Photometric Monitoring of β Pictoris in 2017

Iva Laginja
Leiden Observatory, The Netherlands
laginja@strw.leidenuniv.nl

November 24, 2016

Abstract

The star β Pictoris is expected to show significant photometric changes between March 2017 and March 2018 due to the Hill sphere transit of its planet β Pictoris b. The astronomy community is organising an observation campaign to collect data from this event. As the star is visible only from the southern hemisphere and even there only during certain parts of the year, we are hoping for the amateur astronomy community to contribute to a longer baseline of photometric observations of the star.

1 The planet β Pictoris b

The star β Pictoris has been the center of attention of many studies ever since the imaging of its edge-on circumstellar disk by Smith and Terrile in 1984. Through further investigation of the disk, a warp has been seen within it and the possibility of a planet causing the warp was inferred. In 2010, Anne-Marie Lagrange reported the detection of an extrasolar planet by direct imaging, β Pictoris b.

The planet itself has a mass of about 11 Jupiter masses and orbits its host star at 10 AU. Furthermore, it is on an almost edge-on orbit as seen from Earth, which favours a transit configuration. Because the star and the planet are very young, it is very likely that there is still a lot of material orbiting the planet itself. Jason Wang and his collaborators showed in 2016 that the planet itself will not pass in front of the star, but it will be close enough that any material around the planet might still block a significant amount of the star light and this is the reason why the almost-transit of β Pictoris b is so interesting - it gives us the opportunity to indirectly probe the environment of a young planet. The space around the planet in which we expect some material is called the planet's Hill sphere. It is the space around the planet in which any material will be gravitationally bound to the planet rather than the star. The size of the Hill sphere can be described by the Hill radius r_H.

Using images from the Gemini Planet Imager (GPI), Wang also worked out when the transit is most likely to happen, which is illustrated in a probability distribution in fig. 2. The middle of the event should take place somewhere towards the end of August 2017. About 5 months before and after, any material

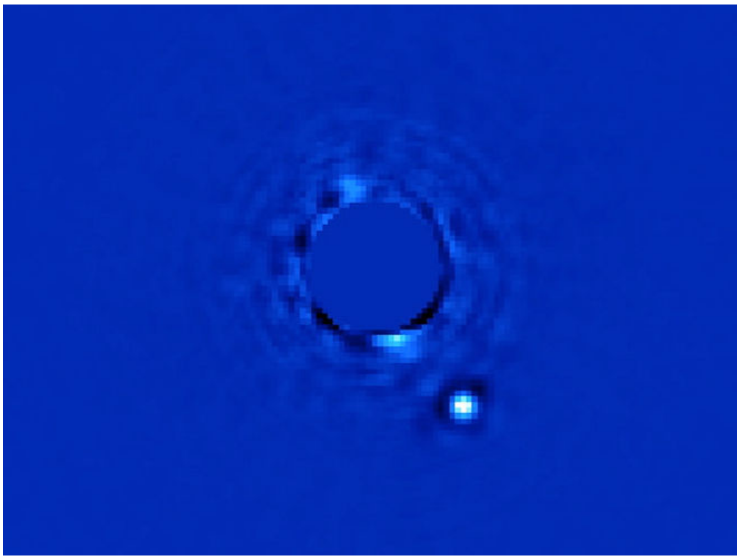

Figure 1: The white light blob in the lower right part of the image is the extrasolar planet β Pictoris b (Christian Marois, NRC). The star in the middle of the image has been cut out to avoid confusion of star light with the planet.

around the planet will impose an effect on the star light and measuring these so called ingress and egress light variations can help us to study the planet.

2 Scheduled Observations

A list of planned observations by the astronomy community, both photometry and spectroscopy, can be found at `http://home.strw.leidenuniv.nl/~kenworthy/beta_pic_b_hill_sphere`, hosted and maintained by Leiden professor Dr. Matthew Kenworthy. There are several reasons why we need as many photometric observation stations as possible:

β Pictoris is a southern hemisphere star As you can see in fig. 3, there is not much land mass in the southern hemisphere, so there are also not many possibilities to set up telescopes or use the ones that already exist. Possible observation sites are South America, the south of Africa, Australia, New Zealand and the Antarctic. Leiden Observatory (The Netherlands) and the University of Rochester (USA) are building one observing station each with the name bRing to be installed in South Africa and Australia respectively. There are two telescopes on a base in the Antarctic that will join the campaign and two cubesats will point their objectives at β Pic as long as they can (see `http://home.strw.leidenuniv.nl/~kenworthy/beta_pic_b_hill_sphere`).

