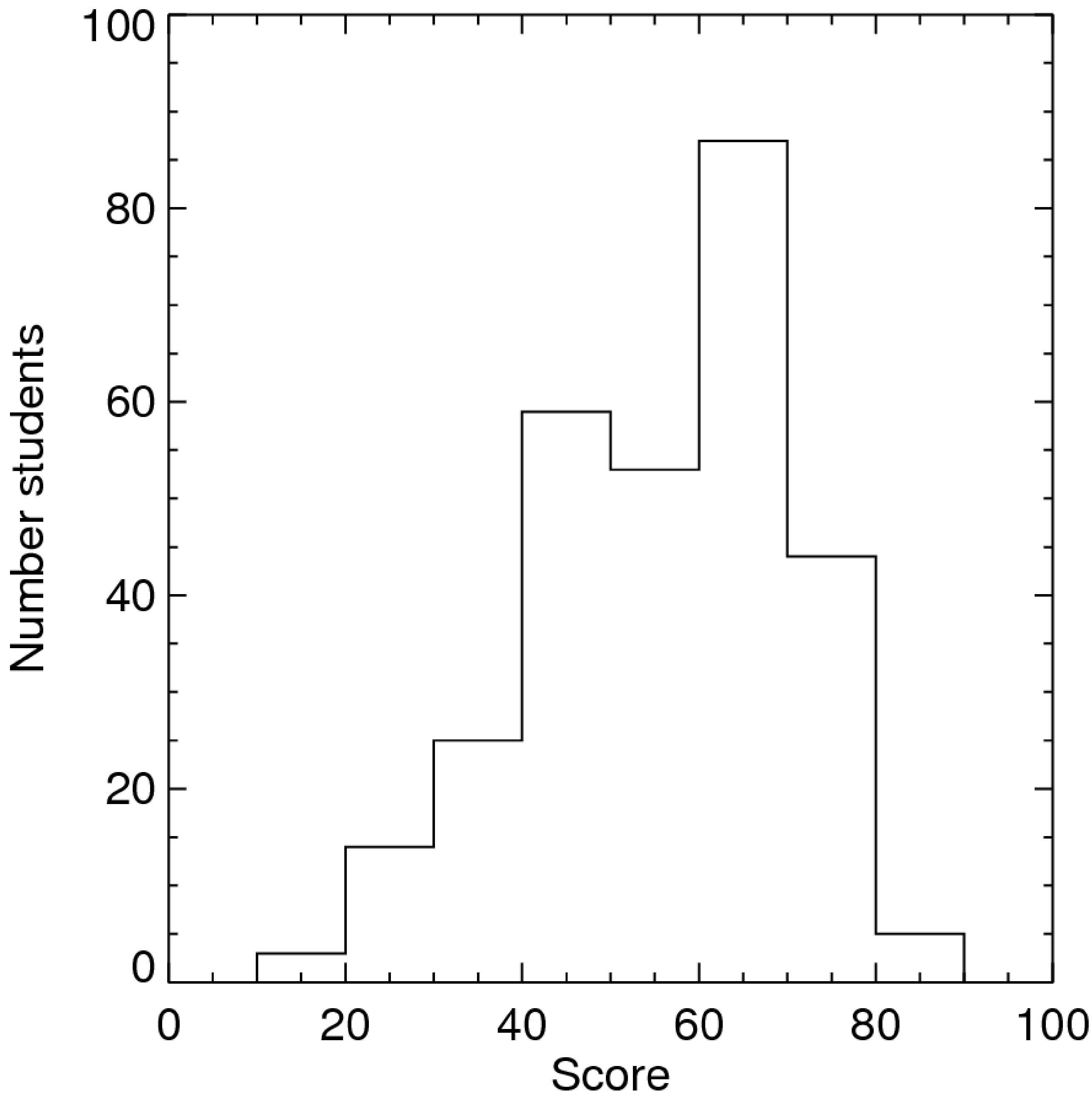
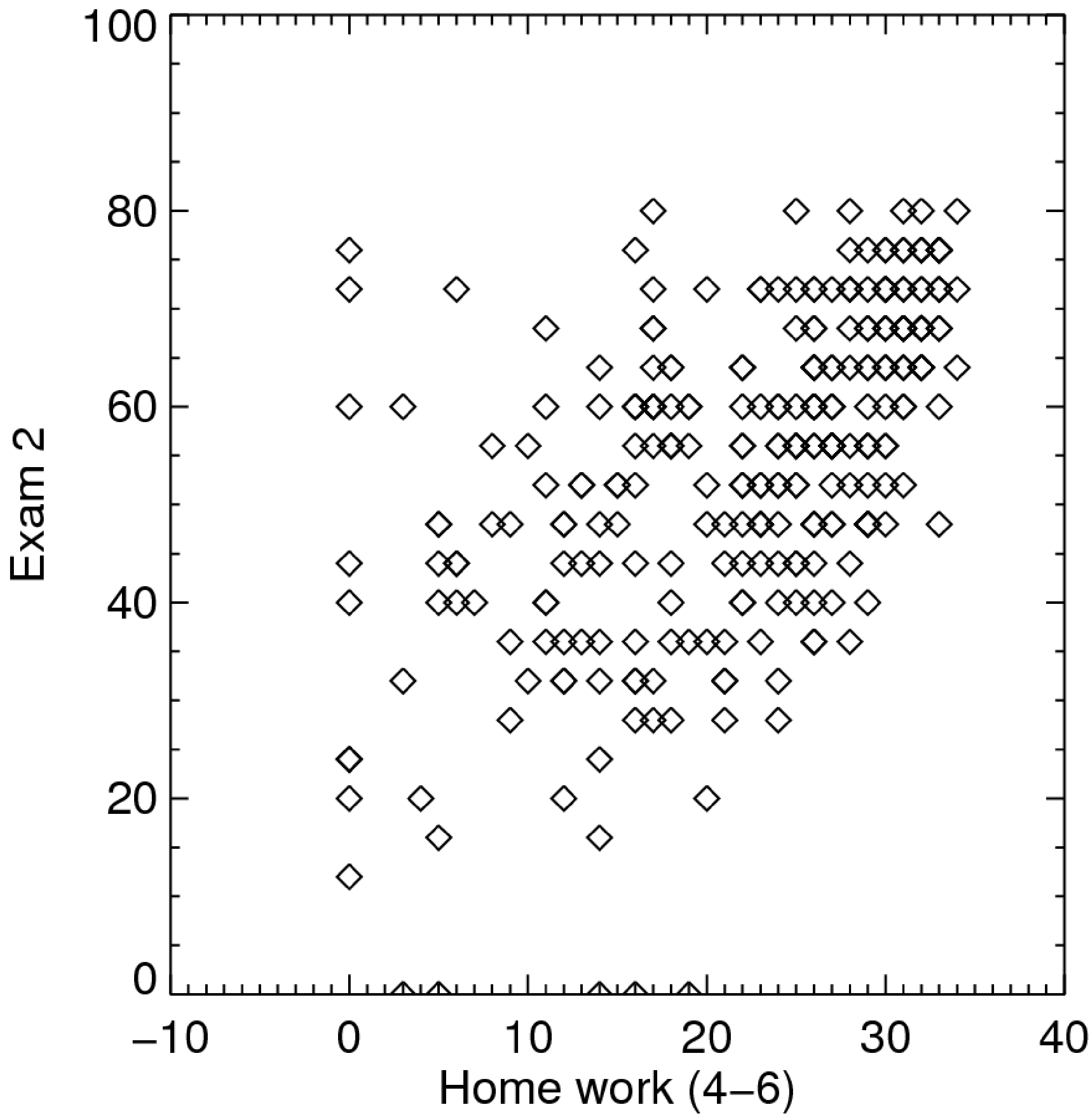
Grades

