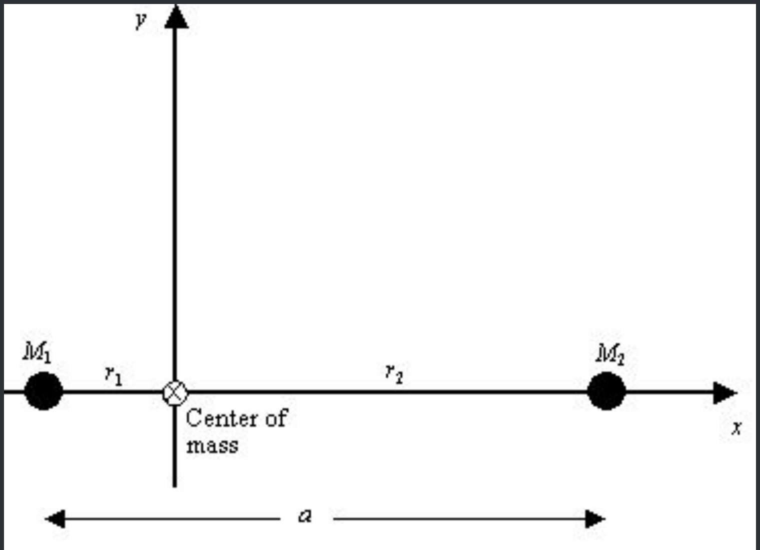
BINARY STAR SYSTEMS

What is a binary star system?

- A system in which there are <u>two</u> stars orbiting each other
- The two stars orbit around a common point
  - This point is the *barycenter* (i.e., the center of mass of the two stars).

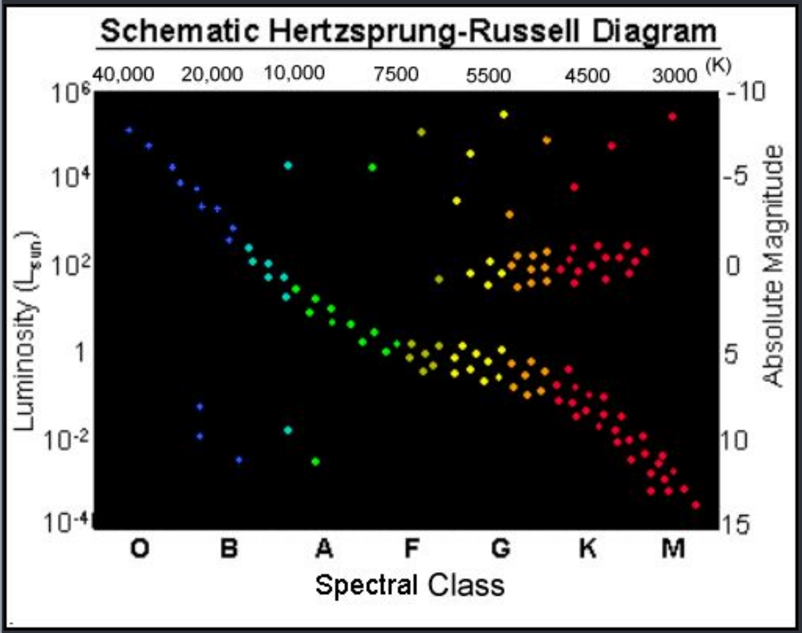


What is a Binary Star System?

Artist impression of
AR Scorpii binary star system

How are these systems formed?

Recall the Main Sequence of the H-R diagram:



- This is not only a "Mass Sequence" and a "Luminosity Sequence" (i.e., Earlier => More massive + luminous)

- It's also a Population Sequence:
  - Spectral classes earlier on the Main Sequence are *less common* than those found later.
  - Hence, Main Sequence stars with less mass are more common than those with more mass.
- But why?

How are these systems formed?