The event lasts almost a year Our night sky undergoes seasonal changes and most stars are observable only during certain times of the year; this also holds true for β Pictoris. If you go far enough south, then the star will be a circumpolar star and you can see it all year long, but that happens only when

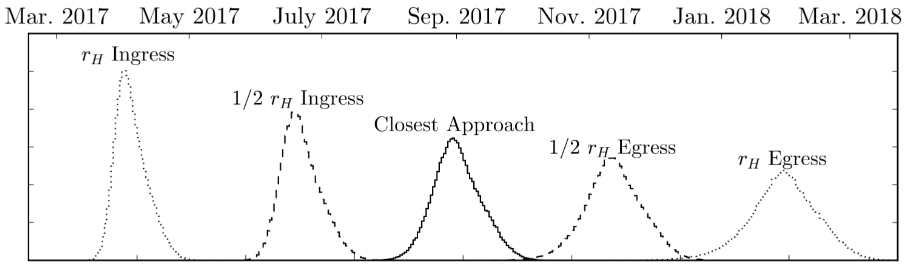

Figure 2: This graph shows the probabilities of when the transit of the material around the exoplanet β Pictoris b is most likely to happen. Closest Approach describes the point when the planet is closest to the star, but it will miss the star by a tiny amount and not be a real planetary transit. Ingress describes the Hill sphere coming over the star to dim its light and during egress it is leaving it slowly again. The whole event lasts a little less than a year. (Wang et al. 2016)

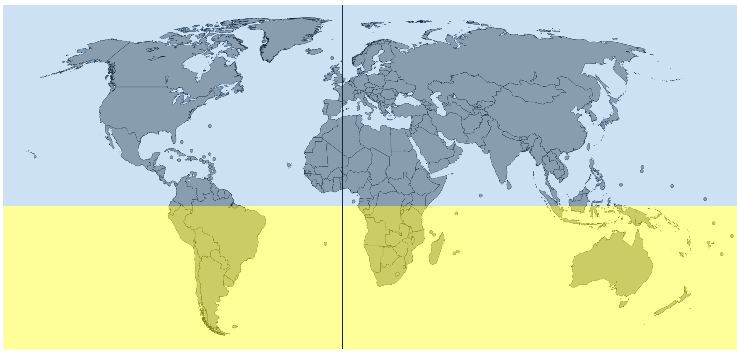

Figure 3: There is not much land mass on the southern hemisphere. Hence, there are not many telescopes that can observe β Pic. (Image Source: Wikipedia)

you are very close to the South Pole, so that is not really an option for setting up a new telescope. Even from the southern most tip of South Africa, β Pictoris will be visible only during a couple of hours during twilight and dawn in the months between May and September 2017, which are not the best observing conditions. To cover the event the best possible, data from as many places as possible is needed.

β Pictoris is a very bright star There have been enough surveys around for the past couple of years that one might ask: Can't they just do the job? The problem is that most of the transit observations undertaken were looking at stars of apparent magnitude 6 or fainter, because their detectors get saturated easily if the star is brighter than that. But β Pictoris has a visual magnitude of 4! This doesn't mean that observations are impossible, but the photometry has to be done carefully and optimised for such a bright star. Usually this means to shorten your exposure time to avoid saturation and to make as many images as possible during a night, with no long observing gaps in between.

3 Help from the Amateur Community

One of the things to keep in mind is that we don't know *exactly* what will be happening during the β Pictoris transit event next year, or when it will start. This is why it would be great to have a long baseline for the photometric observations of the star, because it would allow us to determine a lot better what is going on in the system (or what is not going on). Because the star is so bright, it is very easily observable already with small telescopes and camera objectives. As for the observations themselves, the standard photometry procedures apply: don't saturate the star on the detector, be sure to have enough reference stars of approximately the same magnitude in the field (at least two, but the more the merrier) that are not variable star and make sure that you know how long your detector needs to read out one image, as this limits the images you can take per time interval. So observing β Pictoris is nothing more complicated than doing normal photometry, except that the data will be useful only if we can achieve a **photometric error of a maximum of 1%** or better. This means that we want to be able to detect flux variations on the order of 0.01mag.

We know that there are a lot of very motivated and skilled observers out there and we are trying to reach as many as possible to join in the investigation of this very special event. So if you have the equipment at one of the β Pictoris sweet spots on Earth during 2017 and you are interested in doing photometry (or if you want to get into it!), start planning your observations, tell your colleagues about it and join the monitoring campaign!