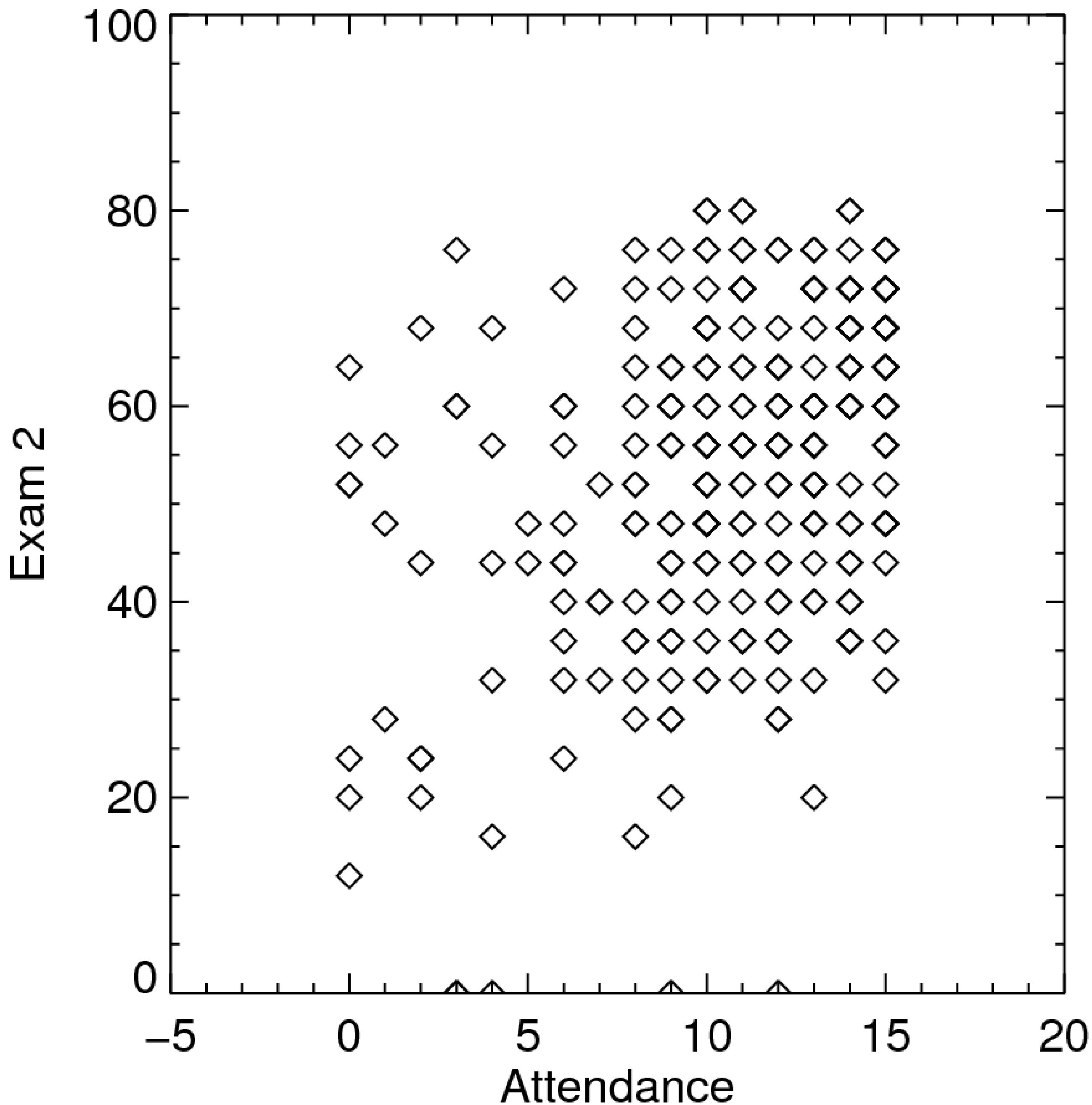
- Scores and curve for exam #2 on ICON, answers and key will come soon
- Extra credit by observing. Two observing lists each worth 10 points. **Deadline for completing first list is March 26.**
- No class on March 13.



100
80
60
40
20
0
Number students
0
20
40
60
80
100
Score



100
80
60
40
20
0
Exam 2
−10
0
10
20
30
40
Home work (4−6)

