Why Study Binary Stars?

- So we can find the mass of a star
- Mass of the star determines its present & future
- Gravitational force of a star curves the orbit of its companion
- Gravitational force depends on the Mass
Nearest Stars

- 50% binary stars
- 13% in triple systems
- 4% in multiple systems

horizon = 13.1 light years
Three Kinds of Binary Stars

- Visual Binary Stars
- Eclipsing Binary Stars
- Spectroscopic Binary Stars
- Depending on Inclination of the Orbit
My Favorite Visual Binary

- Mizar (my czar) middle star in Big Dipper is the horse
- For Alcor, the rider. Traditional test of eyesight
Mizar and Alcor

- 1 & 2 are Mizar A & B a “Visual Binary” at 78ly=24pc
- 3 Alcor distance 81±1 ly =25pc
- Same proper motion so “Visual Binary” with Mizar
- 4 Sidus Ludoviciana is at a distance of 600ly =180pc so a chance superposition “Optical Double”
The Optical Interferometer

- Navy Prototype Optical Interferometer
- Combines a few small telescopes to equal one 38m diameter
- Resolution ~0.01 milliarcsec
Visual Binary: Mizar Aa, Ab Movie

NPOI Observations of Mizar A
(ζ¹ Ursa Majoris)

Mizar, 88 light years distant, is the middle star in the handle of the Big Dipper. It was the first binary star system to be imaged with a telescope. Spectroscopic observations show periodic Doppler shifts in the spectra of Mizar A and B, indicating that they are each binary stars. But they were too close to be directly imaged - until 2 May 1996, when the NPOI produced the first image of Mizar A. That image was the highest angular resolution image ever made in optical astronomy. Since then, the NPOI has observed Mizar A in 23 different positions over half the binary orbit. These images have been combined here to make a movie of the orbit. As a reference point, one component has been fixed at the map center; in reality, the two stars are of comparable size and revolve about a common central position.

Orbital Phase: 000°
Multiple-Star Systems

- Mizar Aa + Ab orbit pair Ba + Bb all orbited by Alcor
- Period + Semi-major Axis + Kepler’s law = Masses
Visual Binary: Sirius A & B

- Bessel measured parallax to be 0.37” in 1844
- Distance is 2.7pc = 9 light years
- Apparent magnitudes are $m_V = -1.4 & 8.7$
- Absolute magnitudes $M_V = +1.6$ and 11.7
Sirius A&B in X-rays

- Bright star 1000 times more luminous
- Faint star: brighter in X-rays – it’s 2.5 times hotter
- Radius 200 times smaller
Kepler’s Law

- Period + Semi-Major Axis in Kepler’s Law = Masses
- So Sirius A has twice mass of sun & Sirius B has same mass as sun
- Radius of the Earth means
- Very large density (bus in an iPod)
Mizar A Spectra

- First spectroscopic binary; discovered by Pickering in 1889

- Single Lined

- Double Lined
Spectroscopic Binary

- Doppler shift gives velocity of stars
- Blueshift for stars coming at us and
- Redshift for stars moving away
Spectroscopic Binary

- Periods of hours to decades
- Most populous class of binary star
- Inclination of orbit unknown so lower limit on masses
Eclipsing Binary Stars - Algol

- First discovered by Arabs as variable star (V=2.2-3.4)
- John Goodricke determined period of 69 hours in 1782
Algol’s Light Curve

- Observations of the brightness of the star = photometry
- Are plotted against time
Total Eclipse

- Vik Dhillion’s observations with ULTRACAM
- M dwarf star eclipses white dwarf
- Eclipsing binary disappears during total eclipse and comparison star is still visible
Depth of Eclipse => Star Temperature

- The amount of light lost depends on eclipsed area & temperature
- The area covered at each minimum is the same
- Depth of the minimum depends on eclipsed star’s temperature
- Primary eclipse is always when the hotter star is behind the cooler star
Width of Eclipse $\Rightarrow$ Star Diameter

- The diameter of the small star is the time from 1 to 2 times the velocity of small star.
- The diameter of the larger star is the time from 1 to 3.
Model of Algol

- From the light curve we can estimate temperature, diameter, spacing of each star and orbital inclination.
- If it is a spectroscopic binary we get the masses as well!
Models
Kepler 10b

- Kepler satellite discovers rocky planet
- Orbits star in 20 hours so close, HOT, synchronous
- Helioseismology says star is old & smaller than sun
- Planet 4.6X Earth mass & 1.4XEarth diameter
Classed as a “super-Earth,” candidate planet KOI (Kepler Object of Interest) 172.02 orbits within the habitable zone of a sun-like star. This means the planet, which has yet to be confirmed by follow-up observations, could have liquid water on its surface, thought to be essential for life.