4 How can I join the observing campaign?

If you have access to a telescope and (CCD-)camera on the southern hemisphere and β Pictoris is visible from that location for at least some time between March 2017 and March 2018 then you can make valuable photometric observations of the star. In the following few subsections I will lay out the most important observing details to keep in mind while acquiring data of β Pictoris and summarize them at the end in a table.

4.1 When and for how long is β Pictoris visible from my location?

The first thing to do is to check when β Pictoris is visible from your location between March 2017 and March 2018. I usually use STARALT (`http://catserver.ing.iac.es/staralt/`, see fig. 4), but there are a lot of other great tools out there and your observing group probably has a favourite way of checking this. Hopefully these times will coincide with the times your telescope is available for use. Don't be bothered by the moon too much. Of course it's problematic for photometry when it's around, but we will also be observing during twilight and dawn just to cover as much time as possible. And remember that β Pic is a really bright star, so it's photometry will be much less affected by the moon than for other stars! So if your telescope is abandoned during a week because other people have given up due to the moon, go ahead and use that time! It is really hard to get a glimpse of β Pictoris, so any data is a win!

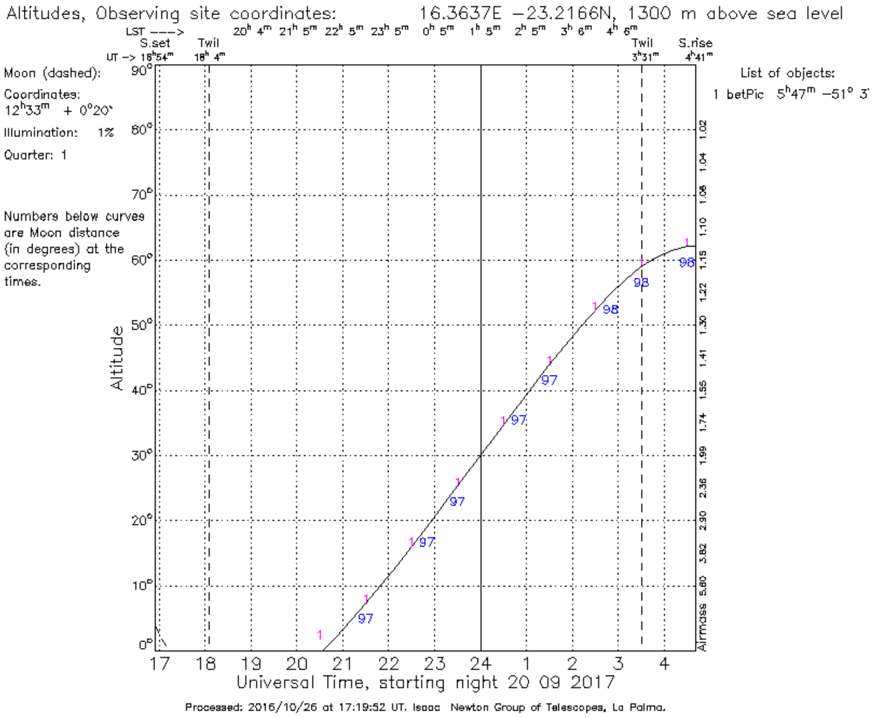

Figure 4: Example for visibility of β Pictoris during the night of September 20th 2017 in Namibia. The x-axis shows the time of the night. The darkest time during the night (UT) is marked with the continuous, vertical black line. The dashed lines indicate twilight and dawn. On the left hand y-axis you can see the altitude over the horizon, the right hand side shows the air mass. During the shown night β Pictoris is visible in the second half of the night, it rises over 30° at midnight and can then be observed until dawn. (Data from STARALT)

4.2 What is the observing field?

With a given telescope and camera you can usually not freely choose your field of view. In principle, the observed star should be imaged at the center of your detector, as the properties of the detector are best in that area. However, a small shift in the observed field of view could move potential reference star onto the image, so it is totally all right if β Pictoris is not in the very center of your images. You should have at least two reference stars in your field that are not saturated - but because β Pic is the brightest star in its patch of sky anyway, if β Pic isn't saturated, none of the other stars will be. Also, reference stars should usually be of a comparable magnitude like your target star but because β Pic is so bright, there are no other really bright stars around and we can't help it but take slightly fainter stars as reference for the photometry.