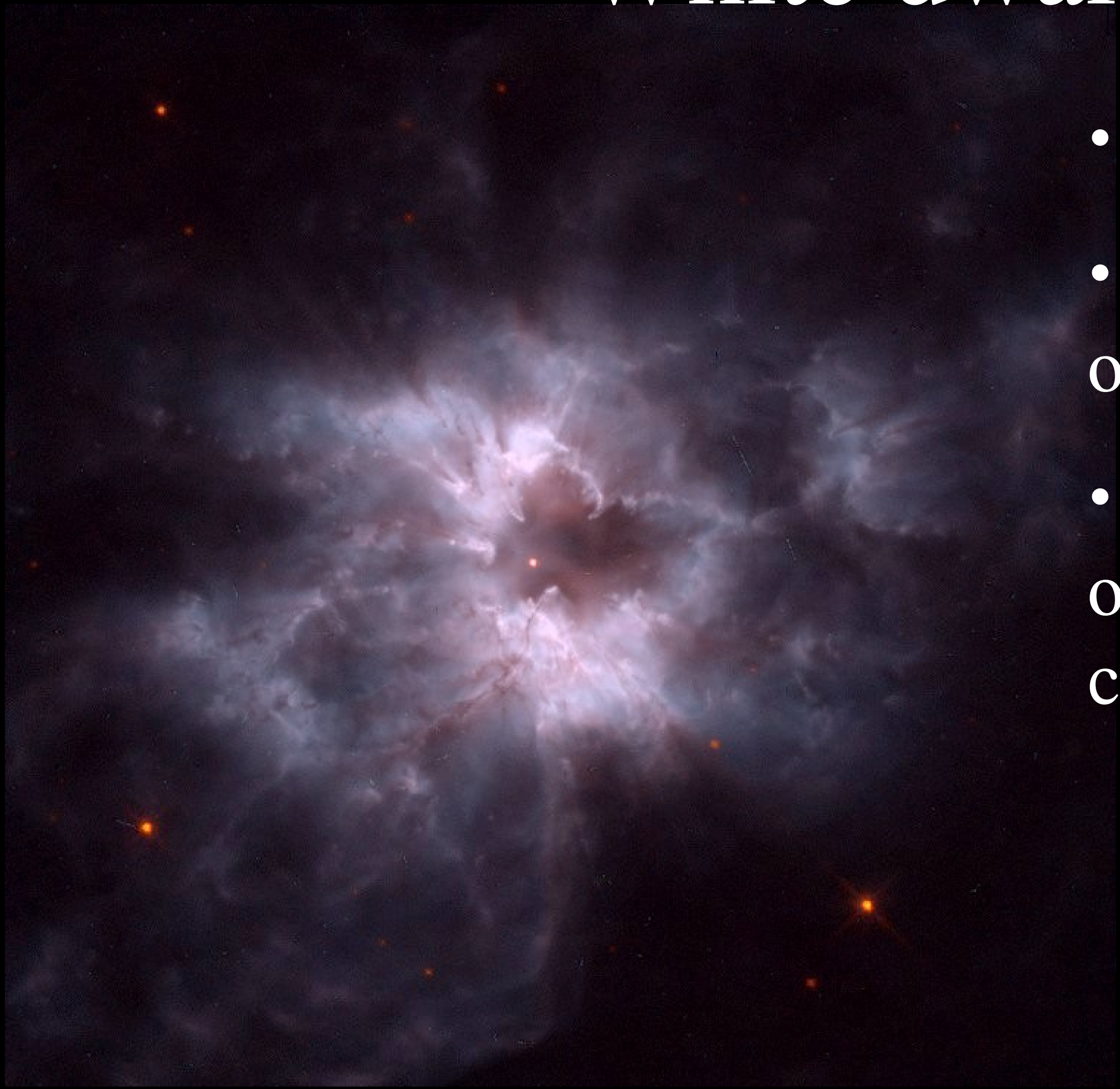


100
80
60
40
20
0
−5
0
5
10
15
20
Exam 2
Attendance

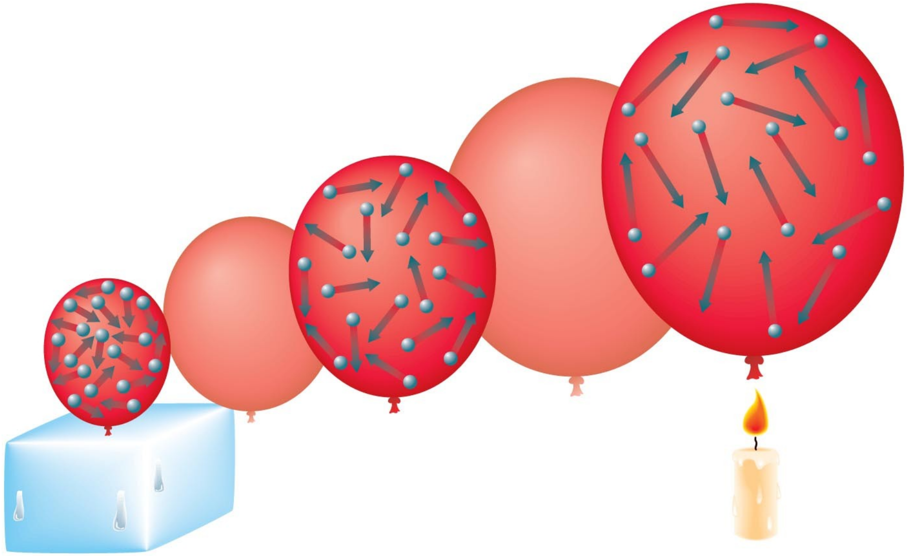
White Dwarfs and Neutron Stars

- White dwarfs
  - Degenerate gases
  - Mass versus radius relation
- Neutron stars
  - Mass versus radius relation
  - Pulsars, magnetars, X-ray pulsars, X-ray bursters

White dwarf



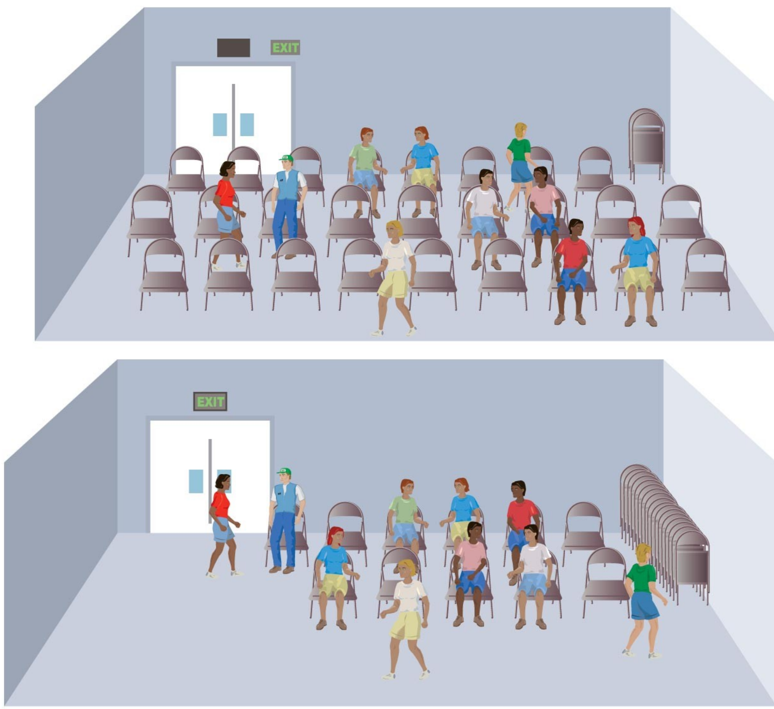
- Core of solar mass star
- Degenerate gas of oxygen and carbon
- No energy from fusion or gravitational contraction



Thermal Pressure:

Depends on heat content

The main form of pressure in most stars



Degeneracy Pressure:

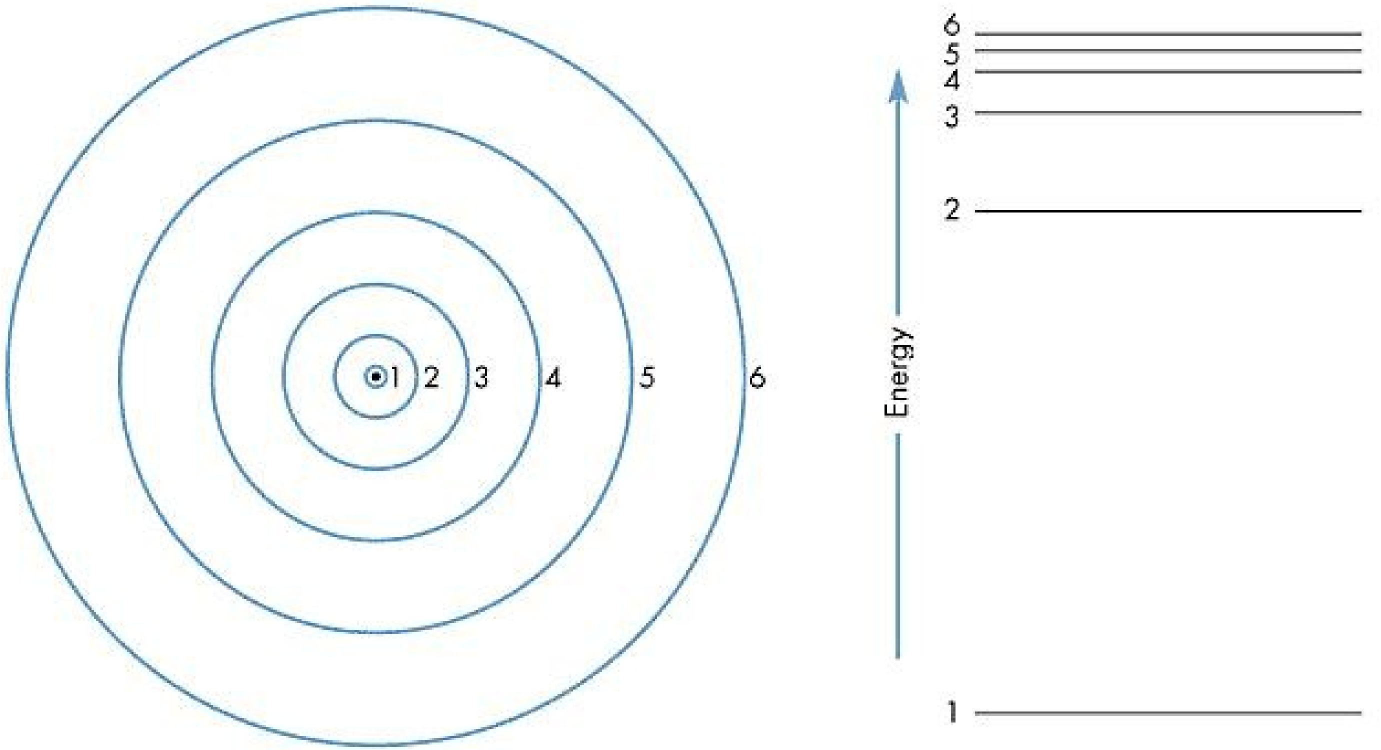
Particles can’t be in same state in same place

Doesn’t depend on heat content

Fermi exclusion principle

- No two electrons can occupy the same quantum state
- Quantum state = energy level + spin
- Electron spin = up or down

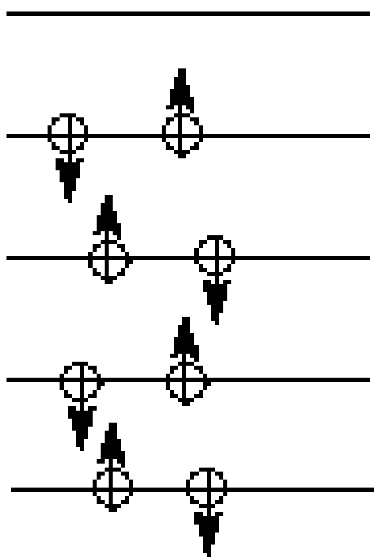
Electron orbits



A Possible distances of the electron in a hydrogen atom **B** Energy levels for the hydrogen atom