Consider a protostar of high mass (i.e., a high-mass ‘blob’) which is “trying to be born” as a high-mass star:

- As it undergoes stellar birth, it will contract.
- Conservation of angular momentum:

$$m_i v_i \cdot r_i = m_f v_f \cdot r_f \Rightarrow v_i \cdot r_i = v_f \cdot r_f$$

- Hence, as the radius decreases, the rotational speed must increase.
- In almost all cases:
  - The high-mass blob collapses to the point where it’s spinning <u>*so fast*</u> that it fragments itself into two “lower-mass” blobs (*fragmentation*)
  - Subsequently, two low-mass stars are born and they form a binary star system.

Why are binary star systems special?

In a sense, they're not:

- The majority of star systems are *binary*.
    - "Single-star" systems are far less common.
- In most of these systems, the stars are far away from each other:
    - They evolve 'normally' — as though they each belong to their own isolated system.

So why should we care about them?

- On rare occasions, the stars are rather *close* to each other.
    - So close that they can interfere with each other's evolution
    - In these cases, much of what we know about Stellar Evolution is thrown out the window.

Close Binary Star Systems: The Preliminaries

Consider a system of two stars — call them Star A and Star B — which are born on the Main Sequence and orbit each other "closely".

Suppose that Star A is more massive than Star B.

- Then we know from "normal" stellar evolution that Star A has a shorter lifespan than Star B.
- Star A's core will collapse and the rest of it will swell to become a red giant as it leaves the Main Sequence.

Close Binary Star Systems: The Accretion Disk

Since the pair of stars are "close" to one another, the outer layers of Star A can expand to the point where they're *gravitationally bound* to Star B.

- The gas then starts 'falling toward' Star B.
- Since the stars orbit each other, the gas has angular momentum.
  - Because of this, the gas doesn't fall 'directly' toward Star B.
  - Instead, the gas settles down into a 'disk' which is *orbiting* Star B.
    - This is called an *accretion disk*.
      - Why?

Close Binary Star Systems: Mass Transfer

In the 'accretion disk', the gas particles rub against each other — this generates friction, which in turn generates heat.

- Subsequently, the gas slowly spirals inward and eventually <u>*crashes into*</u> Star B.
  - Thus, Star B gains mass from these collisions — the process of which is known as *accretion*.

But wait: The more <u>*massive*</u> a star is, the <u>*shorter*</u> it lives on the Main Sequence.

- Hence, as Star B gains more mass, it may eventually evolve off the Main Sequence prematurely.
- Star B then swells to become a red giant, and mass is transferred back to Star A.

Occasionally, we discover binary systems with a red giant which has <u>*less mass*</u> than its companion.

Close Binary Star Systems: A High-mass Companion

Most of the time, both stars in the system are of low mass (recall fragmentation).

- On rare occasions, one of the stars will be high-mass.

When one star (say, Star A) is high-mass, it spends a very short time on the Main Sequence and eventually swells to become a supergiant.

- Mass is then transferred to Star B, much like before.

<u>But:</u> Mass transfer doesn't change the fact that the core of Star A is ready to implode.

- Star A will then go supernova — but Star B can actually survive the explosion.
- If it survives, Star B will become a red giant.
  - The mass transfer/accretion disk process is similar, with a neutron star or a black hole on the receiving end.