4.3 Does the star saturate my detector?

After you found out when you can observe β Pictoris it is of utmost importance to make sure that the star doesn't saturate the detector during the observations, which would make the data unusable. To find exposure times that will not saturate the star, you will need to make some test images of the star.

Because β Pictoris is so bright, it will usually saturate already after a couple of seconds of exposure time. The best way to find a suitable exposure time is to make a couple of images at, lets say, 3 seconds. Then open them in image program that can handle astronomical images, like MaximDL, DS9 or AstroImageJ and check the pixel values of the star, in order to compare them to the Full-well capacity of your detector. If the pixel values are close to or match the full-well capacity then the star is saturated and you need to choose a shorter exposure time. If the full-well capacity of your detector is e.g. 64.000, then ideal pixel values would be about half of that, 32.000 in this case. If your camera has a full-well capacity of 100.000, then you should aim for around 50.000 counts per pixel. If your pixel values lie below half the value of your full-well capacity, then you should increase your exposure time. If even the shortest possible exposure time saturates the star, you can try to defocus your telescope or camera a tiny bit. This spreads the star light over more pixels than initially and can help to avoid saturation.

One more thing to note is that as the star rises and falls, the air mass will change, and so will the pixel counts if you keep the exposure time constant. So if you find a good exposure time while the star is still at an elevation of 30°, once it reaches a higher position (e.g. 50°) it might start saturating the detector or be out of the optimal count range. In Chapter 7 of his book "Exoplanet Observing for Amateurs" [1], Gary gives a way to estimate the maximum counts you will have at a certain elevation once you you know the counts for a lower position. If C_0 are your counts that you measure at air mass AM_0 at the beginning of your observations, then you can calculate the maximum counts C_{max} that you will get at the minimum air mass AM_{min} when the star is at its highest elevation of the night (which you can look up in beforehand). The formula for this is given in equation 1:

$$C_{max} = \left(\frac{AM_{min}}{AM_0} \right)^{-2/3} \cdot C_0 \tag{1}$$

If this small calculation reveals that you will have way more counts than the optimum count level (about half of your full-well capacity, see above), then you should either adjust the exposure time every now and then during your observations or you will have to pick a lower exposure time from the beginning.

Note: I have set the optimum count level to be about half of the full-well capacity of your detector. The reason is that at these values the detector will certainly still behave linearly. If you know that the linearity of your detector goes beyond this limit, then you have a bigger scope for choosing exposure times and it is totally all right if your counts exceed half of the full-well capacity. More on this can be found in chapter 7 in Gary's "Exoplanet Observing for Amateurs" [1], which is generally worth a read when you are preparing exoplanet observations!

4.4 How often should I take images of the β Pictoris field?

As the exposure time for the star will be rather short, it will be the readout time of your camera that will limit the amount of pictures you can take in a certain time interval. During an observation run it would be ideal to take as many images as possible during two to three hours (or even more). The reason for this is that during the data reduction, we can combine all images from a 5 minute interval into a single images and like this achieve a higher precision in the photometry. The observing duration of a couple of hours allows us to maximize the length of the created light curve for that night. As β Pictoris will not be visible during the entire night anyway, you can use the rest of the night for pretty pictures of nebulae and other extended objects.

Data taken between July and November 2017 will especially valuable, as this is the time where the planet β Pictoris b will be at closest approach to the star.

4.5 Should I calibrate my data?

Absolutely. If you have been observing with your telescope for a while already, you know best how to make the standard reduction routine with darks/bias and flats. Don't forget to include the time you need to take calibration data in your observation planning and make sure to take enough flats for every filter you are using!

4.6 Which filter should I use?

Because of the of the bright magnitude of the star there is no fear of losing too much light with filters with bad transmission. Using slightly longer exposure times (still on the order of a couple of seconds) you can thus also use filters in the near infrared (NIR), like the I filter. In general you should always use broadband filters, so you can totally ignore narrow filters like the Hα filter which is often used for images of nebulae. While the classical photometry filter B (blue) and V (visual/green) are suitable, the R (red) filter has a small advantage: As the star will be observed over a couple of hours, its altitude will change over time. This also means than the air mass will vary and atmospheric extinction comes into play. As this effect is smaller for longer wavelengths, the R filter is slightly better for long-term photometry. Dedicated exoplanet filters or blue-blocking

(BB) filters are adequate as well, but they are usually not standardised and thus an indication of the central wavelength and wavelength range would be useful.

