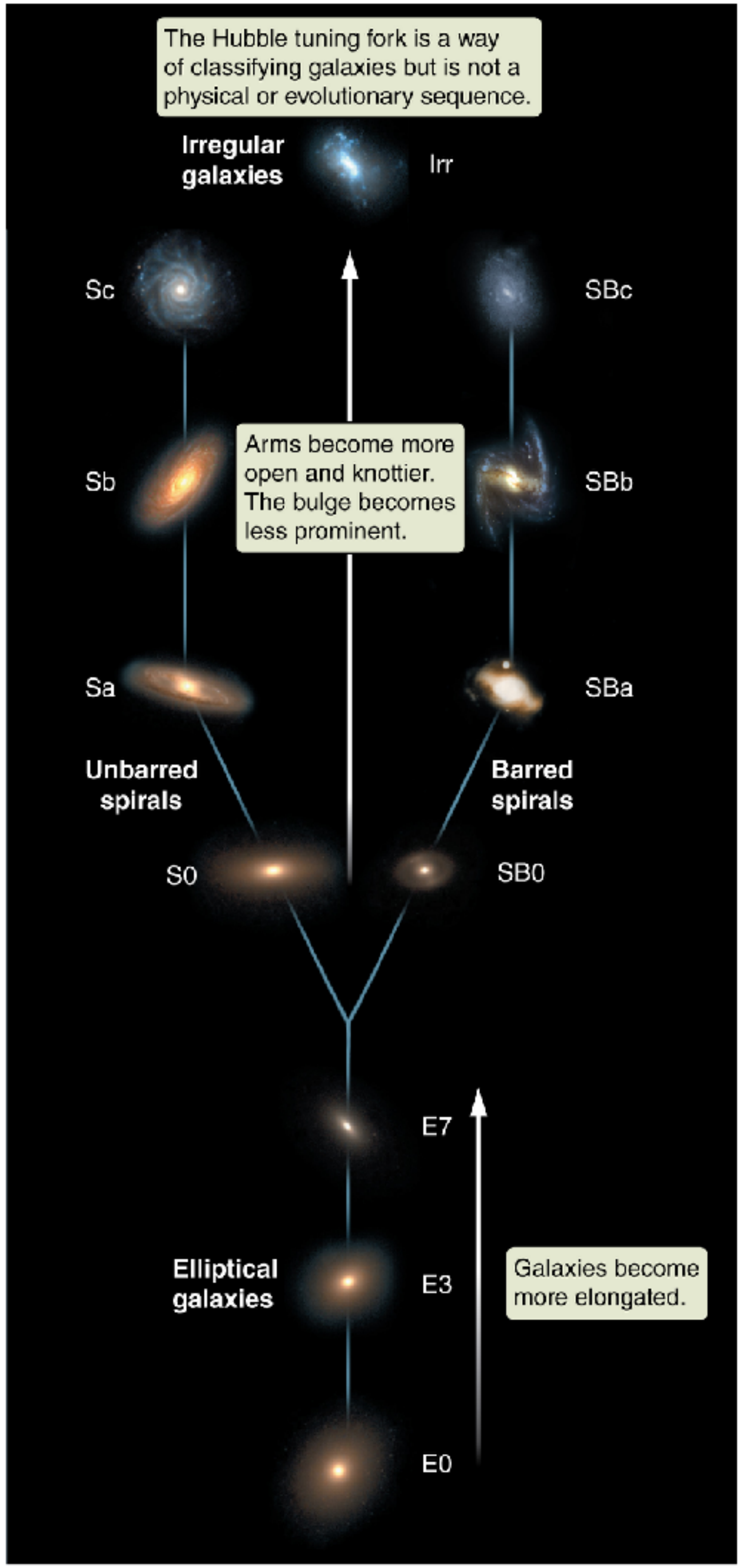


Neutron Stars

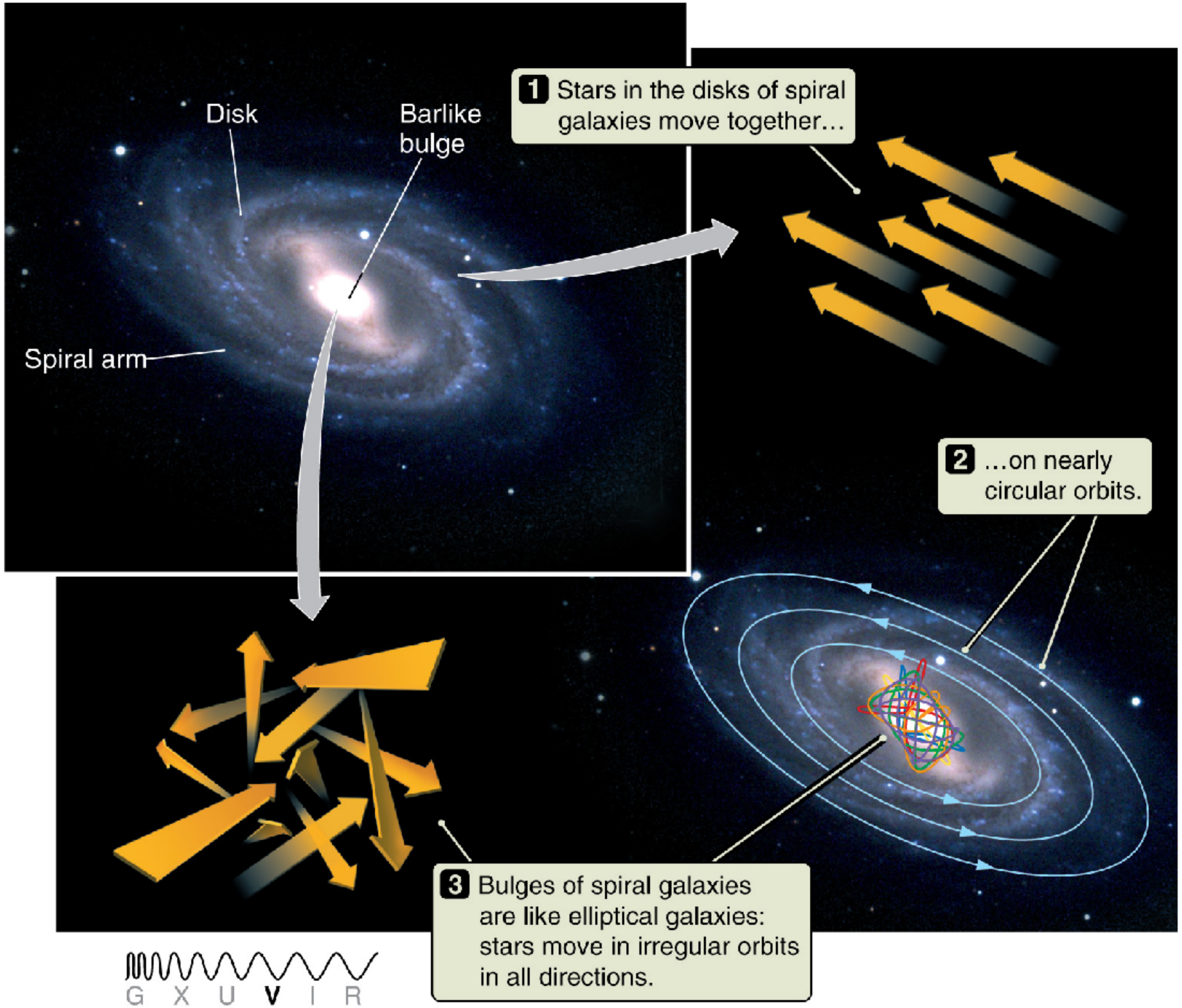
Black Holes

$$R_S = \frac{2GM_{BH}}{c^2} \sim 3\ \mathrm{km}\frac{M_{BH}}{M_\odot}$$



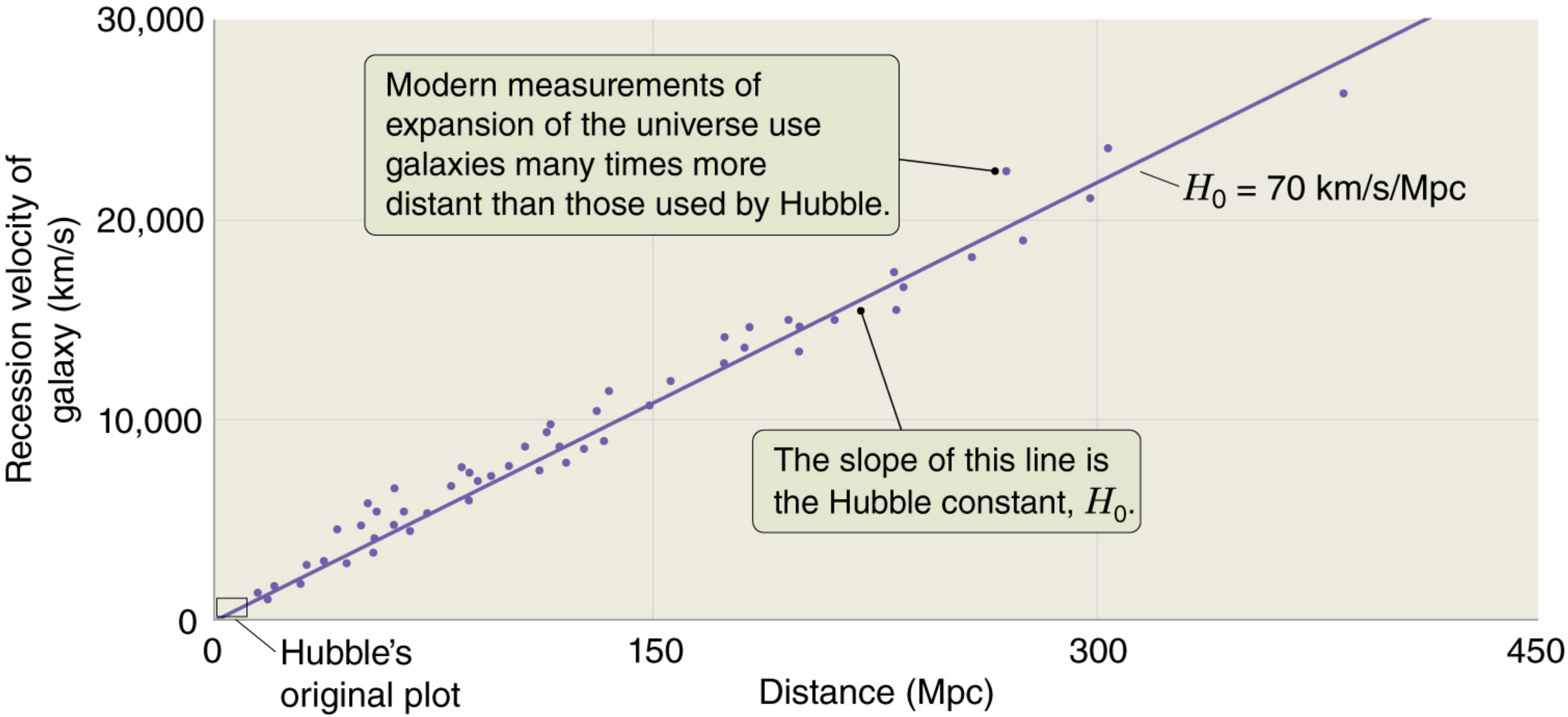


The Hubble tuning fork is a way of classifying galaxies but is not a physical or evolutionary sequence.
Irregular galaxies
Irr
Sc
SBc
Arms become more open and knottier. The bulge becomes less prominent.
Sb
SBb
Sa
SBa
Unbarred spirals
Barred spirals
S0
SB0
E7
Elliptical galaxies
E3
Galaxies become more elongated.
E0



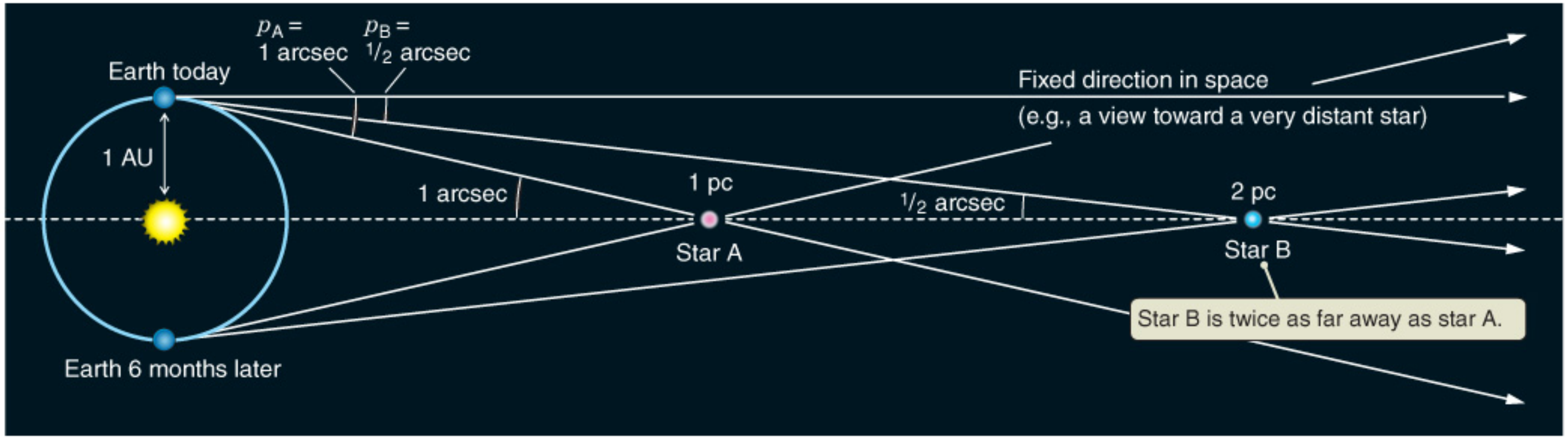
Disk
Barlike bulge
1 Stars in the disks of spiral galaxies move together…
Spiral arm
2 …on nearly circular orbits.
3 Bulges of spiral galaxies are like elliptical galaxies: stars move in irregular orbits in all directions.
G X U V I R

