Catch a Star 2005

The mystery of mass and motion in the *X Trianguli* system

- An eclipsing binary and its third companion -

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1. Abstract: Who is who and what is it all about?

We, Malte and Helena, the star-catchers of 2006, are members of an astronomy group of two local high schools, which is carefully supervised by our teacher Martin Falk. Our place of observation is situated in Northern Germany, some 40 kilometres south of Hamburg.
Our project this year refers to the eclipsing binary-system of X Trianguli (below simply named X Tri). The variable X Tri is a fine specimen for the observation of variables, because a change of more than 2 magnitudes occurs within some 4 hours during a short period of less than 24 hours. In astronomical research it has often been examined, too.
A comparison of our data with the data from international observers directed our interest to a hitherto unclarified exceptional case:
The binary star-system X Tri has a very weak visual companion of 12^{th} magnitude, which is, according to publications, of no influence on the often observed period variations of the principal components. Interestingly we have been lucky to observe a stellar motion of this “third companion” by own observations and resulting research with the help of international data provided by the “Aladin” internet server. This tiny star is hard to observe and has in accordance with our assumptions and calculations an extremely high tangential velocity, which has obviously not been observed according to international data.
We want to clear up these curiosities by a description and measurement of the third companion in our piece of work, in order to contribute to a better understanding of the X Tri “triple-or even more” star-system.

2. A Portrait of our "star"

Two of our many photographs showing the contrast in brightness and a simulation of what possibly is going on 540 light years away in the constellation of Triangulum (just a few degrees south of the Andromeda nebula). Note the tiny reddish star northeast and very close to X Tri, which is in focus of our further findings.

2.1 Variables in General

Stars which change their visual brightness within observable periods of time, such as minutes, hours, days or even years are named variable stars and belong therefore to certain categories. Of the many categories that exist because of the ongoing processes causing the change in brightness we can only refer to a very popular type, which provides lots of information by analysing the process of darkening by means of a graphic display called light curve.

2.2 Eclipsing Binaries

These stars are physical binaries which revolve their common center of gravity so that the individual stars cover each other at certain periodic moments in the line of sight from Earth. The separate stars have regularly a constant luminosity; the observable change of brightness from earth is the result of the coverage of the brighter star by the less bright one.
Talking about visual variables of the Algol-type, named after the main star in the constellation of "Perseus", we are mostly concerned with a cooler star revolving around a hotter star. When the hotter and therefore brighter star is covered by the cooler one, an occultation is visible, which can easily be measured as the principal minimum. When the coverage is reversed, we can observe the secondary minimum, normally a slight darkening of the approximately constant normal luminosity-level. X Tri is a visual variable of the Algol-type. The shape of the plotted variations of

brightness in a graph, called light-curve, provides reliable information about the stellar parameters – especially when spectroscopic light-analysis is added. So every introductory book of astronomy can be consulted for further information. Amateur astronomers like us are easy to fascinate by this heavenly "merry-go-round", because they become eye-witnesses of real "happenings" in our local universe.

2.3 Stellar parameters of X Tri (according to catalogue-data and verified by an observation of our astronomy group in 2003)

Main components:	eclipsing binary, consisting of an A5- and a G2 (subgiant)star
Position:	RA 02h 00m 42s; DE +27°54' (E2000)
Distance:	540,7 light years
Proper motion:	+ 32 milliarcseconds (marcsec) in right ascension and -15 marcsec in declination per year
Period:	0,9715196 days
Visual magnitude:	8,55 – 11,2
Masses:	1,81 and 0,89 solar masses
Duration of principle minimum:	~12 minutes with total darkening of the A companion
Inclination:	~89°
Orbital velocity:	293, 783 km/s

The physical shape of the system is assumed to be **"semi-detached"**: the G-star fills the space (called Roche-limit) up to the centre of gravity of the system - that means the star is deformed to a drop-shaped object, as it is often the case with narrow binaries. However, there is no mass-transfer assumed or measured.
Furthermore, there is a **third visual component**, a star of the 12th magnitude in the distance of ~7 arc seconds. Our further examinations refer mainly to this object.

