continuous monitoring studies. Hilton et al. [2010] have discovered flares in the time resolved SDSS spectroscopic sample, using a Flare Line Index based on Hα and Hβ line strength.

The evolution and migration of starspots on contact binaries has been tracked with doppler imaging [Hendry and Mochnacki, 2000] and more recently, in Kepler data [Tran et al., 2013, Balaji et al., 2015]. Starspots are magnetic phenomenon, and so their occurrence is related to the magnetic activity of their host star [Berdyugina, 2005].

2.10 Remaining Questions

3 Observations

Q: What kind of observations can astronomers obtain from contact binary systems?

Astronomy is unique as a science because all the information that can be obtained from an object in the sky comes to us as electromagnetic waves. Perhaps *THE* question in observational astronomy is: "What can we learn from these electromagnetic waves?". The study of contact binary stars is no different. In this section, we will learn the ways that researchers study electromagnetic waves from contact binary stars.

3.1 Images of Contact Binaries

The oldest type of astronomical information is image data: "What do I see when I look through the telescope?". To put this question in more formal language: "What is the distribution of the intensity of visible light as a function of position?". When we look at the moon, for example, we can learn a lot about it: we might see some crater "over here", with a given size, shape, color, etc. We might see a dark lunar mare (or "sea"), "over there", with another size, shape, color, etc. The moon is what we call a "resolved source", meaning that features on it are distinguishable: we can separate "over here" from "over there". In other words, the distance between "over here" and "over there" is larger than the resolution limit of our telescope.

Let's see if we can reasonably obtain image data from a contact binary:

On a still, clear night at the Las Campanas observatory in Chile, the atmospheric resolution limit (or "seeing") is 0.5 arcseconds. This is the best resolution that can be expected from a telescope on earth: Chile's Atacama desert is know for some of the best seeing on earth.

$$0.5 \text{ arcseconds} * \frac{1}{3600}\frac{\text{arcseconds}}{\text{degrees}} = 1.4 \times 10^{-4} \text{ degrees} * \frac{\pi}{180}\frac{\text{radians}}{\text{degrees}} = 2.4 \times 10^{-6} \text{ radians} \tag{3.1}$$

In order to distinguish between the two components of a contact binary, the resolution limit of our telescope must be smaller than the distance between the centers of the two components.

For a contact binary star of solar type, this is about one solar radius: $1R_\odot = 6.957 \times 10^5$ km. Let us place this hypothetical contact binary at the same distance as the nearest star, *Proxima Centauri*, which is 4.243 light years = 1.301 parsecs = 4.014×10^{13} km.

To calculate the angle that a solar type-contact binary at the distance of *Proxima Centauri* would subtend, we will use the small angle approximation:

$$\sin(\theta) \approx \theta, \qquad \cos(\theta) \approx 1 - \frac{\theta^2}{2}, \qquad \tan(\theta) = \frac{\sin(\theta)}{\cos(\theta)} = \frac{\theta}{1 - \frac{\theta^2}{2}} \Rightarrow \tan(\theta) \approx \theta \tag{3.2}$$

If we set up a right triangle (as in Fig. 17), we see than the tangent of the angle θ is equal to the radius of the sun divided by the distance to *Proxima Centauri*.

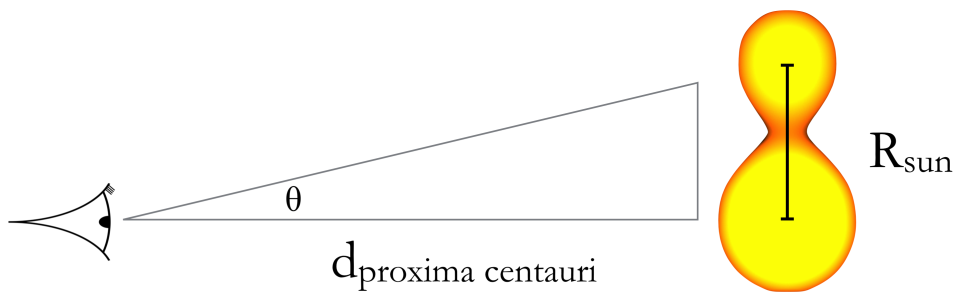

Figure 17: Calculating the angle θ subtended by a solar-type contact binary at the distance of the nearest star.

$$\frac{R_{\text{sun}}}{d_{\text{proxima centauri}}} = \frac{6.957 \times 10^5 \text{ km}}{4.014 \times 10^{13} \text{ km}} = \tan(\theta) \approx \theta = 1.733 \times 10^{-8} \text{ radians} \tag{3.3}$$

When comparing the resolution necessary to distinguish the components of a contact binary to the best resolution possible on earth:

$$\frac{1.733 \times 10^{-8} \text{ radians}}{2.4 \times 10^{-6} \text{ radians}} \approx 0.01 \tag{3.4}$$

To summarize: we would need 100 times the resolving power achievable from the earth to obtain image data from a large contact binary at the distance of the nearest star. In actuality, the situation is worse. 44 Bootis is the nearest contact binary system to earth, at a distance of 13 parsecs (42 light years) it is 10 times further away than *Proxima Centauri* [Eker et al., 2008]. For this reason, we cannot obtain usable image data from contact binaries [1].

[1] it is possible to achieve this resolution (as good as 0.0005”) through long-baseline interferometry. Using

3.2 Photometry of Contact Binaries

Q: Why does the flux received from a contact binary vary over time? Q: How was the light-curve used to determine what a contact binary was? Q: How can light-curve data be used to learn about contact binary systems?

In images, contact binaries appear as an unresolved point source. At first glance, it may appear that astronomers are stuck: they cannot "see" the contact binary and so must remain uncertain about its characteristics. However, as Kempf and Müller learned in 1903, the amount of light received from a contact binary varies as a function of time. This function is called the light-curve:

$$f(\text{Time}) = \text{ Flux Received at Telescope} \tag{3.5}$$

A light curve is constructed from observations: by repeatedly measuring the brightness of a source over a certain time span, an astronomer can sample the light-curve and approximate its true shape.

Kempf and Müller knew that they could used the light-curve to learn about the shape of the contact binary system. First, they noted that the light-curve was periodic: after a certain amount of time, the trend in flux *exactly repeated* itself. Thus they knew that the process that was responsible for the variation in the flux was cyclical in nature.

They knew that the period of the light variation in W UMa was very stable ("The error of the period can hardly be more than 0.5s..."). They assumed that a rotational or orbital mechanism was responsible for the light variation. They thought that the presence of a large dark spot on a rapidly rotating single star, which was hypothesized to be "in an advanced stage of cooling". However, W UMa was a white star, not a cool red star, leading Kempf and Müller to discredit this model. They also considered a single star in the shape of an ellipsoid - a large, however they calculated that this model did not describe the shape of the light-curve very well. In 1903, the eclipsing binary model was already proposed as a mechanism for the light-curves of certain stars (most notably Algol). To construct their model, they looked at existing eclipsing binary light curves and imagined what would happen if they brought the two stars close together. If they brought the two stars close enough together so that the stars were almost touching, there was always variation in the light-curve, just like they observed.

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the CHARA array on Mount Wilson, researchers have constructed a resolved image of the eclipsing binary system β *Lyrae* [Zhao et al., 2008]. However, interferometric imaging is only possible for the brightest stars, so is not useful for contact binaries.