Hubble's law demonstrates that the universe is expanding

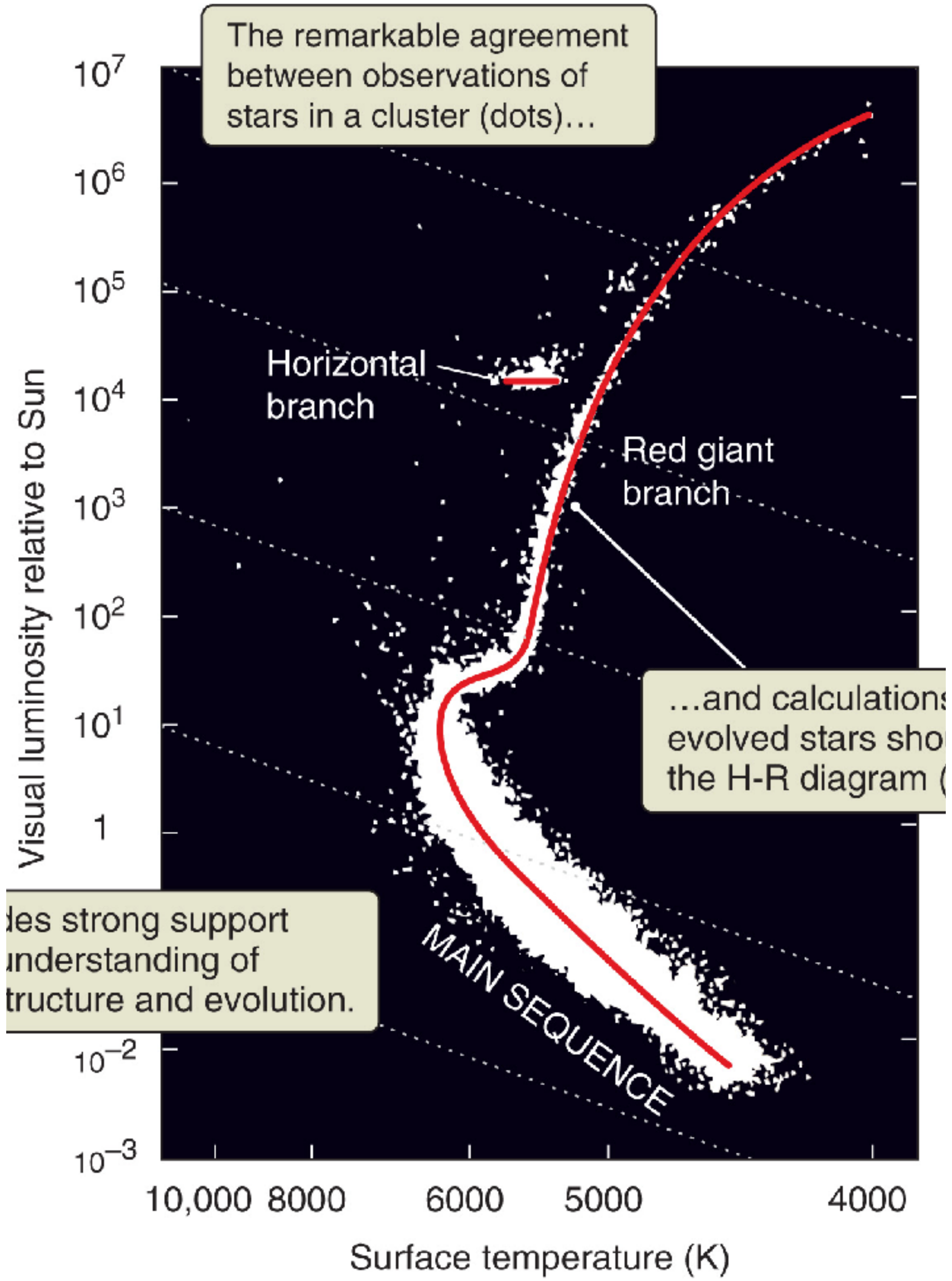


Distance Ladder

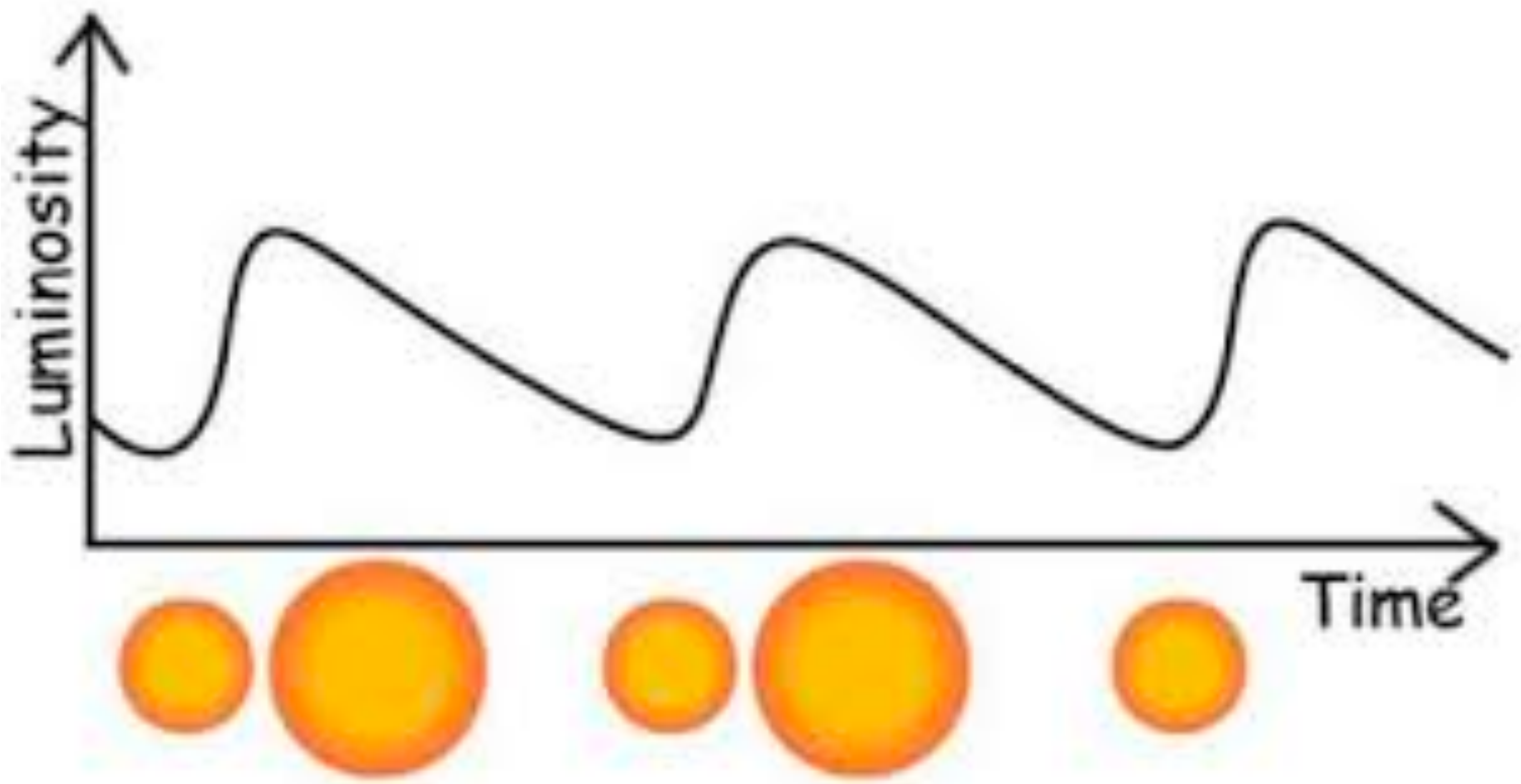
Parallax



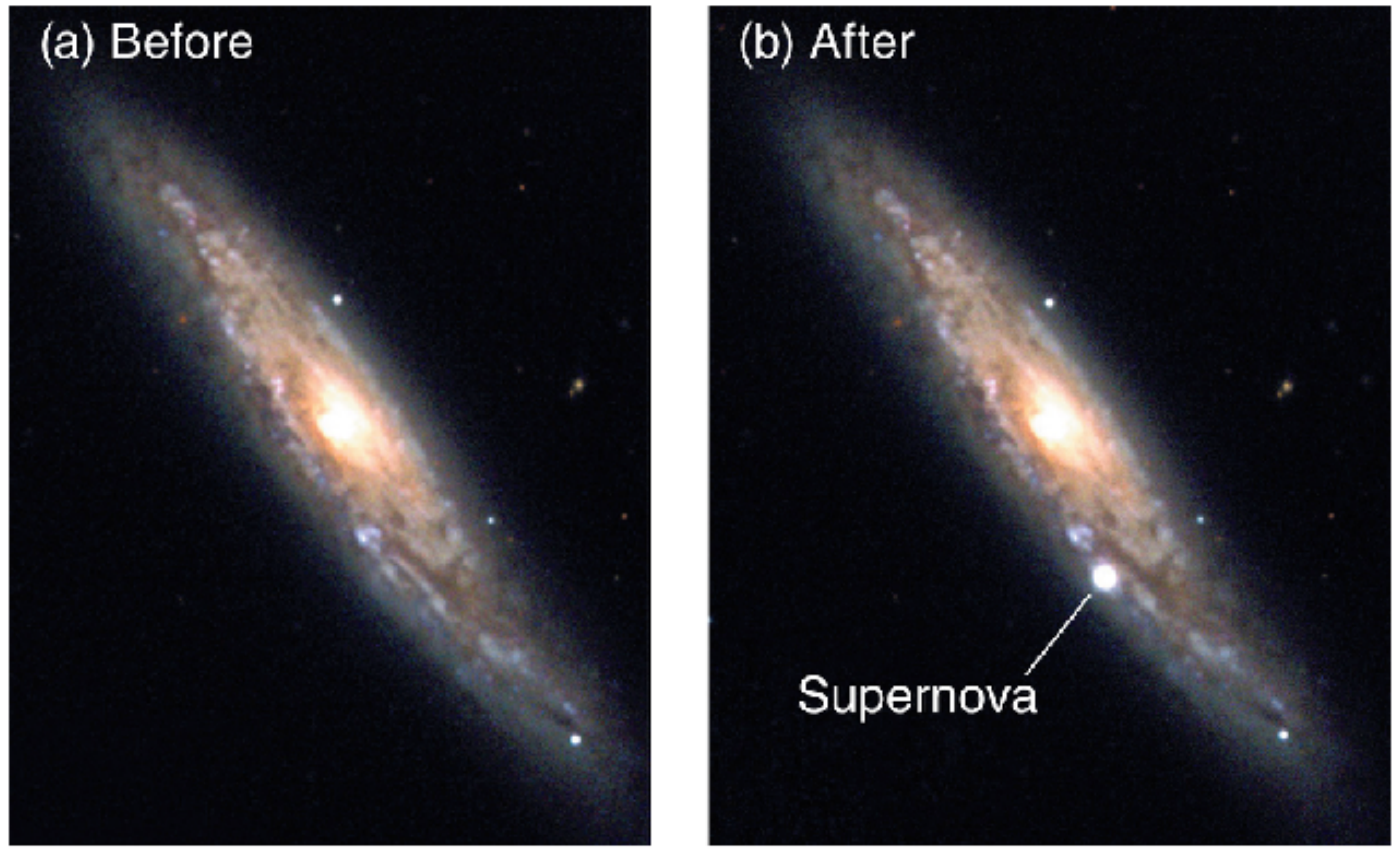
Spectroscopic Parallax



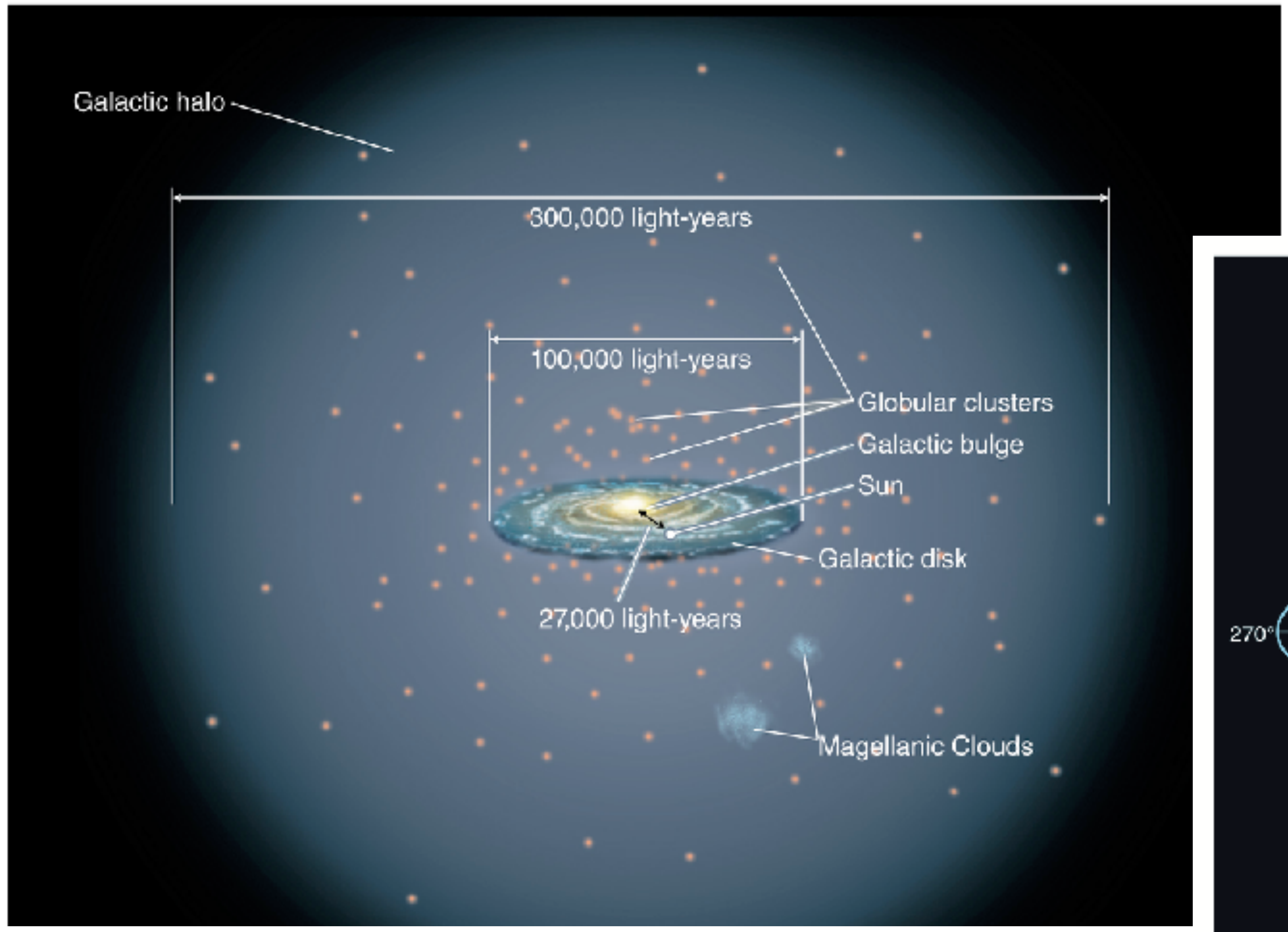
Cepheid Variables

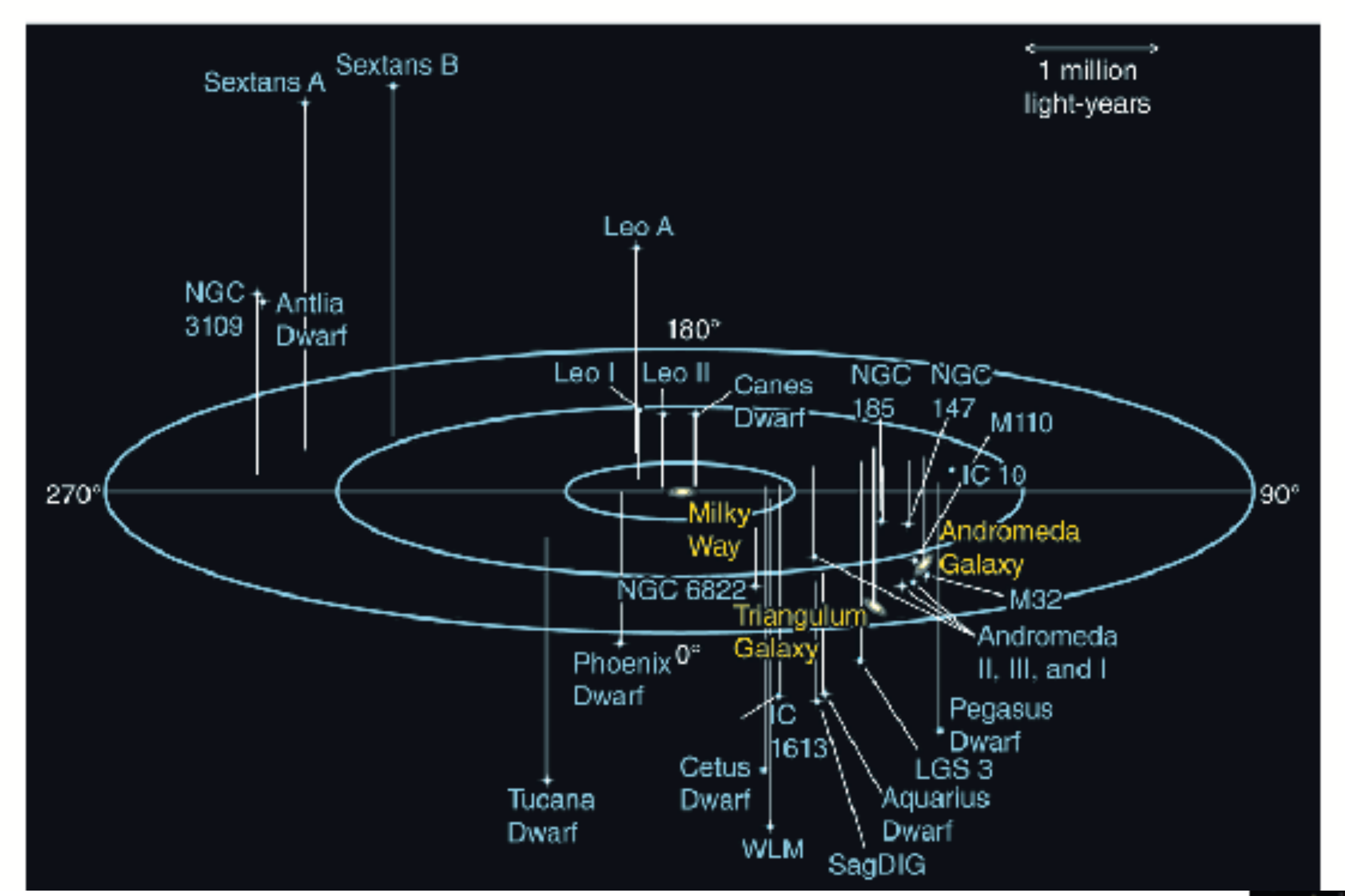


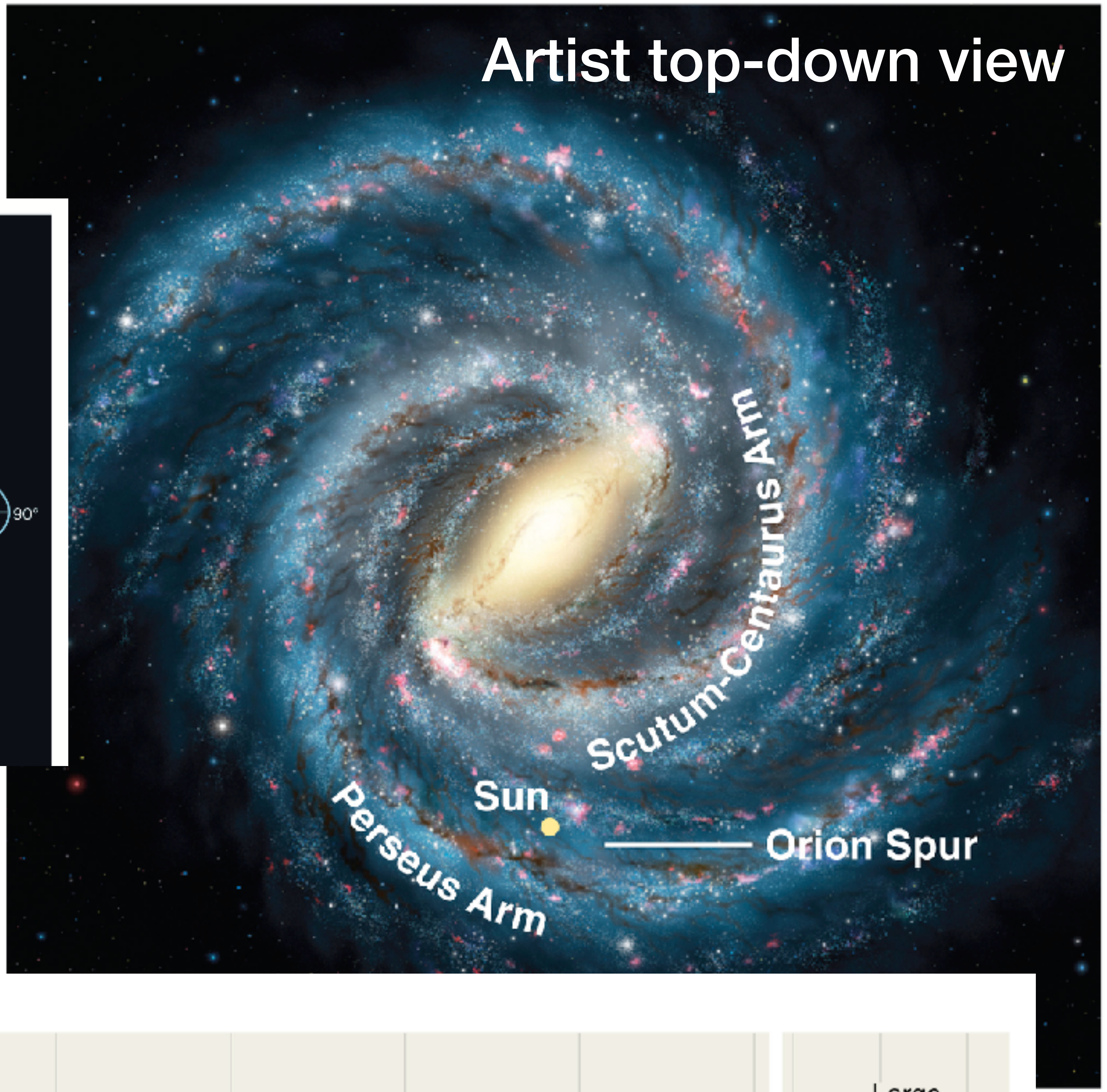
Type Ia SNe

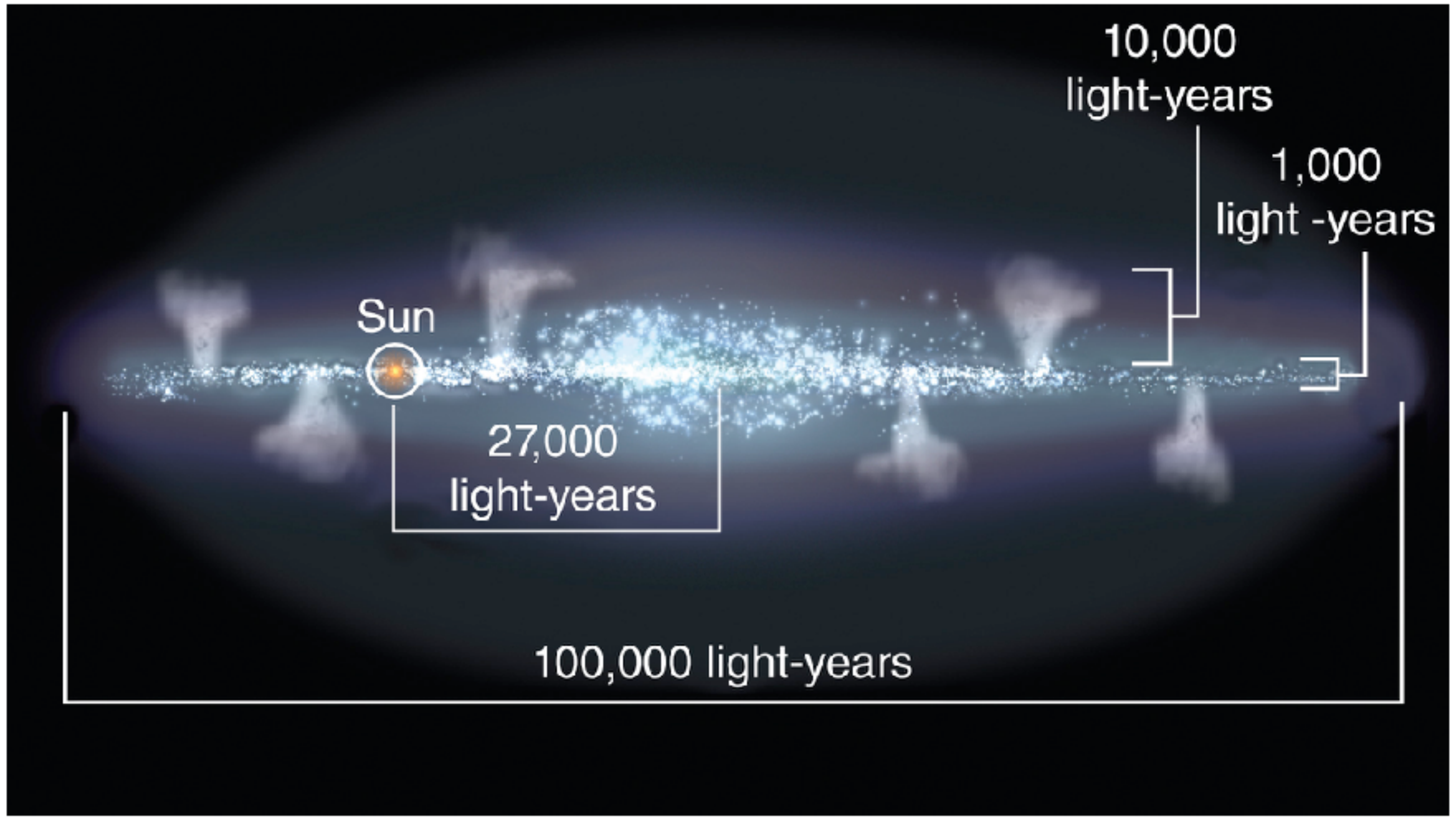


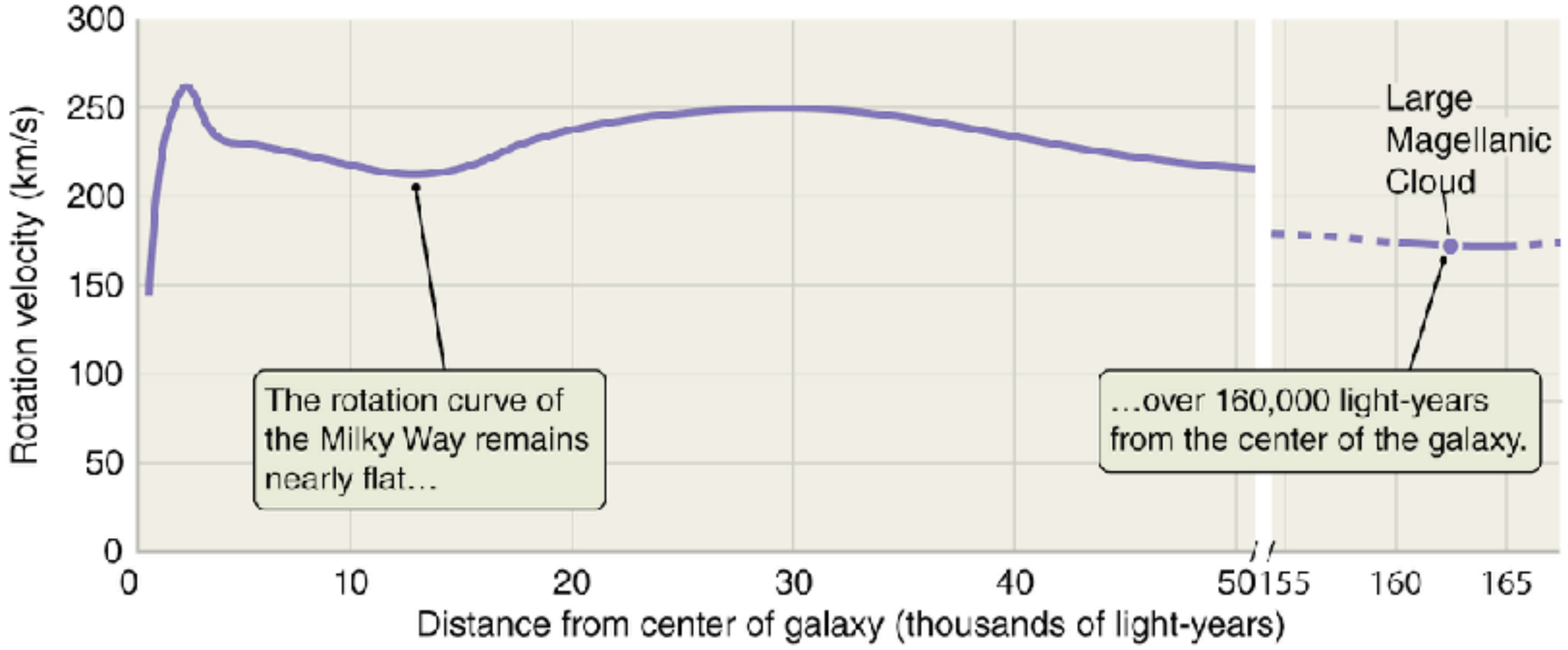
Milky Way


Galactic halo