<table>
<thead>
<tr>
<th></th>
<th>KOI 172.02</th>
<th>Earth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diameter</td>
<td>11,900 miles (19,000 km)</td>
<td>7,926 miles (12,756 km)</td>
</tr>
<tr>
<td>Orbital distance from star</td>
<td>70 million miles (112 million km)</td>
<td>93 million miles (150 million km)</td>
</tr>
<tr>
<td>Year in Earth days</td>
<td>242 days</td>
<td>365 days</td>
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Center of Mass of Sirius A&B

- Position of the faint star (secondary) relative to bright star (primary) gives the relative orbit

\[ \alpha_2 \quad \alpha_1 \]

\[ M_2 \quad a \quad M_1 \]

1990

Sirius A

Sirius B

Center of Mass

Orbit of White Dwarf

\[ \frac{M_1}{M_2} = 3.6; \quad e = 0.0 \]
51 Pegasus

- Single lined spectroscopic binary
- Discovered in 1995 by Mayor et al.
- Radial velocity curve gives:
- Minimum mass of ~Jupiter in a 4 day orbit

![51 Peg diagram](image)
Eclipsing Binary Light Curve

- Primary minimum 2 is deeper than secondary minimum/eclipse 4
- Eclipses can be total=4, annular=2 or partial=slopes
Inclination of Orbit

- $0^\circ$ inclination = face on: **Visual Binary** no radial velocity variations
- Only measure radial component of velocity for other inclinations
- $90^\circ$ inclination is **Eclipsing Binary** and all velocity is radial
Cygnus X-1

- Nearest Black Hole
- Lots of complications: tides, mutual heating, limb darkening, spots, pulsations, elliptical orbits, rapid rotation
Fomalhaut b & HR 8799 b,c,d

- Both announced 13Nov08
HD209458

- First transiting/eclipsing planet 2000
- Depth of eclipse => radius of planet
- Radial velocity variations give mass
Eclipsing Binary Stars

- Eclipsing binary periods range from an hour to a decade – most \(~\) 1 day
- Rarest class of binary stars
Partial Eclipse

- Partial Eclipses – some of the star is visible at mid eclipse
HR8799 b,c,d
- Young 5th mag star in Peg
- Parallax=0.025'' D=?pc
- AO system reveals 3 planets at 24, 37, 67 AU just inside dust disk
Fomalhaut b

- Parallax=0.125”  \( D = \)
- \( A = 100 \text{AU}: \ P^2 = A^3 \)
- How can we tell a planet from a background star?
- Planet just inside dust ring
Radial Velocity Curve of Mizar A

- Velocity times Period gives Distance traveled which equals Circumference of orbit thus radius of orbit in kilometers
- \((M_1 + M_2) = A^3 / P^2\) gives total mass times sine inclination (upper limit)
- \(V_1 / V_2 = M_2 / M_1\) gives ratio of Masses
Algol Movies

- CHARA observations & animations
Double-Lined Spectroscopic Binary Animation

Animation:

Double-Lined Spectroscopic Binaries
57 Cyg Line Doubling
Contact Binary

- Star expands as it ages and begins to dump material on secondary star
- Sometimes both Roche lobes fill giving a contact binary shaped like a peanut
X-ray Binary Animation

- Secondary star can be very small (Black Hole or Neutron star) and cannot absorb material and forms disk
Visual Binary Castor

- First binary star orbital motion discovered by William Herschel in 1790
Astrometric Binary

- Astrometric binary is when you can’t see the companion
- Until Alvan Clark discovered the secondary in 1862
- Semi-major axis $A$ is 7.5” times distance of $2.7 \text{pc} = 20 \text{ AU}$
Center of Mass

- $M_1/M_2 = a_2/a_1$
Spectroscopic/Eclipsing Binary

- Measure radial velocities from spectra
- Measure period from light curve – gives radius of orbit
- Gives diameters and masses of stars in km and kilograms
Single Lined Spectroscopic Binary

- Radial Velocity curve of Mizar B
- No information of the masses of the stars