Only two electrons (one up, one down) can go into each energy level

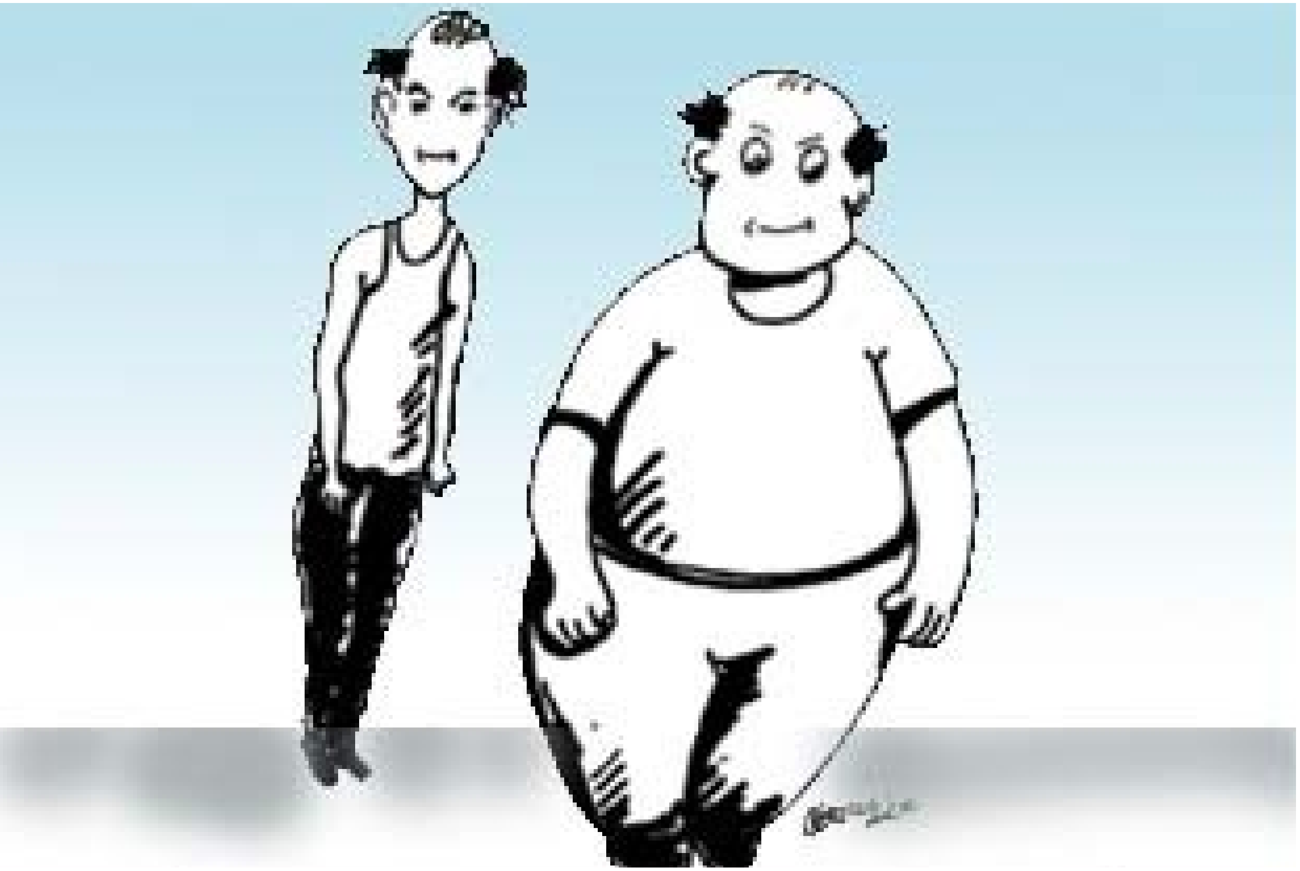
Electron energy levels



Degenerate gas: all lower energy levels filled with two particles each (opposite spins). Particles **locked** in place.

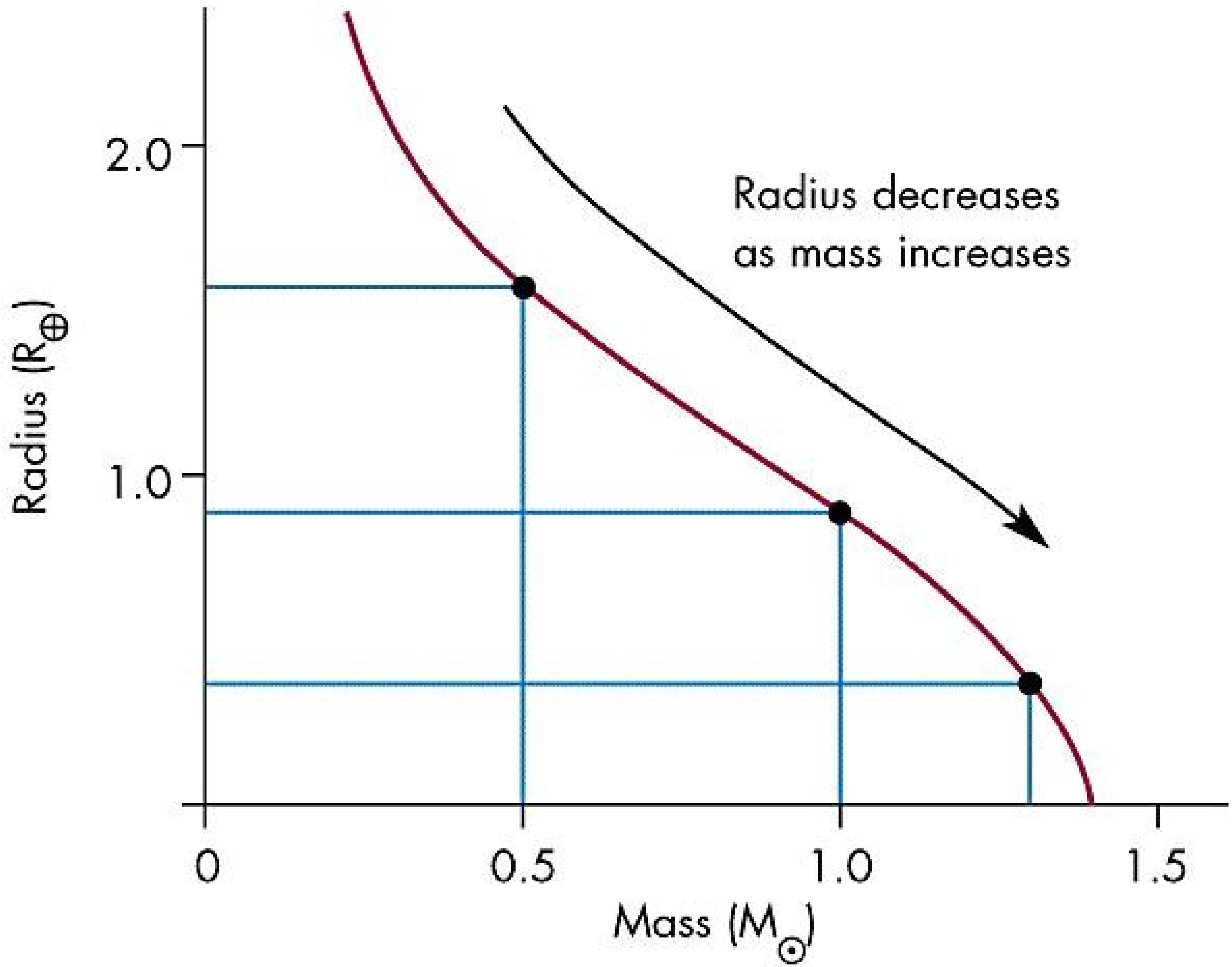
- Only two electrons (one up, one down) can go into each energy level.
- In a degenerate gas, all low energy levels are filled.
- Electrons have energy, and therefore are in motion and exert pressure even if temperature is zero.
- White dwarfs are supported by electron degeneracy.