300,000 light-years
100,000 light-years
Globular clusters
Galactic bulge
Sun
Galactic disk
27,000 light-years
Magellanic Clouds

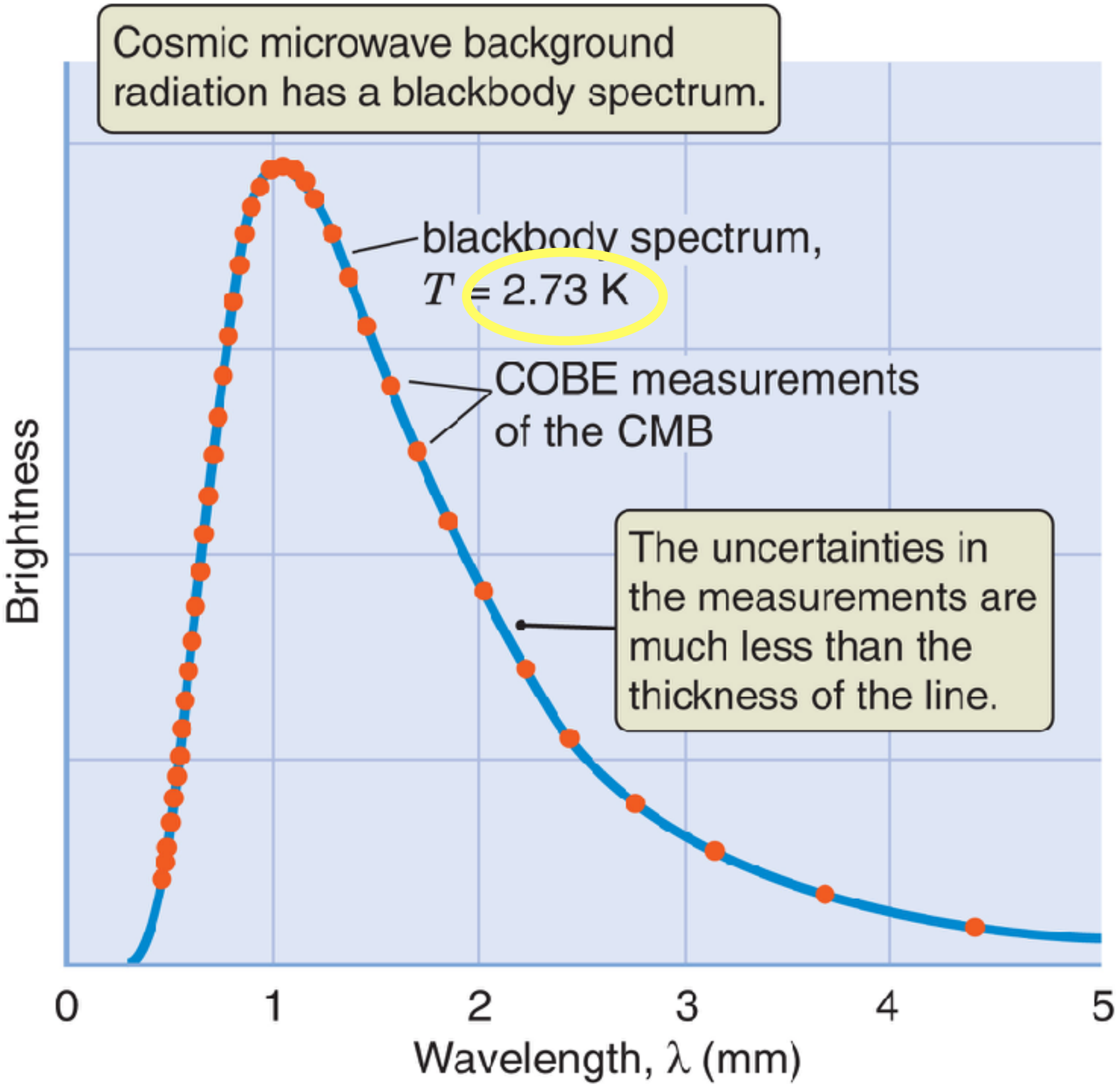

1 million light-years
Sextans A
Sextans B
Leo A
NGC 3109
Antlia Dwarf
180°
Leo I
Leo II
Canes Dwarf
NGC 185
NGC 147
M110
IC 10
270°
90°
Milky Way
Andromeda Galaxy
NGC 6822
M32
Triangulum Galaxy
Andromeda II, III, and I
Phoenix Dwarf
0°
Pegasus Dwarf
IC 1613
LGS 3
Cetus Dwarf
Aquarius Dwarf
Tucana Dwarf
WLM
SagDIG

