**Lecture 6: Variables & Binaries**

* 1. Variations over time
     1. Stars often thought of as fixed on sky
     2. But they do vary: usually over VERY long time scales
     3. But there are some stars that vary over short time scales
     4. And some stars vary because they are part of a stellar system: a binary
     5. E.g. here are RR Lyrae stars in a globular cluster; see them vary
     6. **What do you notice about which stars are varying and which are not?**
     7. Here is a binary; one you can easily see, and some of you have; motion of these stars is measurable over human time scales (many binaries have much shorter periods)
  2. Types of variables
     1. Some stars vary on their own
     2. They have an instability in their atmosphere that causes this
     3. Star is actually changing size over time
     4. Some are short periods (days or weeks) like Cepheids & RR Lyrae, some are long-period (Mira-type)
  3. Cepheids
     1. Cepheids are a special type with an interesting historical context
     2. This is a typical light curve and shows dramatic changes
     3. One of the first of this type to be discovered was Delta Cephei in 1784, and they are named after this one.
     4. What makes them so interesting is that their variation follows an interesting pattern: the more luminous the star, the longer the variability period. You can think of this very simply as being because the star is bigger it takes longer to oscillate.
     5. This was discovered by Henrietta Leavitt and Pickering in 1912, by looking at stars in the LMC.
     6. Modern data looks like this, with a vary clean relationship.
     7. Why is this interesting? Well, Cepheids in the MW can have their distances measured; e.g. delta Cephei is 273 pc away, known from parallax.
     8. This means we can determine how far away the LMC is. Just look at Cepheid of same period and compare flux
     9. Once we know the distance to the LMC, we can also work out the distance to other galaxies. THE major program in first decade of Hubble Space Telescope. E.g. find Cepheids in outskirts of nearby galaxies. Measure their period, then their distance. Dozens of galaxy distances known in this way, extremely important measurement tying down our understanding of the further universe.
  4. RR Lyrae
     1. Very similar star to Cepheids. At first thought to be the same as Cepheid, but now known to be a somewhat different, less massive class. mechanism of variability is the same.
     2. Whereas Cepheids are massive stars, RR Lyrae are lower mass stars. Become RR Lyrae at late stage so they are old. Common in globular clusters
     3. Also have a period luminosity relation, can be used to get distances to globulars.
     4. This was one of their earliest uses, by Harlow Shapley
     5. We are at red point here. Note ALL the globulars are on one side of the sky. Shapley determined their distances and found distance to their center of ~ 25,000 pc. Too big by about a factor three (because he assumes P-L is same as Cepheids). But an early indicator of the vastness of the Galaxy
  5. Long-period variables
     1. Mira-type variable have much longer period, less regular. Due to pulsations ejecting outer layers of star. The past ejections are visible as they trail behind the star.
  6. Novae
     1. An entire other class of variable stars are those that are due to the binary nature of the star. A classic example is the "novae". Most typically, these are close binary stars, where one companion has evolved and become a white dwarf. When the companion becomes a red giant, its atmosphere can be funneled down onto WD. A WD is about the size of the Earth, but the mass of the Sun. So gravity is very strong. Gas is highly compressed, fusion starts. Nuclear explosions go off, and cause these flares. In some cases this happens quite regularly.
     2. Recently discovered related phenomenon. Neutron stars
  7. Binaries
     1. But this is just one example of a binary. Not all are that violent.
     2. E.g. Mizar. It is of course paired on the sky with Alcor, but it isn't known if they are bound.
     3. Mizar has a close companion, with which it is gravitationally bound, Zeta Ursa Majoris.
     4. This companion was itself the first "spectroscopic" binary, where we know it is a binary but its companion is too close to image it separately, and Mizar is now known to be one as well. So is Alcor
     5. Sirius and Procyon are binaries with WD companion
     6. Binary stars are very common!
  8. But what is a spectroscopic binary?
     1. Spectroscopic binaries use the Doppler effect
     2. Explain Doppler
     3. So if the star is moving, we can measure it.
     4. Of course, all stars are moving with respect to us. But if it is in a binary, that velocity is changing, because they are orbiting around each other.
     5. The larger the masses, the faster the orbits at a given distance. This is the source of our empirical knowledge of the masses of stars.
  9. Eclipsing binaries
     1. Algol is typical. One star eclipsed by another.
     2. Note there are two dips, since either one passing in front of other reduces light