Mass versus radius relation



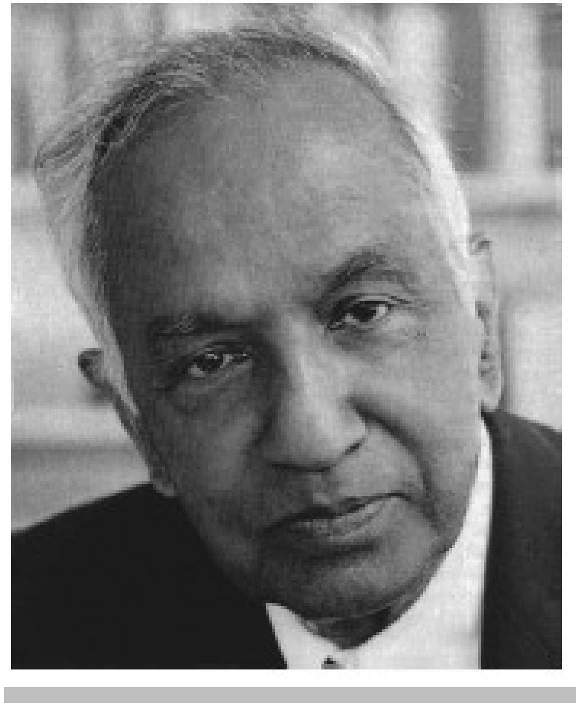
- For objects made of normal matter, radius tends to increase with mass

Mass versus radius relation



Maximum white dwarf mass

- Electron degeneracy cannot support a white dwarf heavier than 1.4 solar masses
- This is the "Chandrasekhar limit"
- Won Chandrasekhar the 1983 Nobel prize in Physics



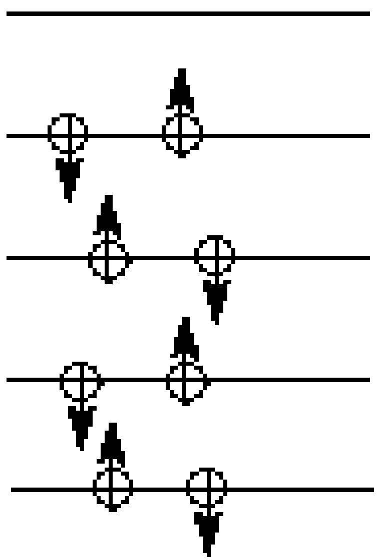
What happens to a star more massive than 1.4 solar masses?

A) There aren't any
B) They shrink to zero size
C) They explode
D) They become something else

Neutron Stars

- Degenerate stars heavier than 1.4 solar masses collapse to become neutron stars
- Formed in supernova explosions
- Electrons are not separate
  - Combine with nuclei to form neutrons
- Neutron stars are degenerate gas of neutrons

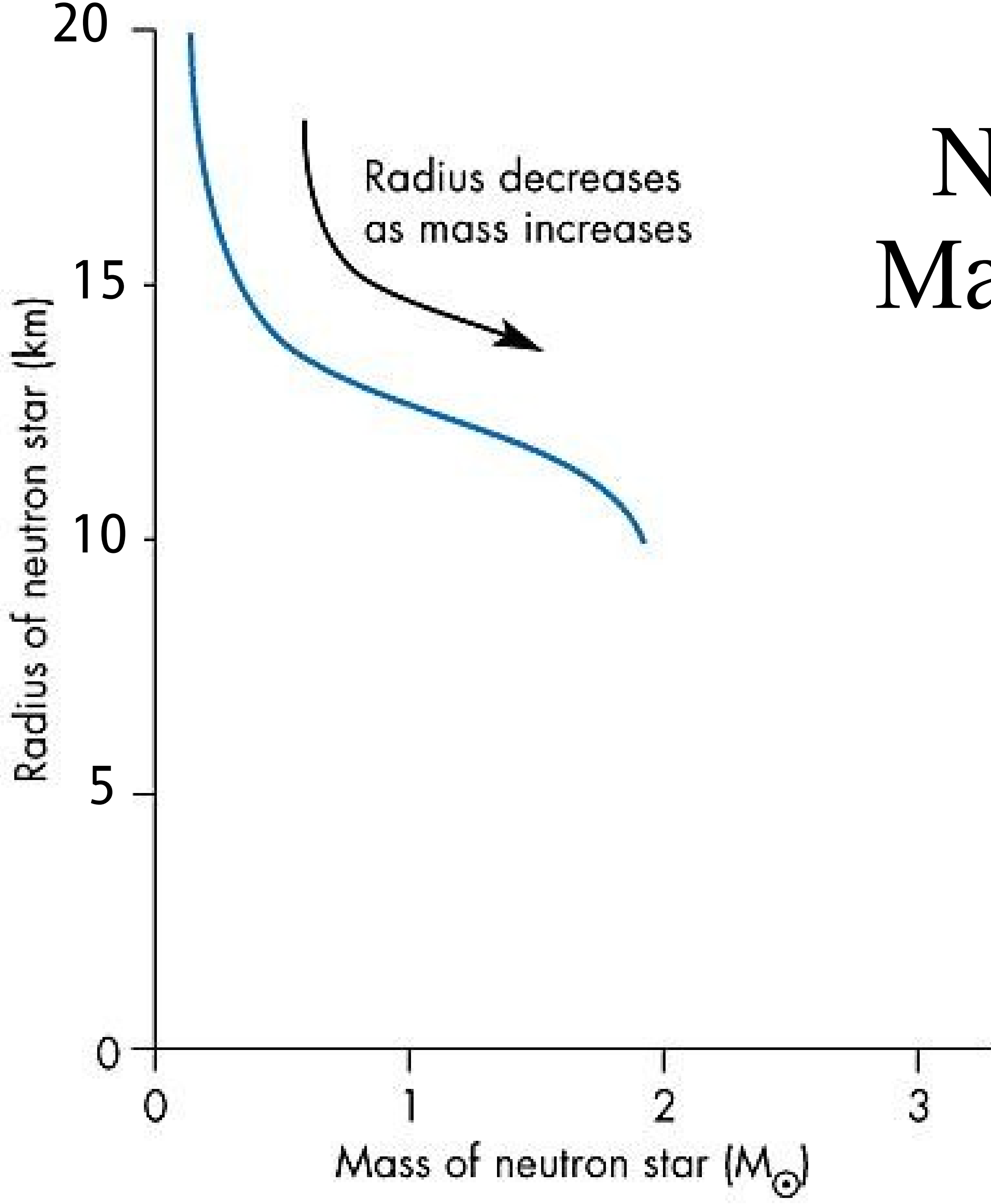
Neutron energy levels



Degenerate gas: all lower energy levels filled with two particles each (opposite spins). Particles **locked** in place.

- Only two neutrons (one up, one down) can go into each energy level.
- In a degenerate gas, all low energy levels are filled.
- Neutrons have energy, and therefore are in motion and exert pressure even if temperature is zero.
- Neutron star are supported by neutron degeneracy.