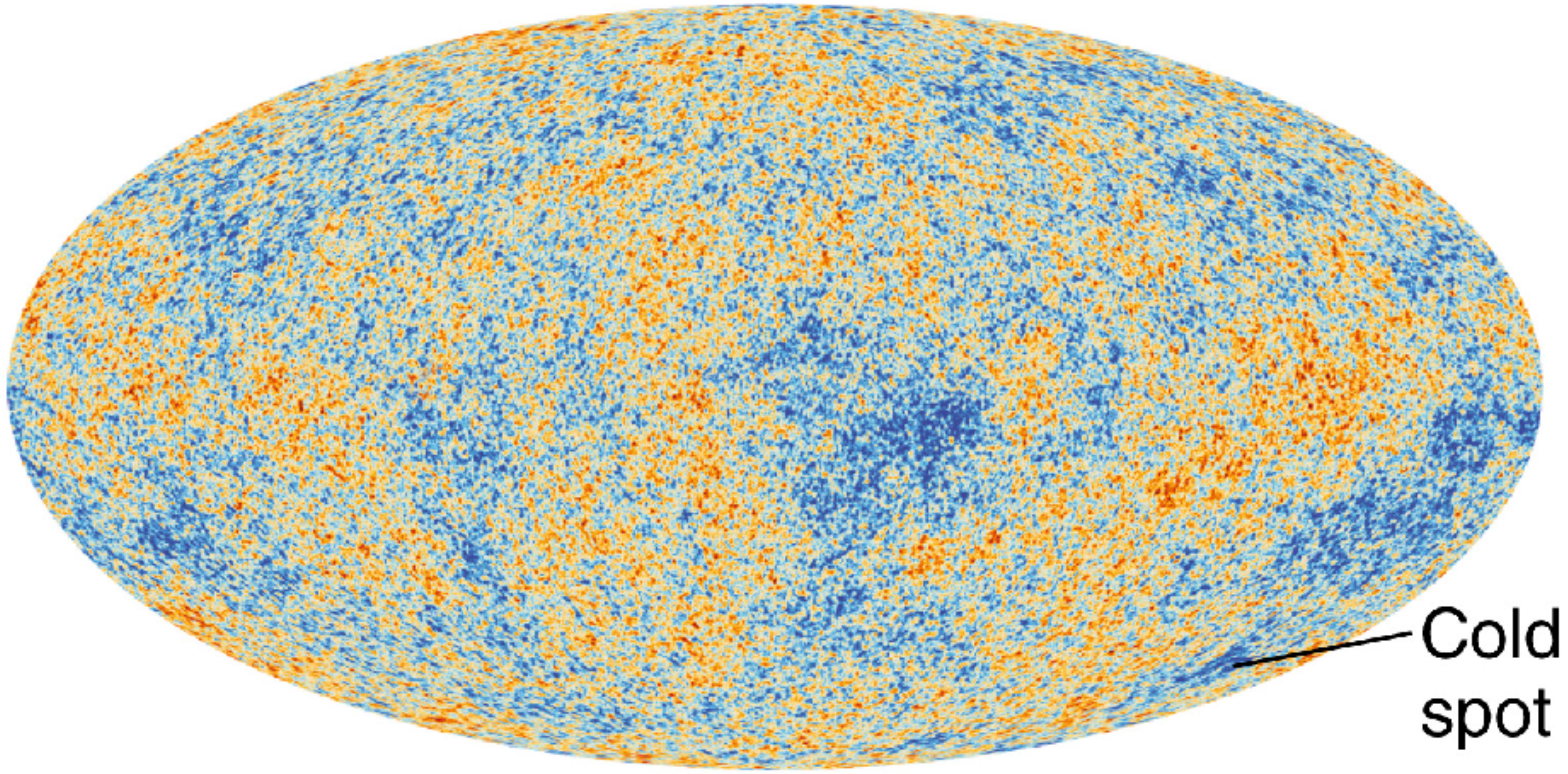

Artist top-down view
Scutum-Centaurus Arm
Sun
Perseus Arm
Orion Spur

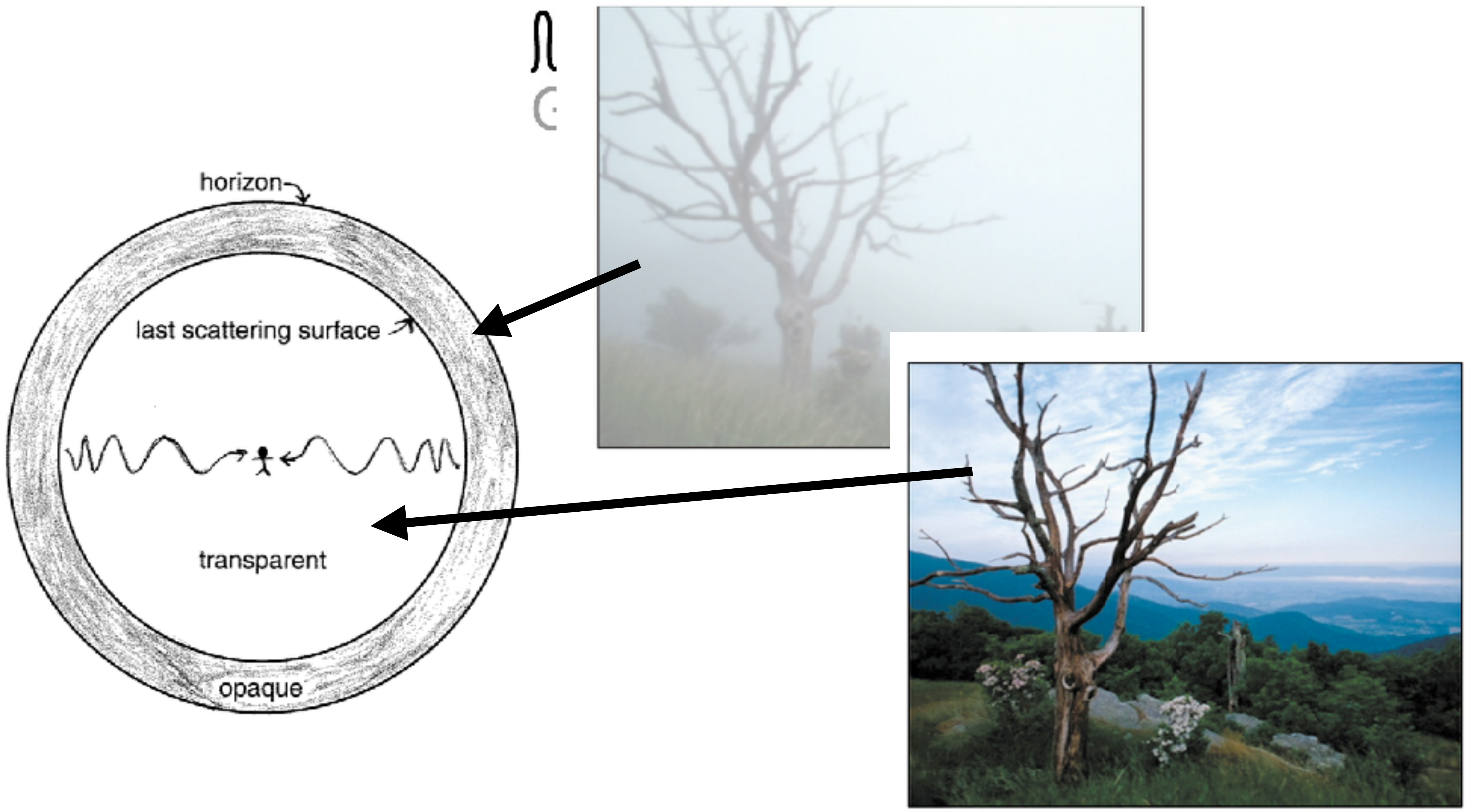

10,000 light-years
1,000 light -years
Sun
27,000 light-years
100,000 light-years


Rotation velocity (km/s)
300
250
200
150
100
50
0
Large Magellanic Cloud
The rotation curve of the Milky Way remains nearly flat...
...over 160,000 light-years from the center of the galaxy.
0
10
20
30
40
50
155
160
165
Distance from center of galaxy (thousands of light-years)