Another question is whether you should use one and the same filter during all of the observations or change between them. The recommended setup is certainly to stick with a filter of your choice for an entire night. Don't forget that you have to figure out a suitable exposure time for each different filter and that you need to take flats for each filter you are using.

4.7 What meta data of the observations is needed?

As the preferred data format for astronomical images are fits files, the required meta data will most likely be stored directly into the header of each image. This includes images coordinates, observation time, location of the observatory, exposure time of the observer, the used filter and a lot more. The just mentioned specifications are essential. Especial a correct time indication is important for the light curves, so make sure that the clocks on all your devices are correct, like your laptop for example.

The names of the observers are often not automatically included in the meta data. If you make observations and then send them off or forward them, it is very important to include the names of all people who took part in the observations. If more than one person is involved, it certainly makes sense to write all the names down already during the observations and include them in your data folder and/or email when sending the data.

4.8 What do I do with my calibrated data?

Once you finished a night's observation - congrats! It takes endurance to sit through a couple of hours of photometric observations! The idea is that after you calibrate your data, we take over with the data reduction. For this purpose, please zip all the calibrated star images of a night and send them either directly to `laginja@strw.leidenuniv.nl` or, if the files are still too big, use a service like WeTransfer (`https://wetransfer.com/`), which lets you upload your data to their server and then we get a download link. Please include the used exposure time(s), filter(s) and the observer name(s) in the message, just to be sure.

If you feel like doing photometry of β Pictoris on your own, go ahead and do so! After all, it is you data that you acquired with your own hard work. This is a nice opportunity to learn photometry if you haven't done it before. Just be aware that this is not a classical planetary transit, so we have no clue what the light curves will look like!

4.9 Summary observation details

Table 1 summarises the most important specifications for photometric observations of β Pictoris.

5 More Information

In case you want to know more about what we hope to see in the Hill sphere of β Pictoris b, check out Matt Kenworthy's website on giant exorings - `http://`

Table 1: Summary of observation details

Observation time frame	March 2017 - March 2018
Vital observation time frame	July 2017 - November 2017
Observed field	centered on β Pictoris
Full-well usage for β Pic	half of full-well capacity
Exposure time	such that star doesn't saturate; approx. half of full-well capacity
Quantity of images	as many as possible during 5 minutes, over a period of several hours
Filter	broadband; R,I,B,V,exoplanet
Flats	at least 10 per filter per night, the more the better
Darks	at least 10 per night, the more the better
Bias	necessary only if darks don't have same exposure time like star image
Altitude of β Pic over horizon	ideally over 30°
Meta data	Object coordinates, observation time, exposure time, observatory location, filter, observer, air mass

home.strw.leidenuniv.nl/~kenworthy/j1407_exorings. This model is made for the planet J1407 b, but there are indications that β Pic b might have similar features.

You can find a general and short introduction to exoplanets and how we observe them at https://www.aavso.org/exoplanet-section.

If you want to learn more about exoplanet observations with amateur equipment, get a copy of Bruce Gary's "Exoplanet Observing for Amateurs". You can download a pdf version here: http://brucegary.net/book_EOA/x.htm.

If you feel like browsing through even more stuff about exoplanet observations for amateurs, there is nice material on Dennis Conti's website: http://www.astrodennis.com/. Here, among other things, you can download "A Practical Guide to Exoplanet Observing", a guide that describes exoplanet observing as well as step-by-step instructions for AstroImageJ, a great photometry tool.

If you have any general remarks, questions or comments about the β Pictoris transiting event and its observations, don't hesitate to contact me under laginja@strw.leidenuniv.nl. I will be updating this document every now and then and make it available on my personal website (http://home.strw.leidenuniv.nl/~laginja/). There you can find a copy of it both in German and English. If you feel like I should put more information in, please let me know by email. Additional ideas and input is always very welcome!

References

[1] Bruce Gary, *Exoplanet Observing for Amateurs*. http://brucegary.net/book_EOA/x.htm

[2] Dennis Conti *A Practical Guide to Exoplanet Observing*. http://www.astrodennis.com/

[3] Matthew Kenworthy *beta Pic b Hill Sphere Transit 2016-2018*. http://home.strw.leidenuniv.nl/~kenworthy/j1407_exorings

[4] Iva Laginja *Photometric Monitoring of β Pictoris in 2017*. http://home.strw.leidenuniv.nl/~laginja/

[5] AAVSO *Exoplanet Section*. https://www.aavso.org/exoplanet-section