3 Classifications of Binary Stars

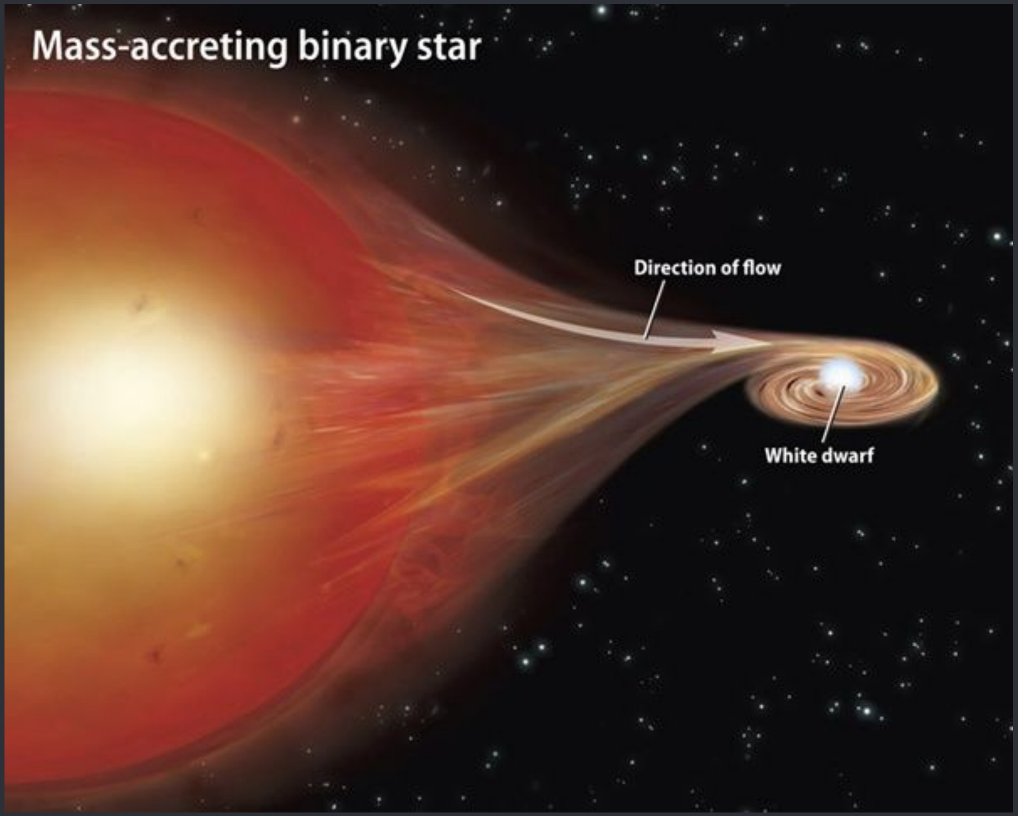
Methods of Classifying Binary Star Systems

Distance

- Wide binaries
- Close binaries
  - Detached
  - Semi-detached
  - Contact

Observational

- Visual binaries
- Spectroscopic binaries
- Eclipsing Binaries
- Astrometric Binaries
- “Exotic” types



Artist rendition of close binary star system

Types

- Algols
  - Two semidetached main-sequence or subgiant stars
- RS Canum Venaticorum & BY Draconis Stars
  - Two chromospherically active stars
- W Ursae Majoris Contact Systems
  - Two short period contact stars
- Cataclysmic Variables & Nova-like Binaries
  - White dwarf primary with cool M-type secondary
- X-ray Binaries
  - Contain neutron star or black hole

4 White Dwarf Binaries

White Dwarf Binaries

No Explosion

- Secondary star - main sequence type G or older
- Period length: From 23 minutes up to 5 days. Most are 1-12 hrs
- Produce dwarf and classical novae when mass transfer rate spikes

Explosion

- Supernova 1a - most consistent type of supernova
- Enough mass falls on the star to surpass Chandrasekhar limit
- Double-degenerate model - two white dwarves, one disintegrates
- Single-degenerate model - one white dwarf, one evolving star

5

X-ray Binaries

Formation

- An evolving star in a binary system survives the supernova of it’s massive companion

OR

- A star captures a nearby isolated neutron star

- For neutron stars, if the accretion disk is large enough, it will turn into a pulsar

- Categorized into LMXBs (low mass X-ray binaries) and MXRBs (massive X-ray binaries)

X-ray Binaries

Resultant Phenomena

- Black Widow Pulsars
  - Pulsar evaporates companion white dwarf
- Double Neutron Star Binaries
  - No mass exchange in a relativistic system
- End of X-ray binary systems
  - If secondary star is also massive, its supernova could potentially blast its companion neutron star into space
  - Merge of two neutron stars or neutron star with black hole: short-hard gamma ray bursts