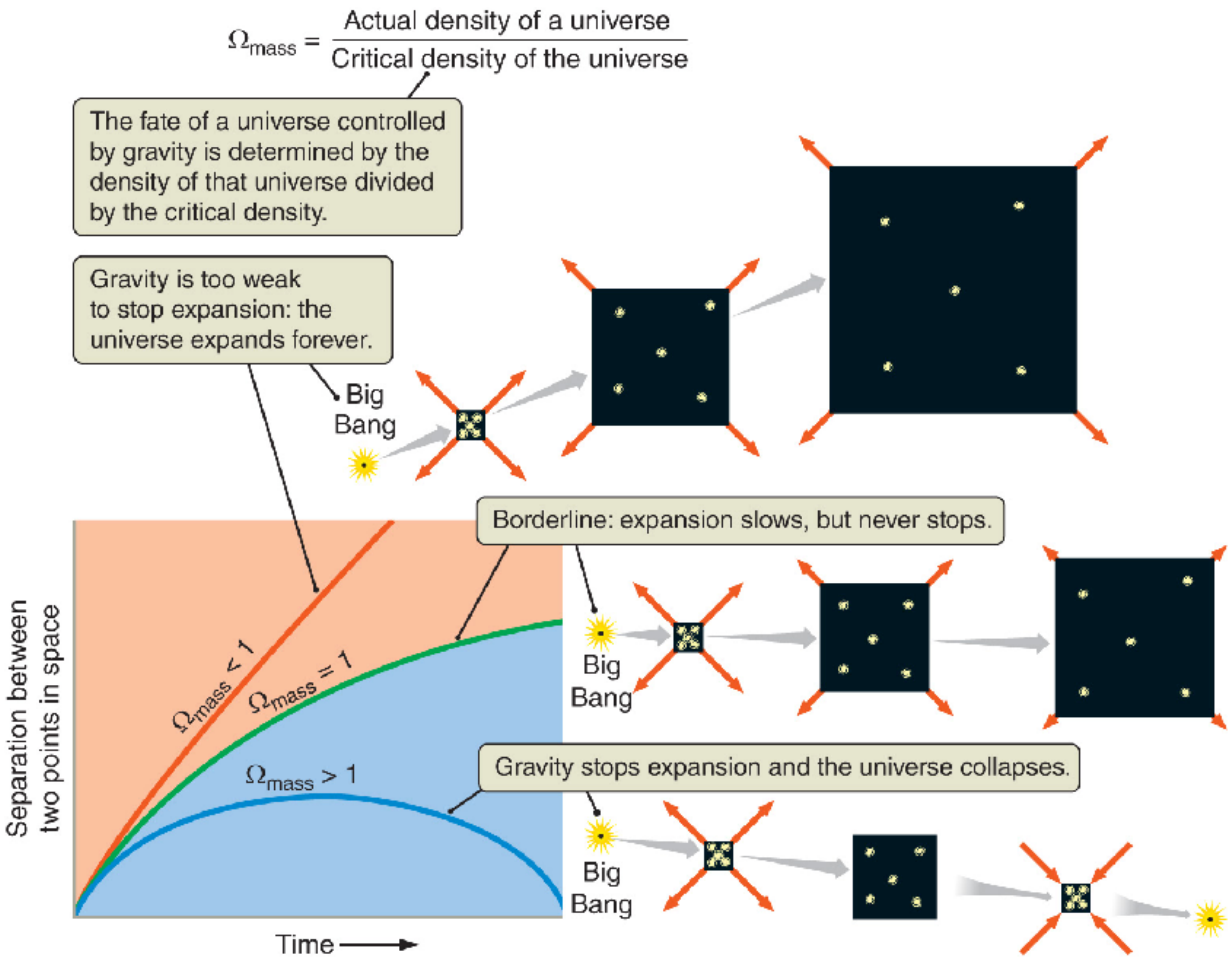
Cosmic Microwave Background - leftover radiation from the big bang