Neutron Star Mass vs Radius

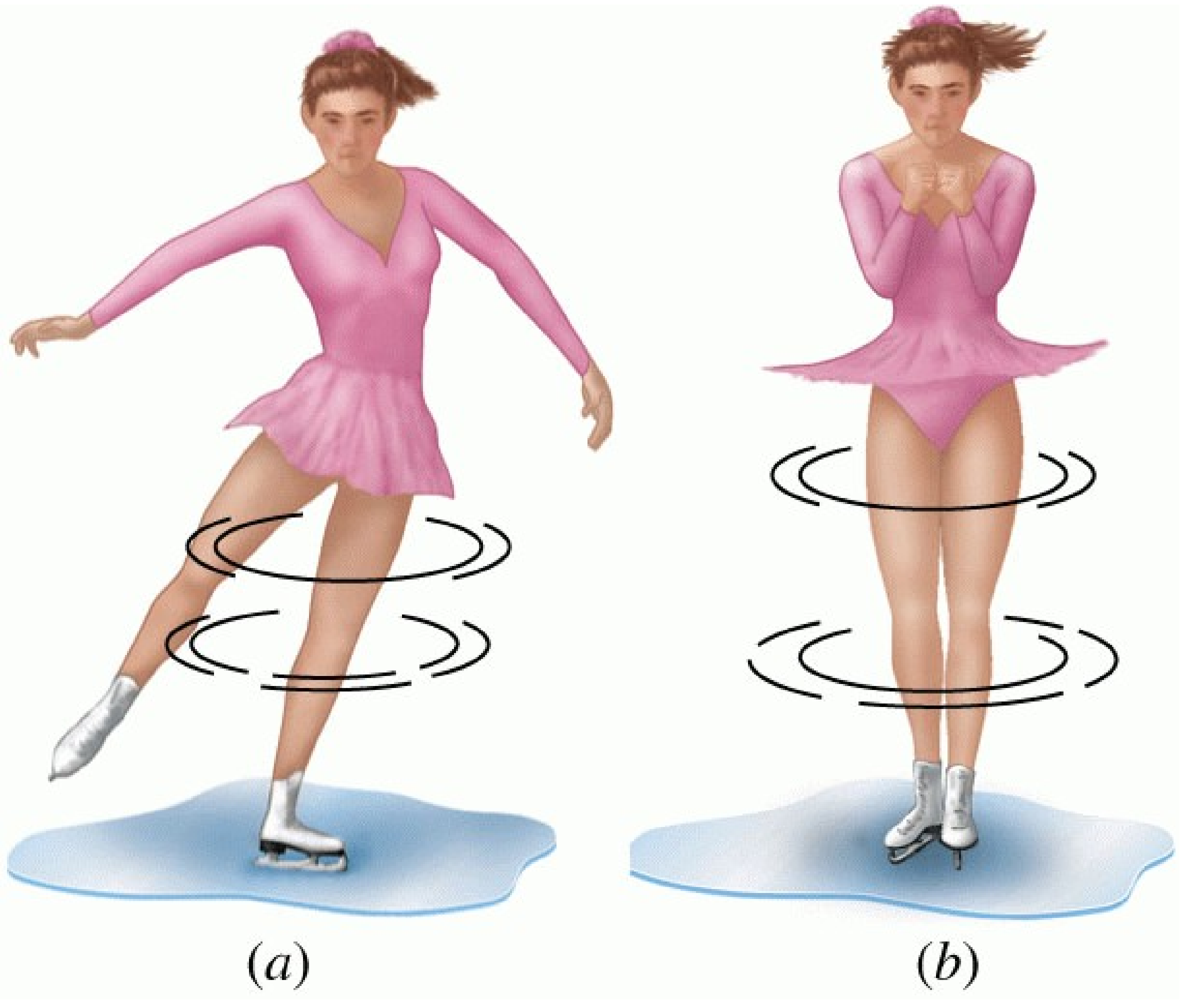


Neutron Stars

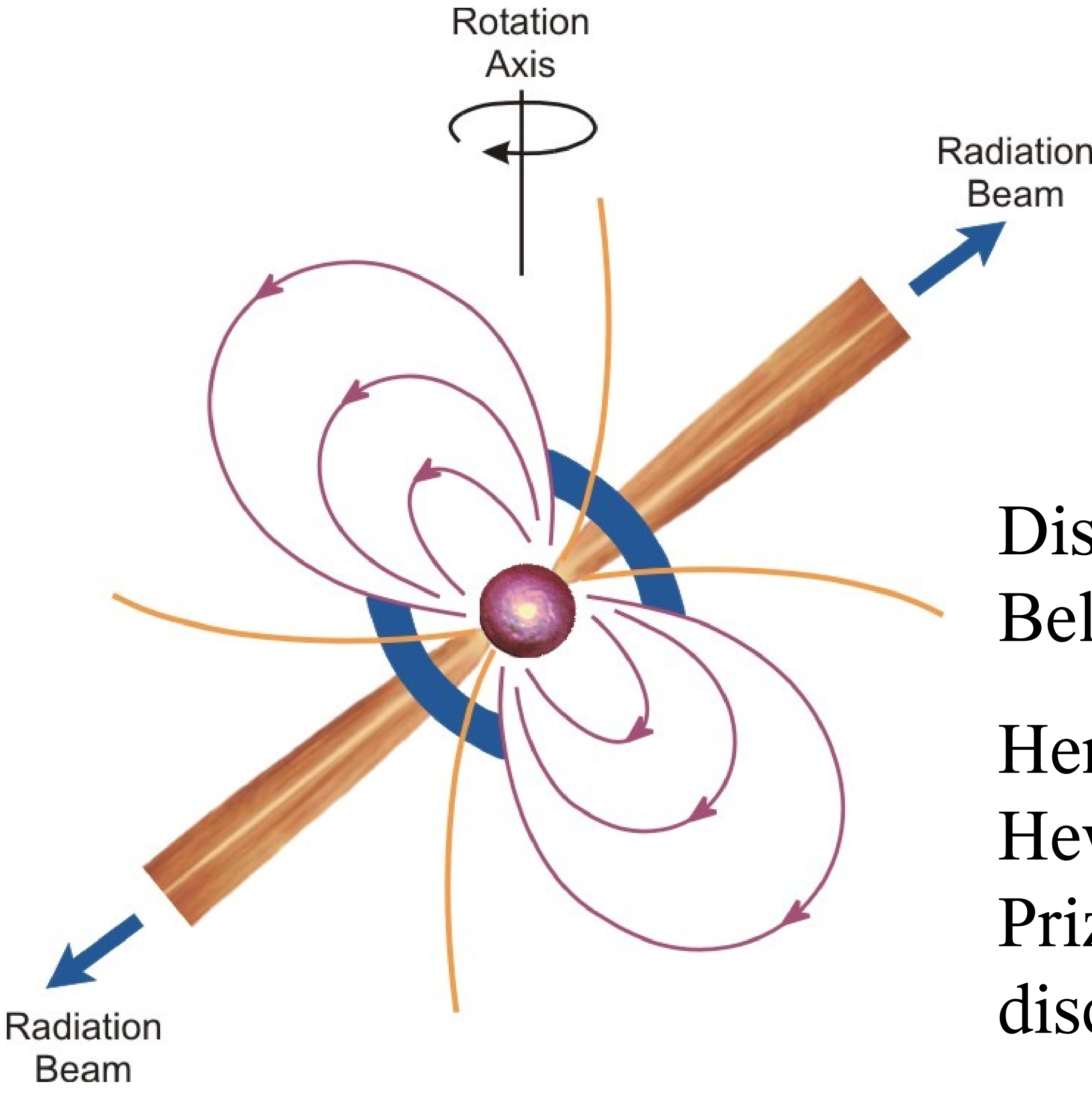
- Very compact – about 10 km radius
- Very dense – one teaspoon of neutron star material weighs as much as all the buildings in Manhattan
- Spin rapidly – as fast as 600 times per second
- High magnetic fields – compressed from magnetic field of progenitor star

Spin up of neutron star

Collapse of star increases both spin and magnetic field



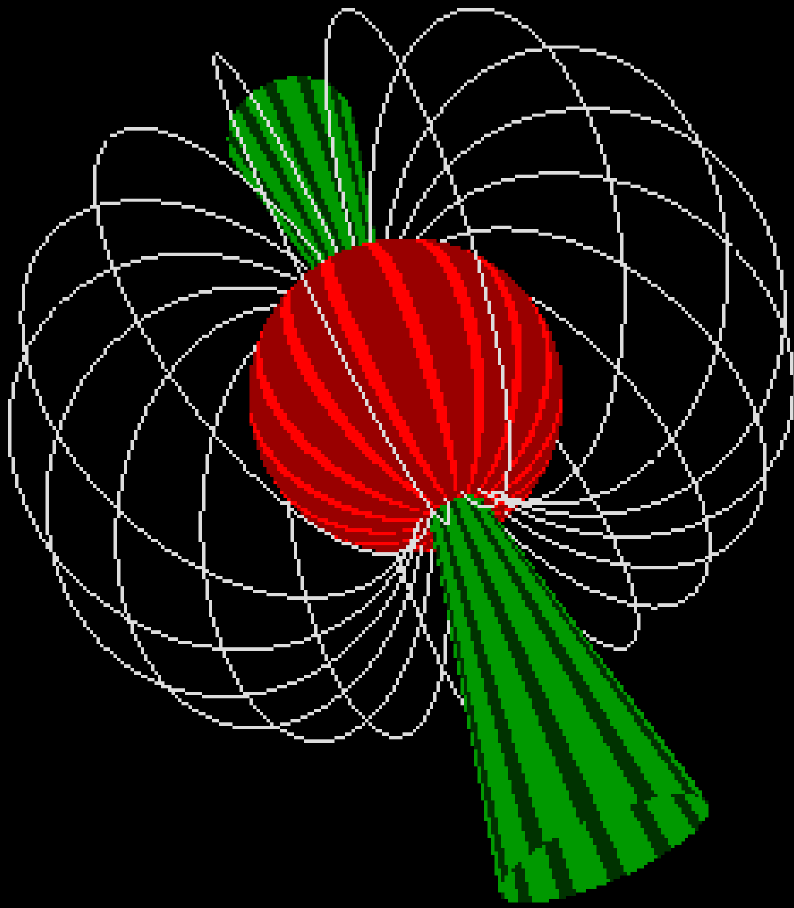
Pulsars



Discovered by Jocelyn Bell in 1967.