6

Role of Binary Star Systems in Proving General Relativity

Role of Binary Star Systems in Proving General Relativity

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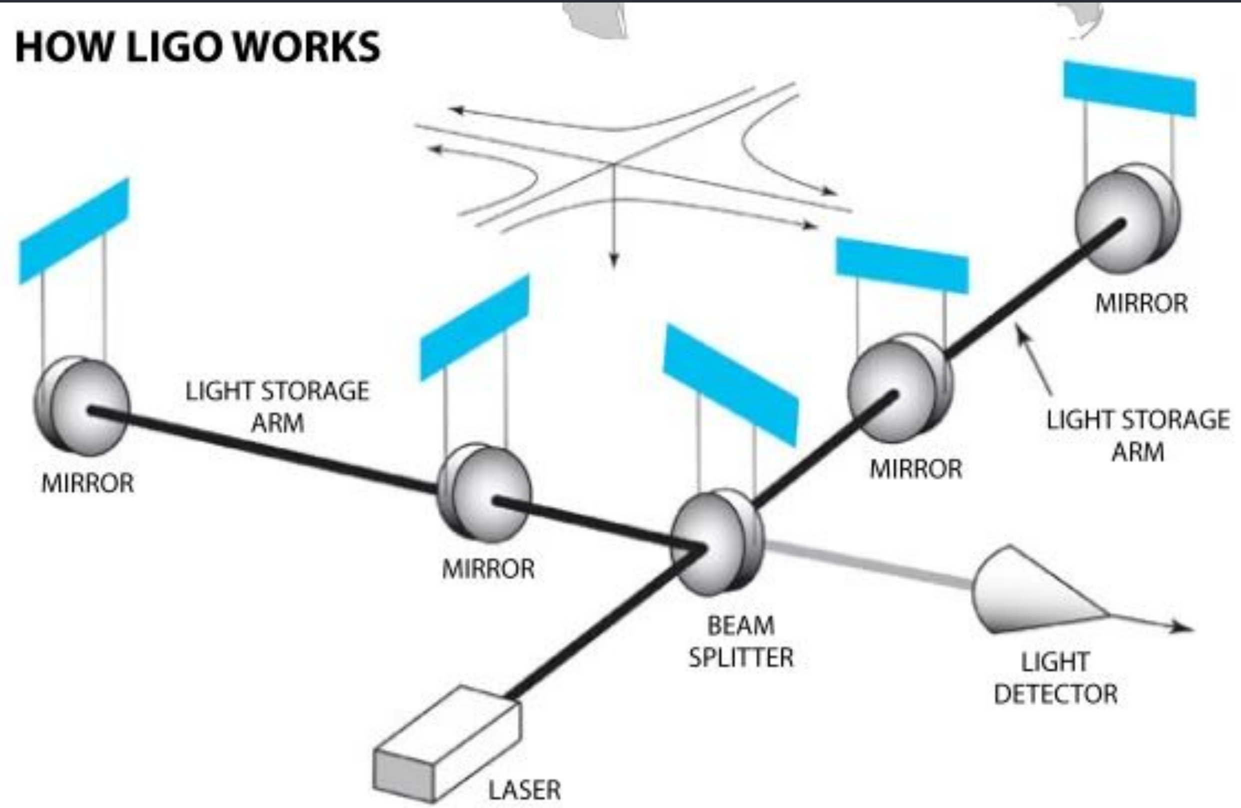
HOW LIGO WORKS



The **Laser Interferometer Gravitational Wave Observatory (LIGO)** searches for distortions in space-time that indicate the passage of gravitational waves through the Earth. A **laser beam** is split down two 2.5-mile (4 kilometers) arms containing mirrors. The laser beams reflect off of mirrors to converge at the crux of the arms, canceling each other out. The passage of a gravitational wave alters the length of the arms, causing the beams to travel different distances. The mismatch is measurable with a light detector. LIGO facilities in Louisiana and Washington state operate simultaneously; the two data points allow triangulation of a wave's source in the sky.

The End!

Sources

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