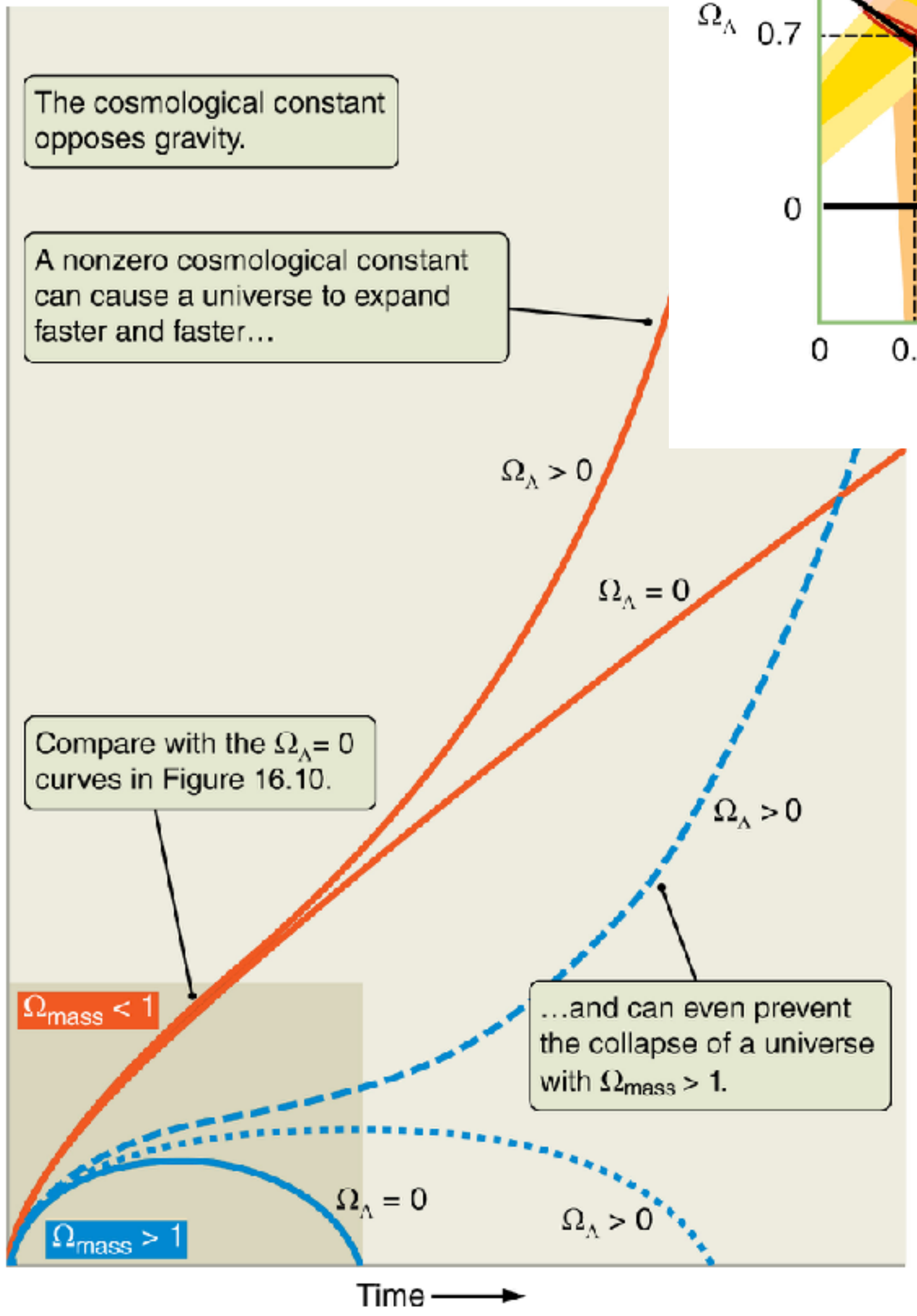


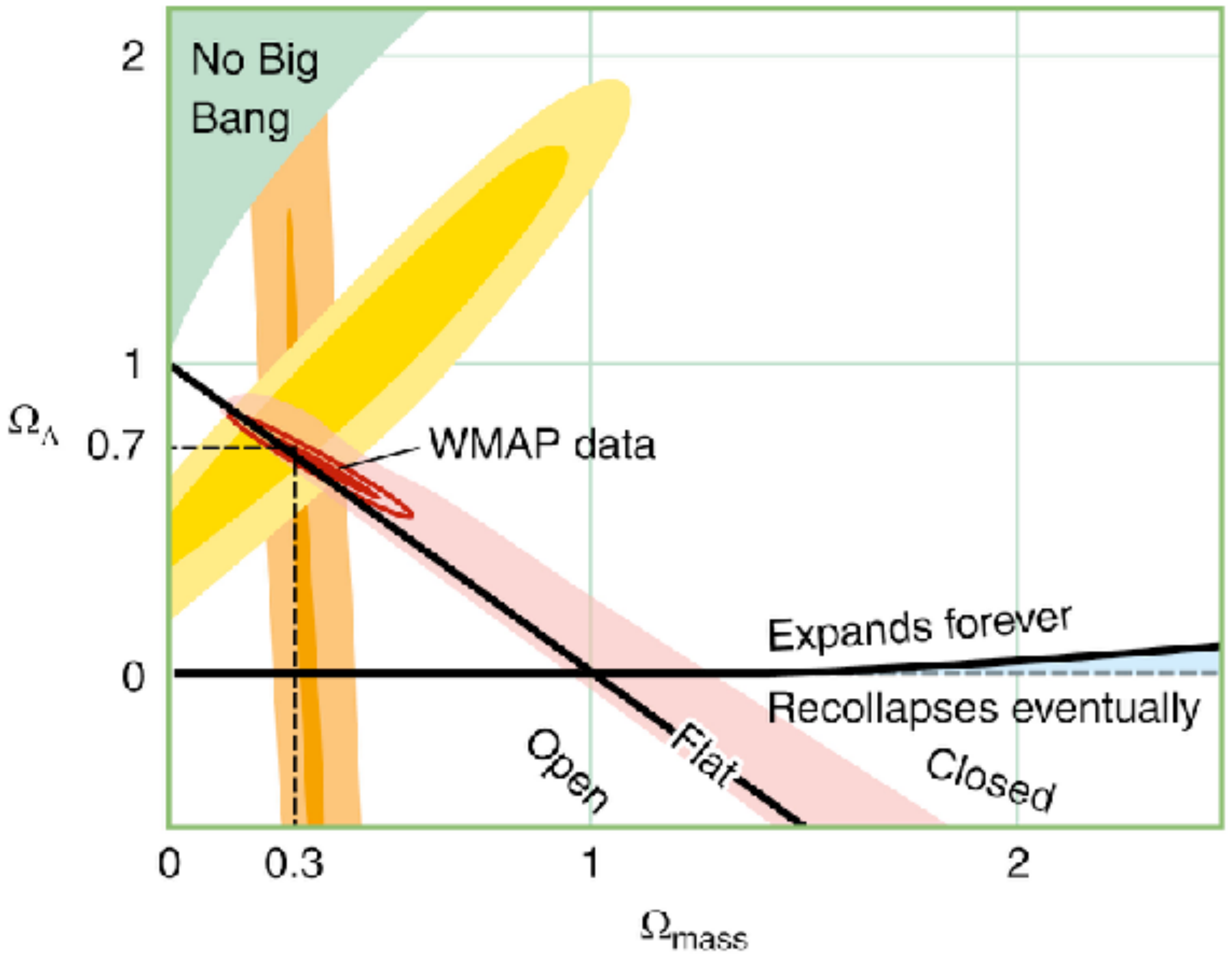


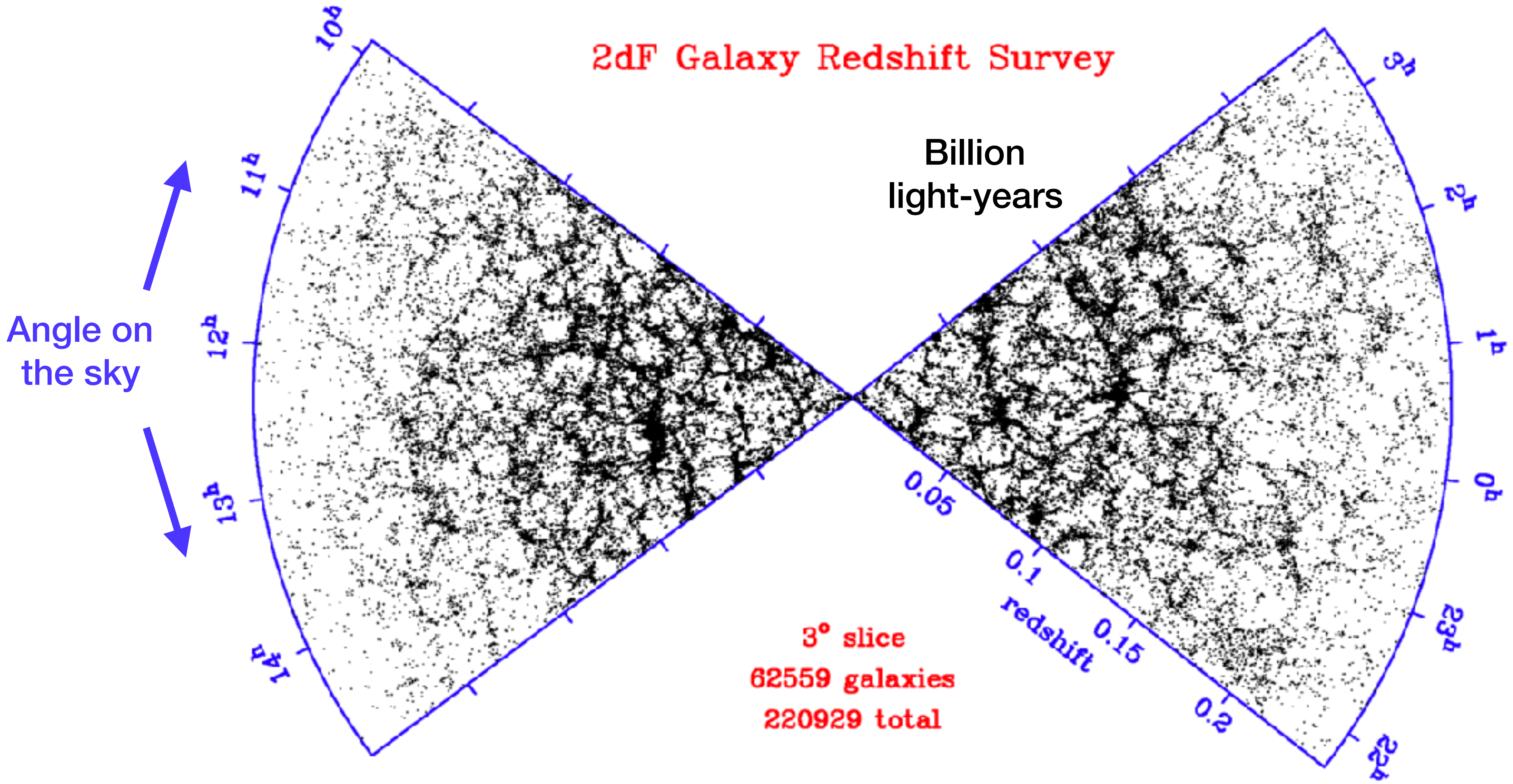


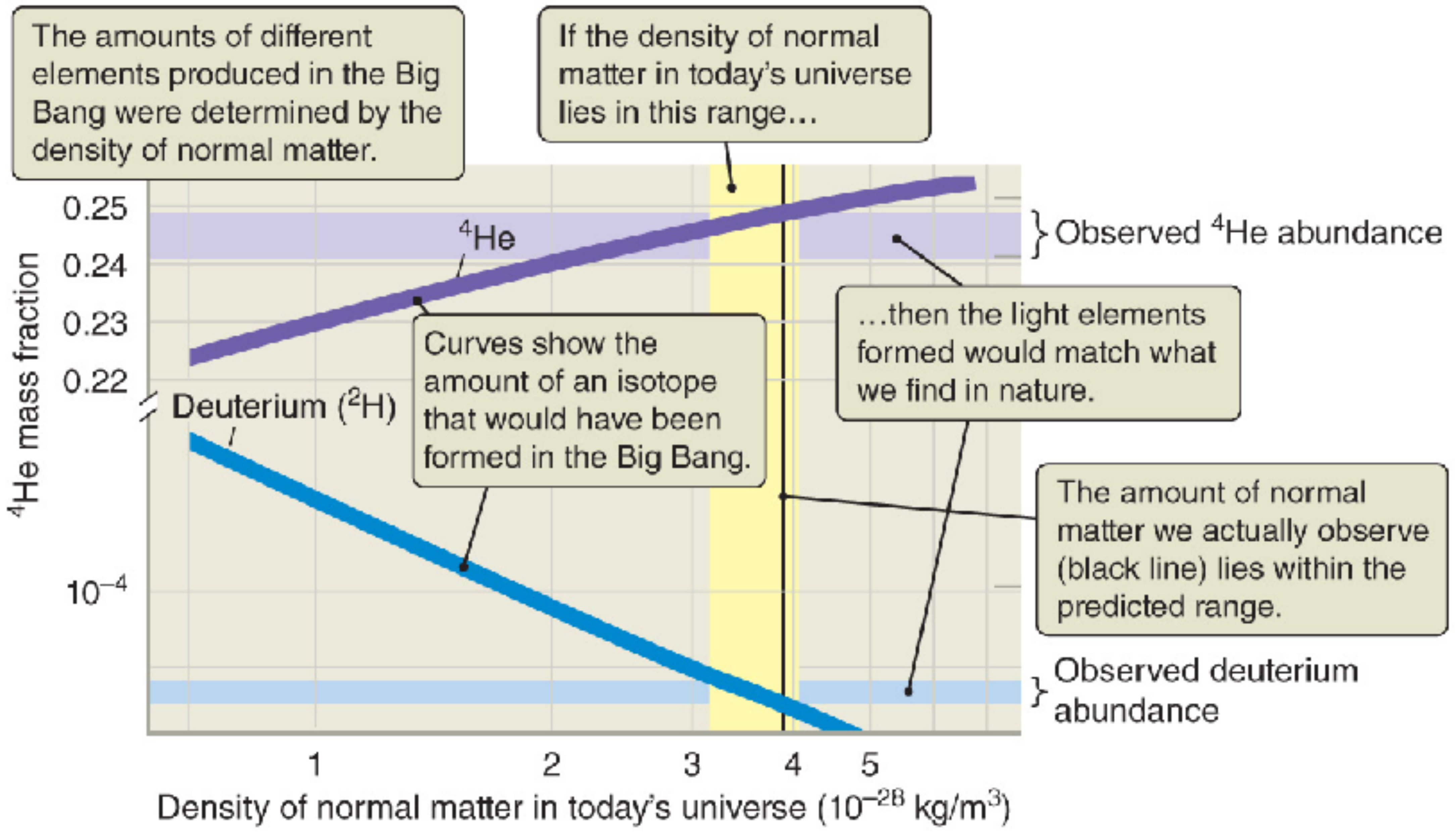
Expansion History of Space

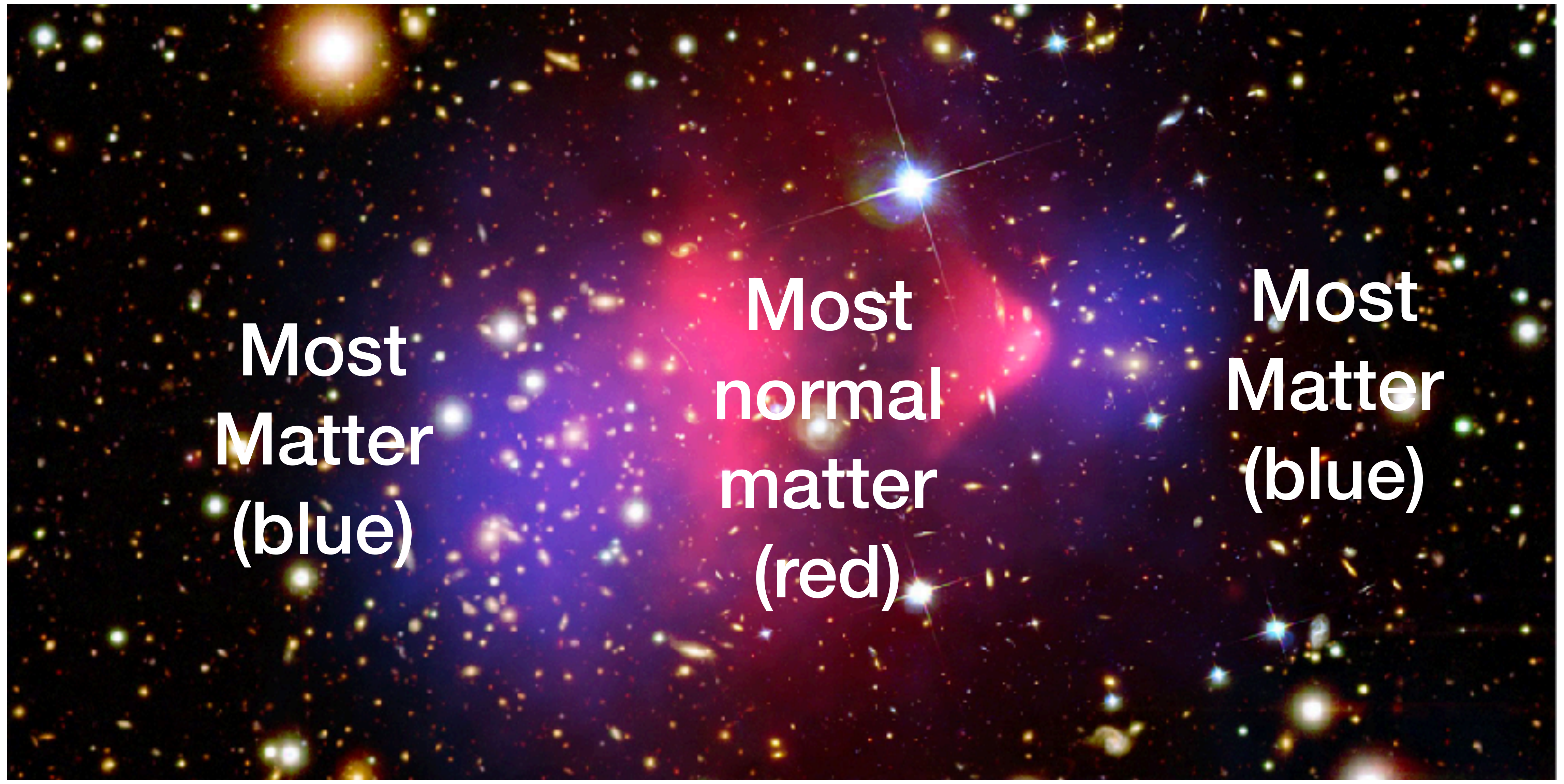


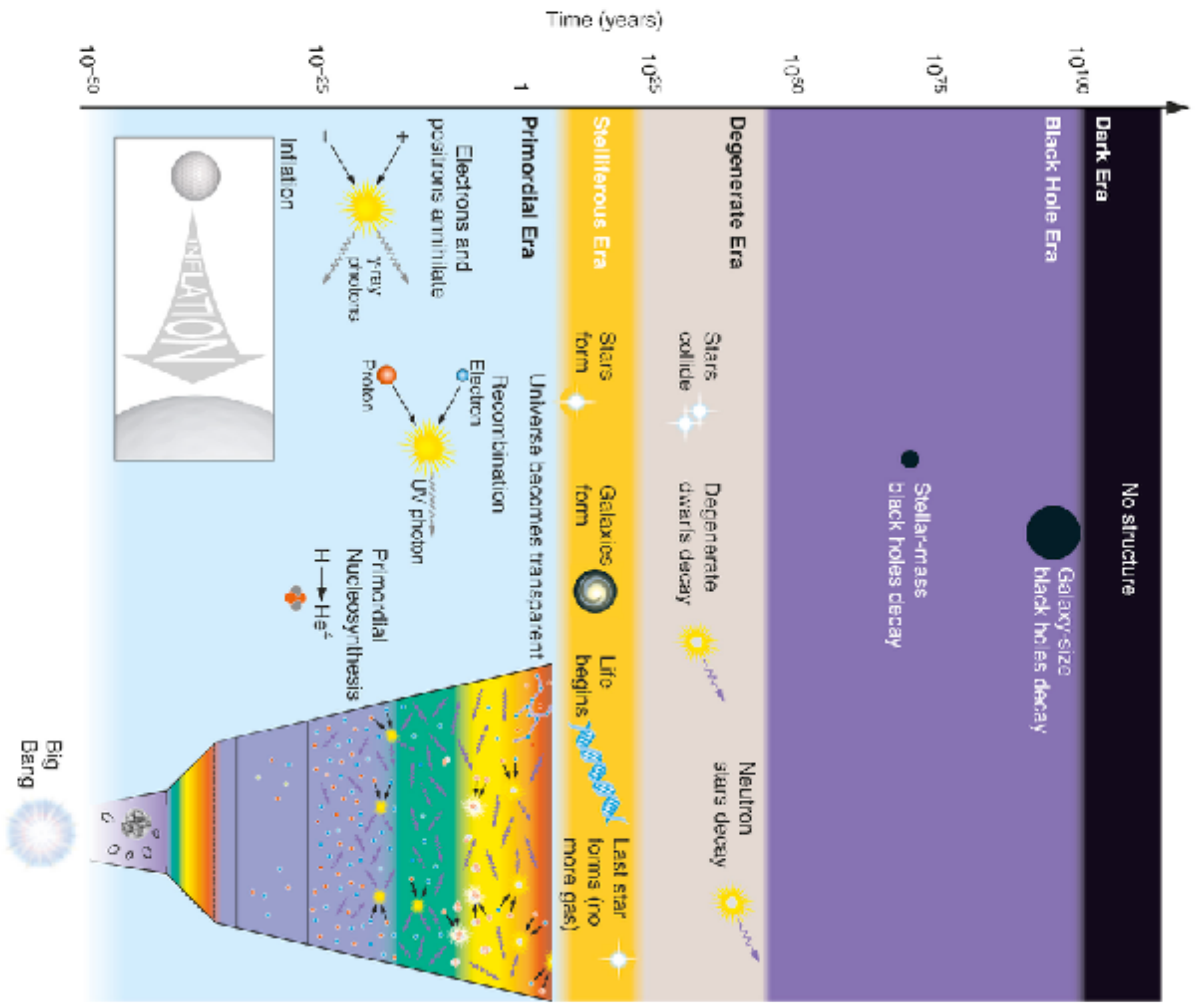


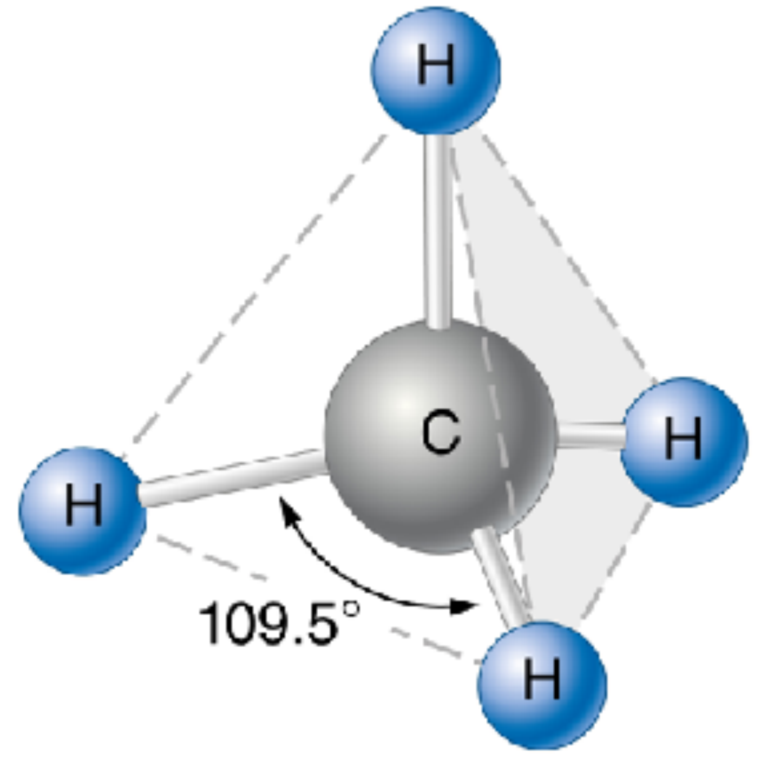



2dF Galaxy Redshift Survey
Billion light-years
Angle on the sky
10h
11h
12h
13h
14h
3h
2h
1h
0h
23h
22h
0.05
0.1
0.15
0.2
redshift
3° slice
62559 galaxies
220929 total

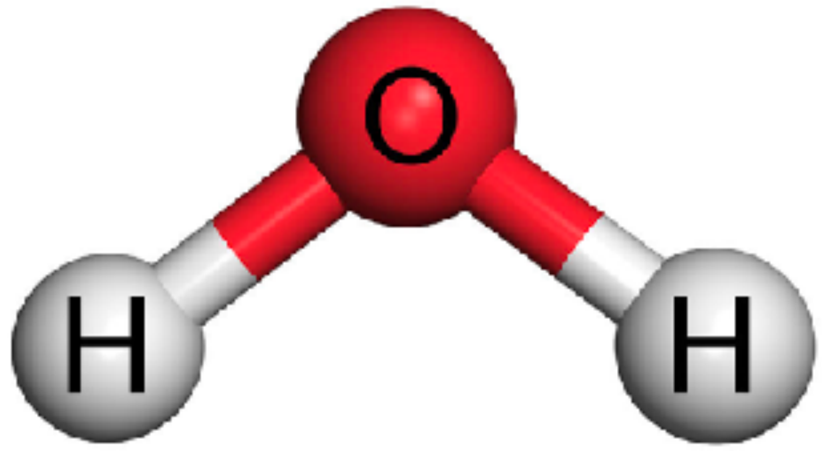

The amounts of different elements produced in the Big Bang were determined by the density of normal matter.
If the density of normal matter in today's universe lies in this range...