Her advisor, Anthony Hewish, won the Nobel Prize in Physics for the discovery in 1974.

Pulsars

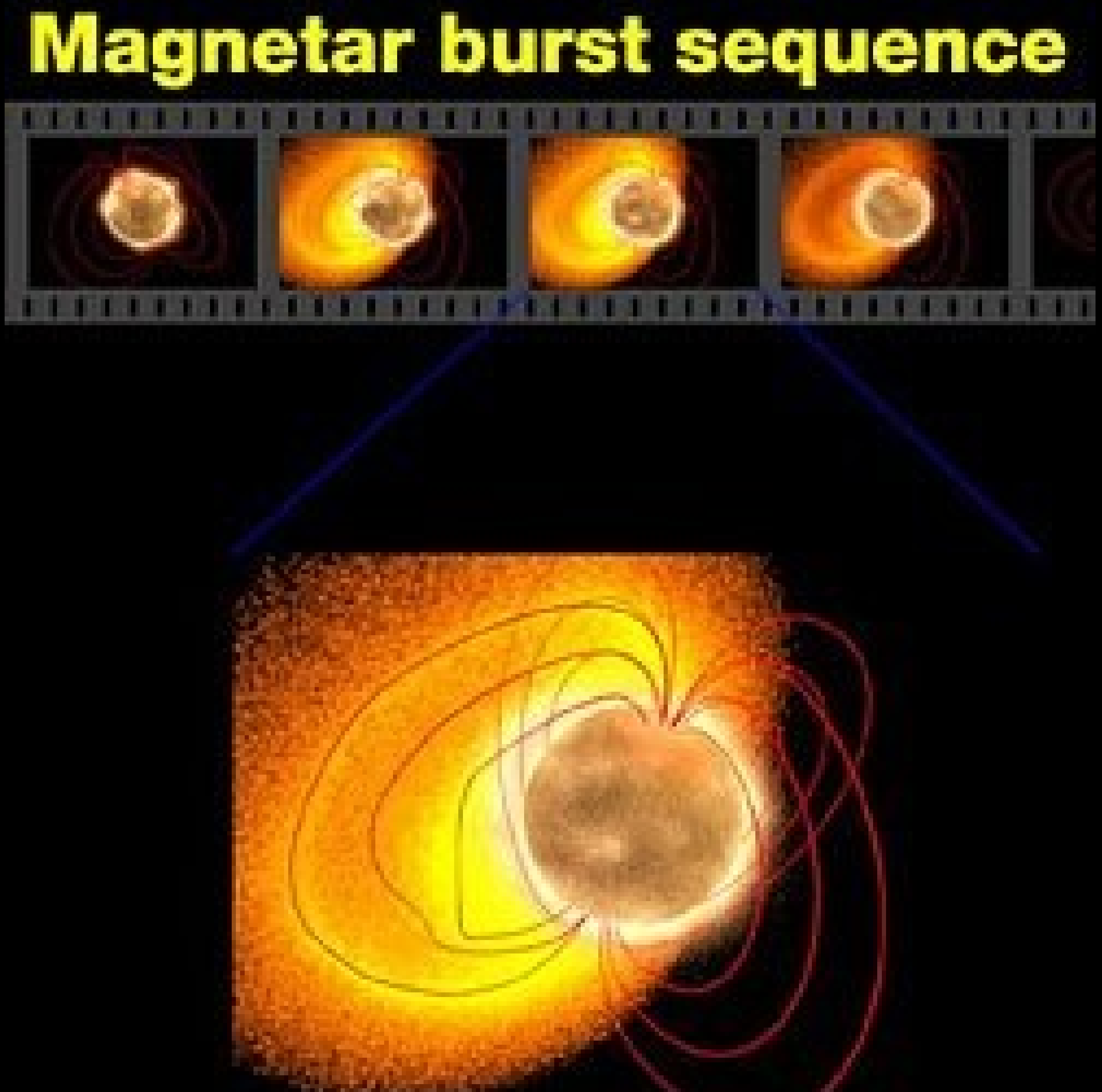


Energy source is spin down of neutron star.

Must lie along pulsar beam to see pulsed signals.

Crab Pulsar

Magnetars

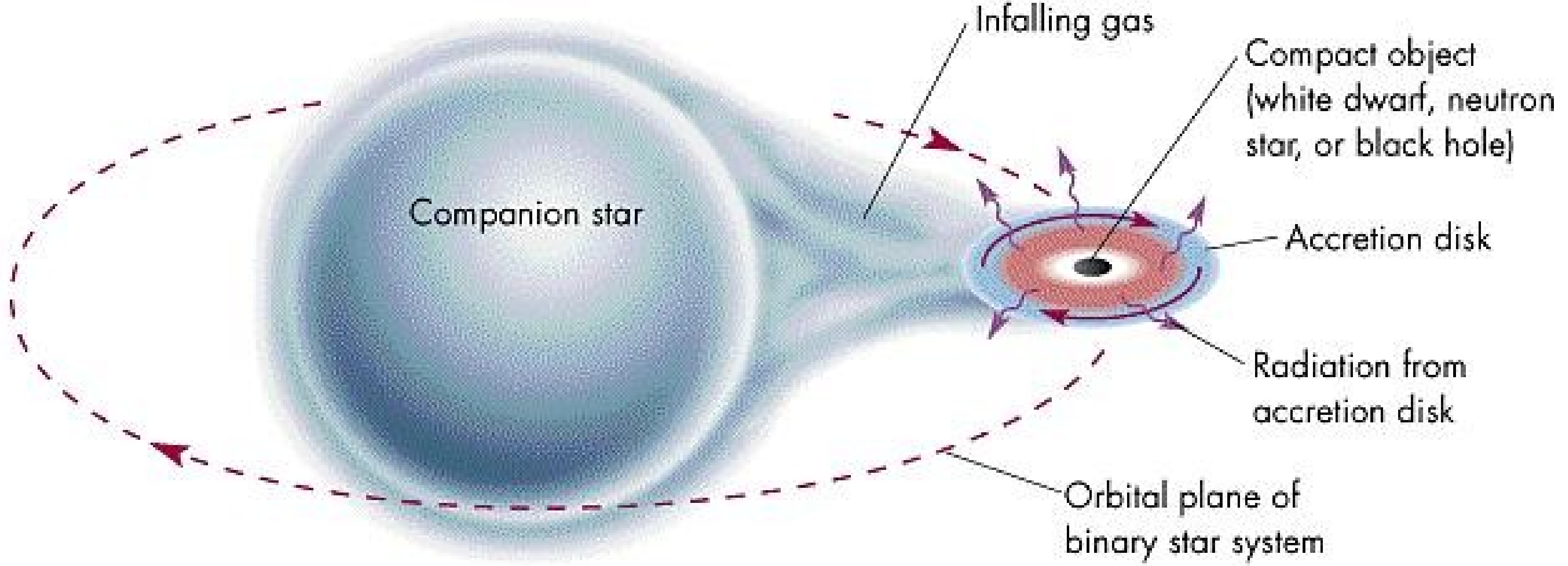


Magnetic fields so strong that they produce starquakes on the neutron star surface.

These quakes produce huge flashes of X-rays and Gamma-rays.