Observed ^{4}He abundance
...then the light elements formed would match what we find in nature.
Curves show the amount of an isotope that would have been formed in the Big Bang.
The amount of normal matter we actually observe (black line) lies within the predicted range.
Observed deuterium abundance
^{4}He
Deuterium (^{2}H)
^{4}He mass fraction
0.25
0.24
0.23
0.22
10^{-4}
1
2
3
4
5
Density of normal matter in today's universe (10^{-28} kg/m^3)

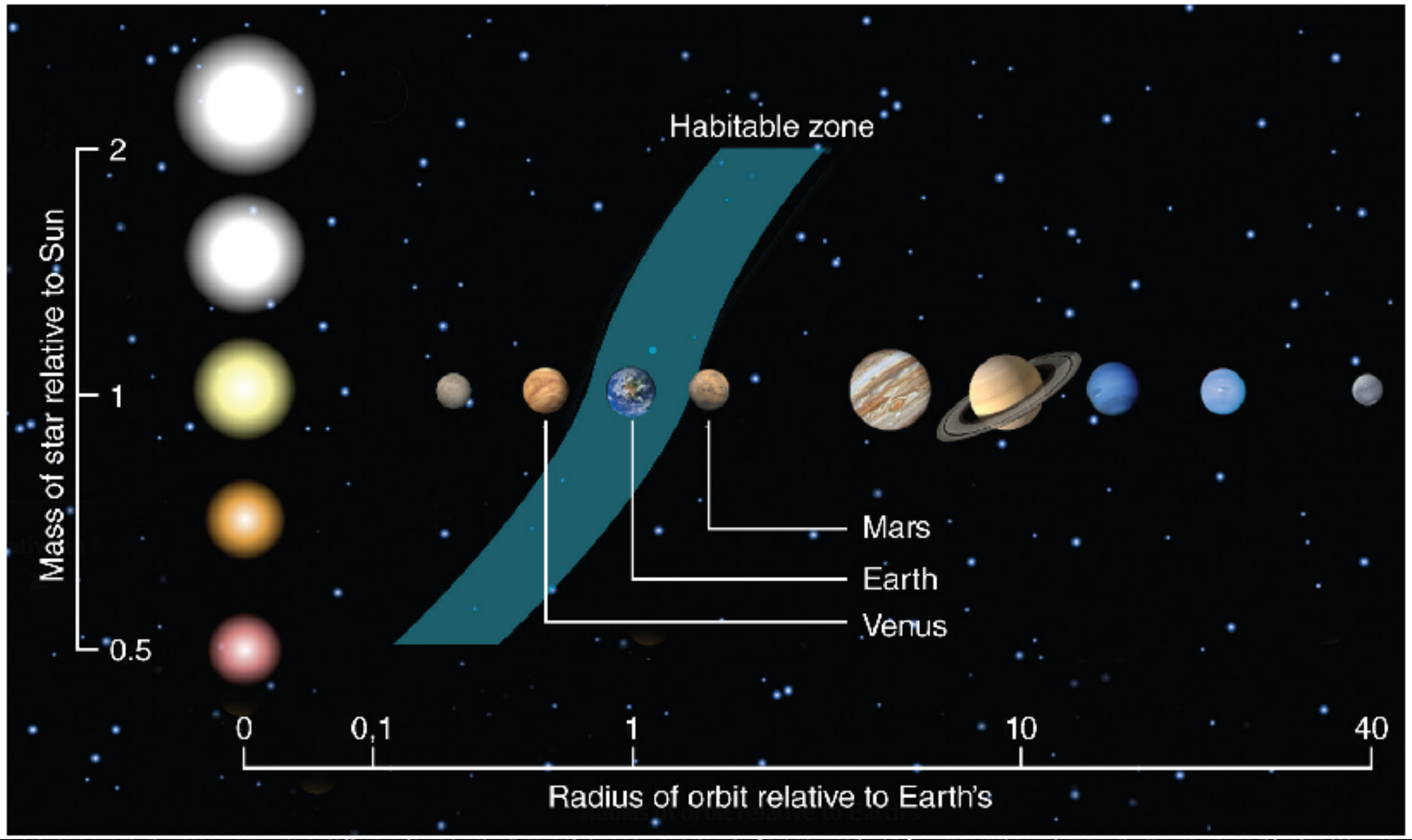

Most Matter (blue)
Most normal matter (red)
Most Matter (blue)

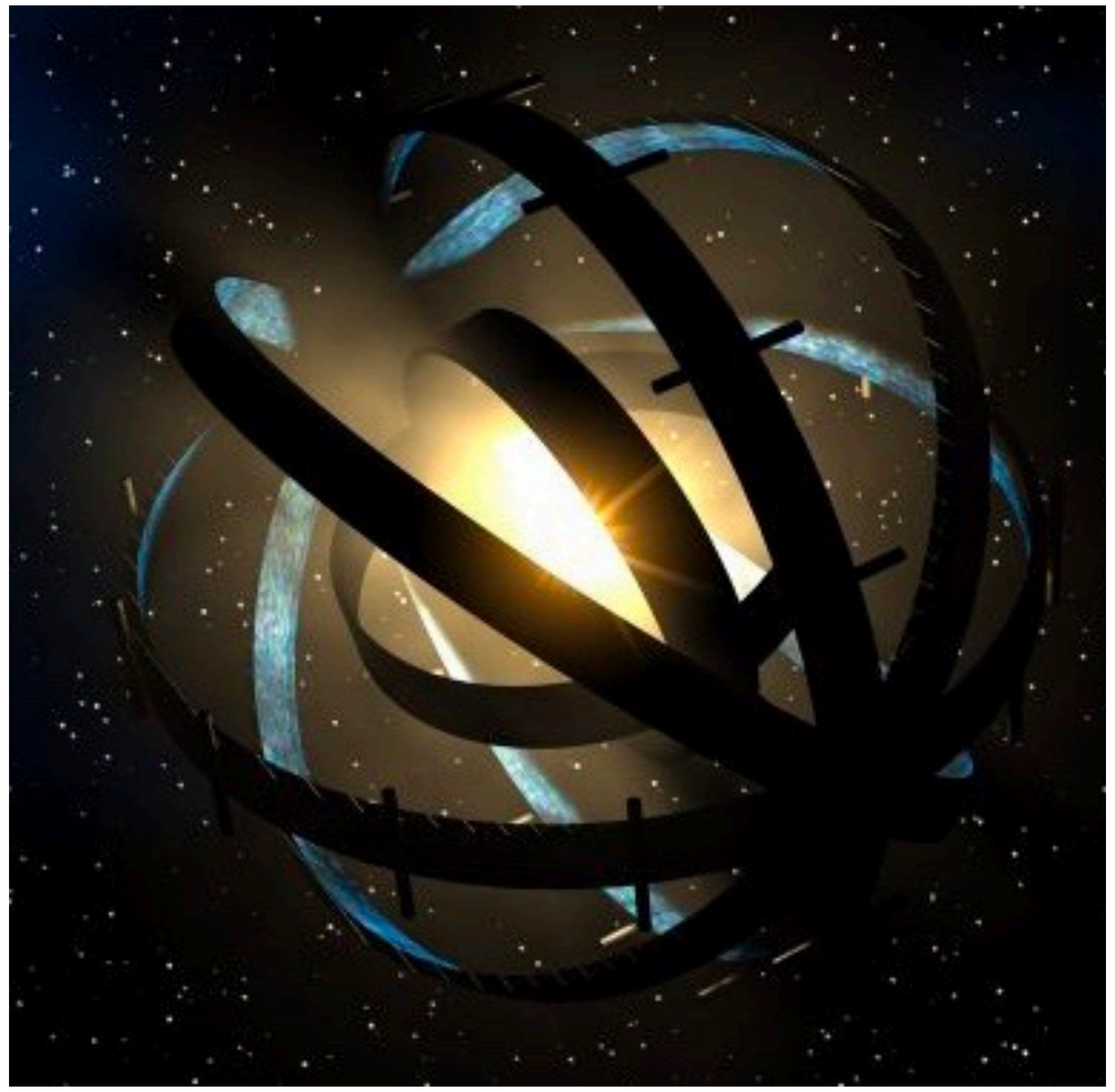

Time (years)
Primordial Era
Stelliferous Era
Degenerate Era
Black Hole Era
Dark Era
Inflation
Big Bang
No structure



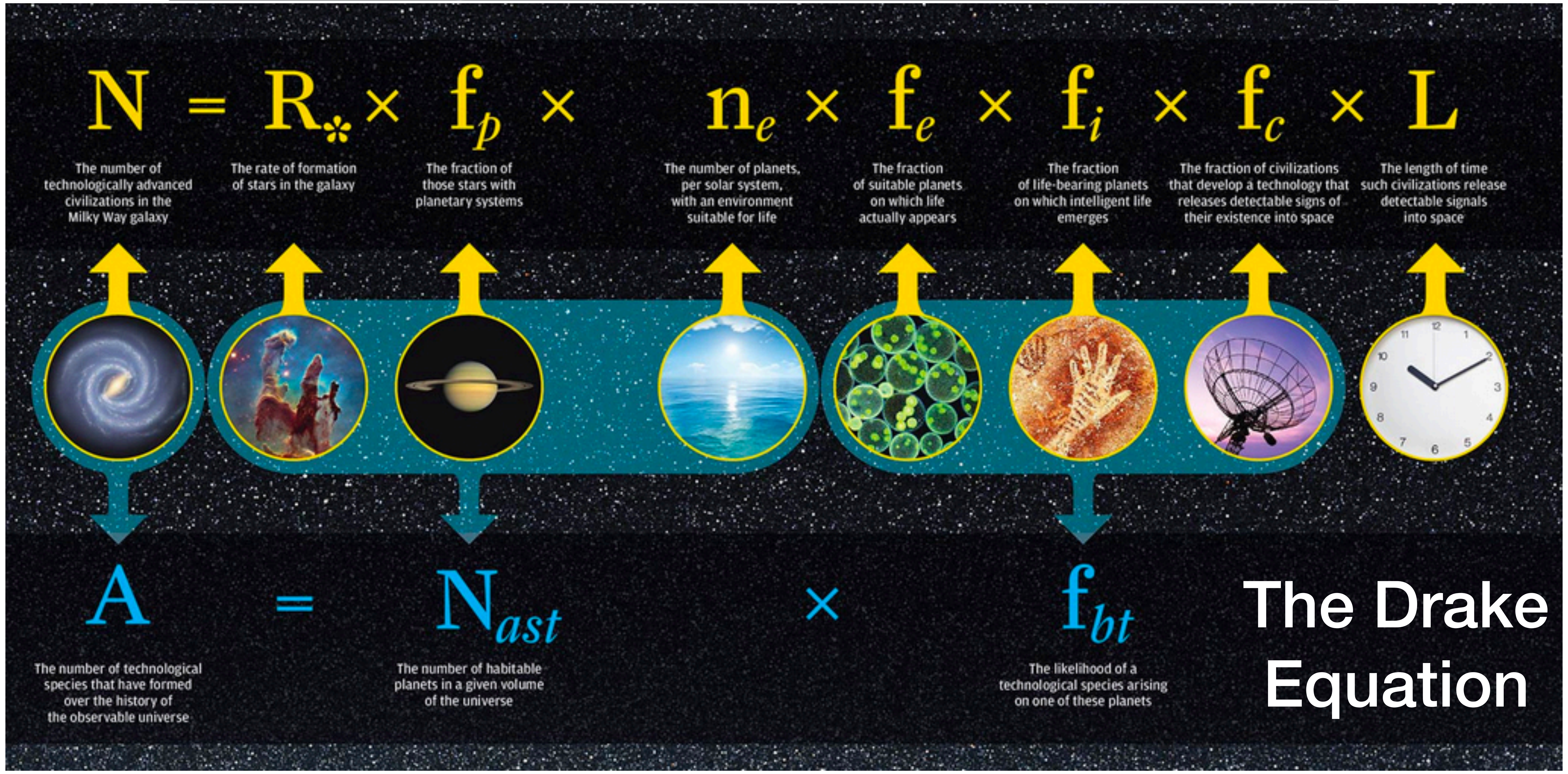
Methane tetrahedron







Dyson Spheres



The Drake Equation

Life needs:

- organic molecules
- water
- energy

Happy Studying!

And now some final remarks on aliens and the universe

‘Oumuamua: alien comet or space probe?!?

Artist’s impression of the object: ESO/M. Kornmesser

On an unbound orbit, about the speed stars move relative to each other

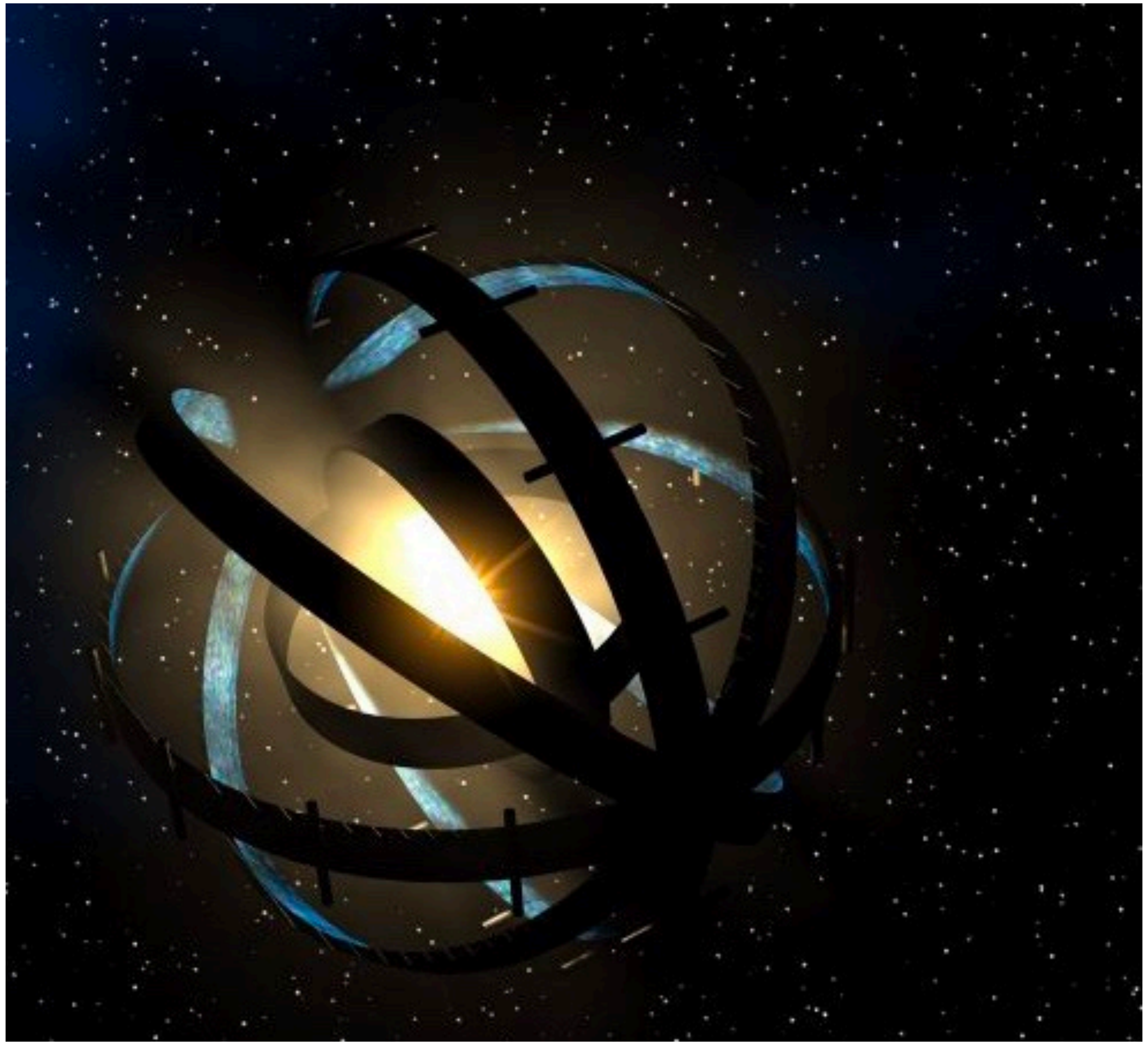
Size uncertain, but likely more cigar shaped spheroidal

Found to be accelerating away from the Sun as it left the solar system

Could it be an alien probe checking us out? Using a solar sail as propulsion?

Or is it just a rock from another star system (possibly carrying microscopic life)?

Dyson Spheres



Artist's conception of a Dyson Sphere (CapnHack)
https://earthsky.org/space/what-is-a-dyson-sphere

More correctly called a Stapleton Sphere, after Olaf Stapleton whose 1937 novel Star Maker inspired Freeman Dyson to propose the search for such objects

Kardeshev Type II civilization: harnesses all the power of its star

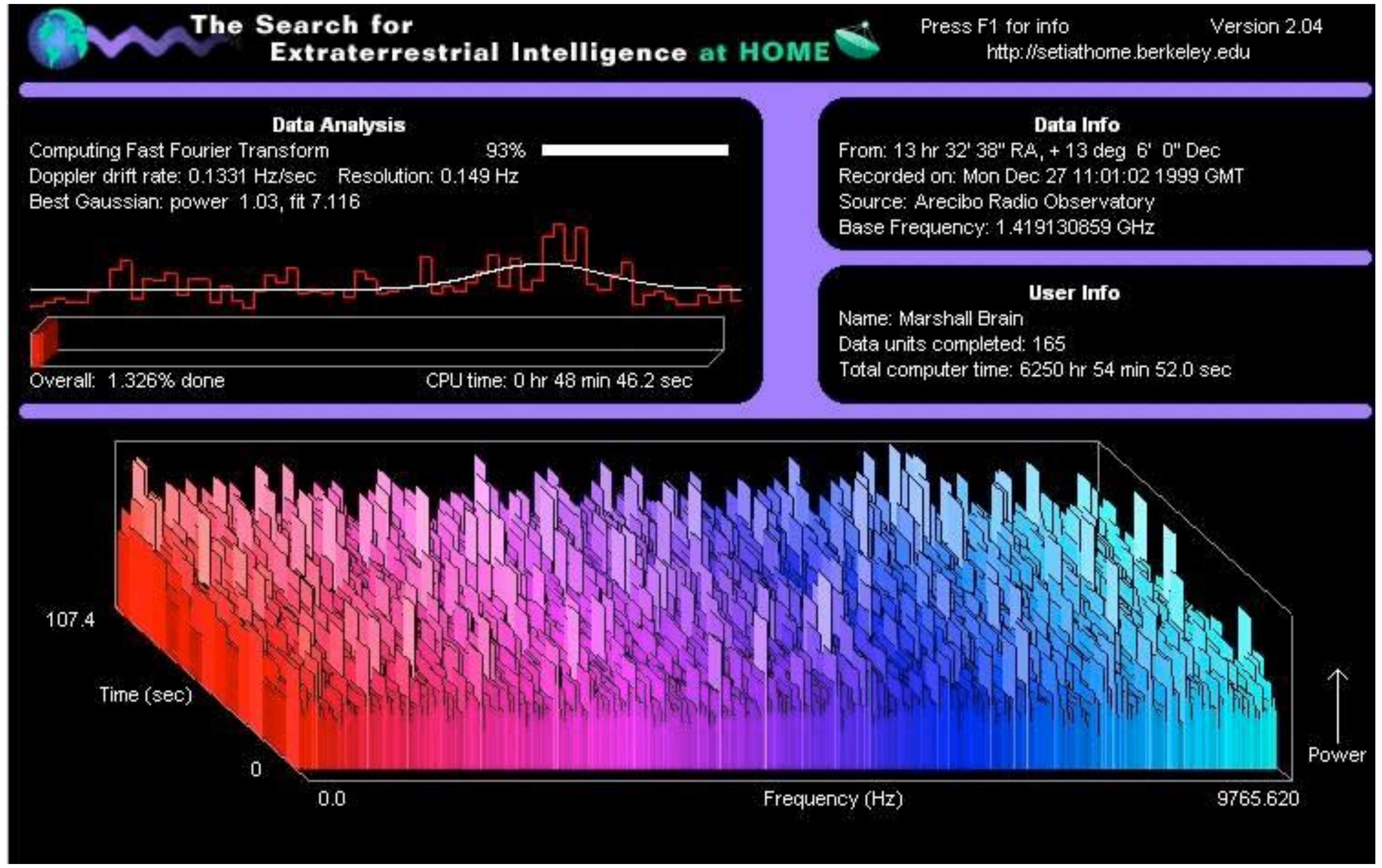
Can search for galaxies with "too much" IR light: sphere would emit waste heat — no evidence of substantial structures yet found

Tabby's star (discovered with Kepler) — alien megastructures or dust? (spoiler, dust)

Kardeshev Type III+ civilization could capture stars with these spheres, out to a distance of 10s of millions of light years away, in an attempt to forestall lack of resources due to dark energy

SETI: Search for Extraterrestrial Intelligence

Contact (1997) movie still frame



Consider again that dot. That's here. That's home. That's us. On it everyone you love, everyone you know, everyone you ever heard of, every human being who ever was, lived out their lives. The aggregate of our joy and suffering, thousands of confident religions, ideologies, and economic doctrines, every hunter and forager, every hero and coward, every creator and destroyer of civilization, every king and peasant, every young couple in love, every mother and father, hopeful child, inventor and explorer, every teacher of morals, every corrupt politician, every "superstar", every "supreme leader", every saint and sinner in the history of our species lived there - on a mote of dust suspended in a sunbeam.

The Earth is a very small stage in a vast cosmic arena. Think of the rivers of blood spilled by all those generals and emperors so that, in glory and triumph, they could become the momentary masters of a fraction of a dot. Think of the endless cruelties visited by the inhabitants of one corner of this pixel on the scarcely distinguishable inhabitants of some other corner, how frequent their misunderstandings, how eager they are to kill one another, how fervent their hatreds.

Our posturings, our imagined self-importance, the delusion that we have some privileged position in the Universe:, are challenged by this point of pale light. Our planet is a lonely speck in the great enveloping cosmic dark. In our obscurity, in all this vastness, there is no hint that help will come from elsewhere to save us from ourselves.

The Earth is the only world known so far to harbor life. There is nowhere else, at least in the near future, to which our species could migrate. Visit, yes. Settle, not yet. Like it or not, for the moment the Earth is where we make our stand.

It has been said that astronomy is a humbling and character-building experience. There is perhaps no better demonstration of the folly of human conceits than this distant image of our tiny world. To me, it underscores our responsibility to deal more kindly with one another, and to preserve and cherish the pale blue dot, the only home we've ever known.

-Carl Sagan (1934-1996)

Hope you learned something!

And had a little fun — I did.

Thank you!