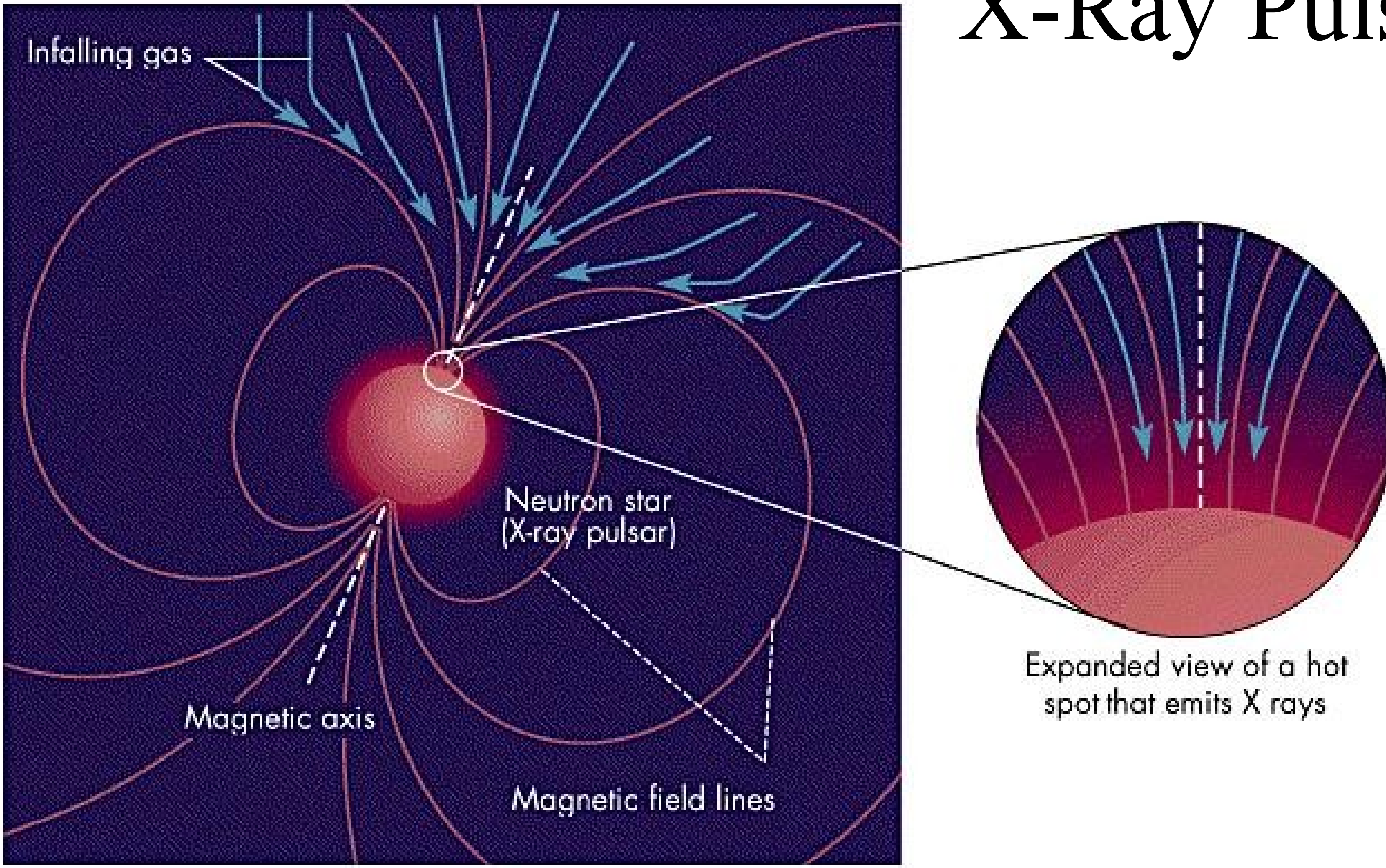
Energy source is magnetic field.

X-Ray Pulsars



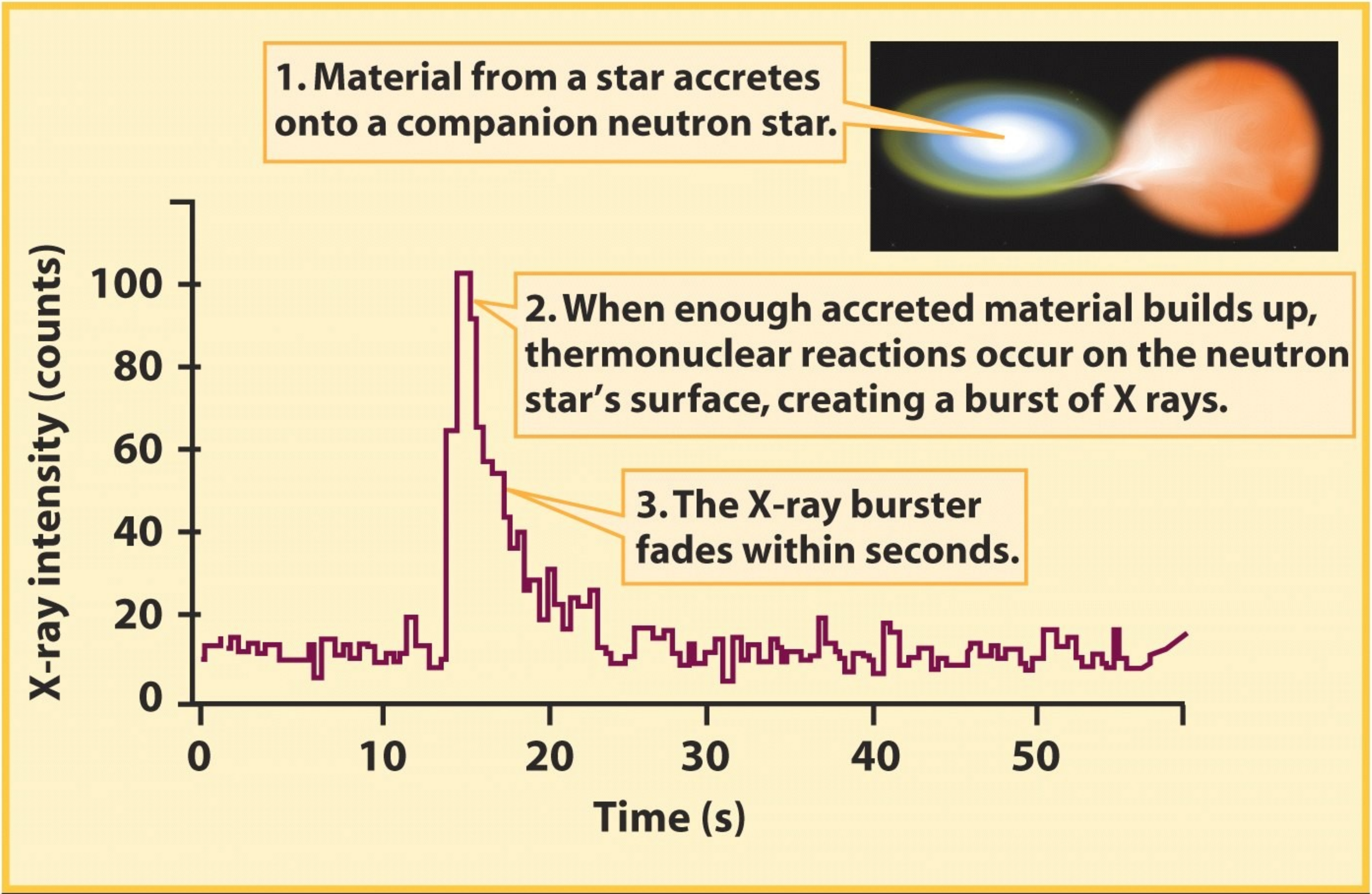
Neutron star in binary system with a normal star

X-Ray Pulsars



High magnetic field neutron stars make regular pulsations. Energy source is gravitational energy of infalling matter.

X-ray Bursters



X-ray Burst

Low magnetic field neutron stars make X-ray bursts.

Source of energy is nuclear burning.

Review Questions

- What is the Fermi exclusion principle?
- Does a more massive white dwarf have a larger or smaller radius than a less massive one?
- What is the maximum mass of a white dwarf?
- What are some of the properties of neutron stars?
- Why do many neutron stars spin rapidly?
- In what different forms does one find neutron stars?