3. The O-C Diagram

For variable binaries the exact data for their minima and maxima can be theoretically calculated, as their movements are based on very precise physical regularities.
In the case of such calculations, the use of the Julian date is recommended in order to compare measurements observed from different locations and times.
The exact observed minimum is to be ascertained with the aid of a light-curve of the binary-system. The "best fitting" straight lines through the descending and ascending branch of the light curve show the exact mean time of occultation. Observing systems such as X Tri, it can be found that the observed data of the exact minimum distinguish from the theoretically calculated ones. As a result, the difference between the observed

and the calculated data can be measured: the “observed minus calculated” cycles (O-C -diagram).
When calculating and measuring the O-C-results, the duration the light takes to travel through our solar system must be taken into consideration, as otherwise a deviation of up to 16 minutes, depending on the ecliptical position of the earth in relation to the observed binary-system, is possible.
By plotting the O-C results of X Tri over decades and putting them in relation to the number of periods of the system, it can be ascertained that the result is not constant during a longer period of time. It seems to vary in a periodic cycle, which was carefully analysed by Rovithis et al.
The cause of this effect could be for example the third visual companion of the system or a hypothetical additional component near to the centre of the system. Another reason for the variations, mentioned in literature, is caused by the magnetic activity of the subgiant component of the binary [1]. The latter is not provable by amateurs.
Therefore it seemed important to us, to measure the actual differences in the O-C diagram. **In the nights of Oct. 29th and Dec. 1st, two precise measurements of the minima times succeeded.** The analysis after conversion into the Julian date did “unfortunately” not reveal any differences from the actual standard provided by the minimum calculator Krakow[2], the up-to-date information we refer to (see photo below).

[1] Astronomy and Astrophysics, H. Rovithis, S.354 Study of the period changes of X Trianguli
[2] http://www.as.wsp.krakow.pl/minicalc/

4. Current Developments in Scientific Research

The research of variables is of high importance in astronomy, because the physical composition –some parameters of the stars- can directly be calculated from the observation data. A large part of the knowledge about stars has been derived from these (even amateur) observations. This applies especially to X Tri and it is easily verifiable for amateur observers, because of the very short period of 0,971 days and the remarkable change of brightness, from 8.5 mag to 11.2 mag.
The first spectroscopic observations of X Tri were obviously made in 1946 by Otto Struve. Many observers had already confirmed a (sometimes drastic and rapid) change of the period and a long-term decrease, since1921. Bozkurt et al. confirmed the inclination of the system in 1975.
In 1999, Rovithis et al. analysed the reports of the period-variations in a complex article about X Tri, which we found in the Internet.
In a subsequent piece of work concerning the problem of the orbital period changes, Qian explained in 2002, as Rovithis did before, that it could be evoked by light-time-effects or magnetic activity cycles. Both authors, though, could not completely exclude that still a “black” component with a corresponding mass arises the variations; both authors were pessimistic in respect to any chances of its observability.

5. Our Equipment

5.1 Telescope

We used the *10’’-MAKSUTOV-CASSEGRAIN*-telescope of our astronomy group for our surveys. It has an aperture (and mirror-diameter) of 250mm and a focal length of 3325mm. In order to enlarge the field of vision (to reach more stars to compare with and to allow shorter exposures) we shortened the focal length with a focal-reducer-lens by 0.6 x. The result is an effective focal length of *f 8/1995*. The telescope is motor-driven in both axis but has to be directed manually to the field of observation. (We spent a lot of time in placing X Tri on the camera sensor.)

5.2 Camera

Our DSLR camera Nikon D50 is fitted to the focus of the telescope and can be operated by infrared shutter release. The adjustments were set to:

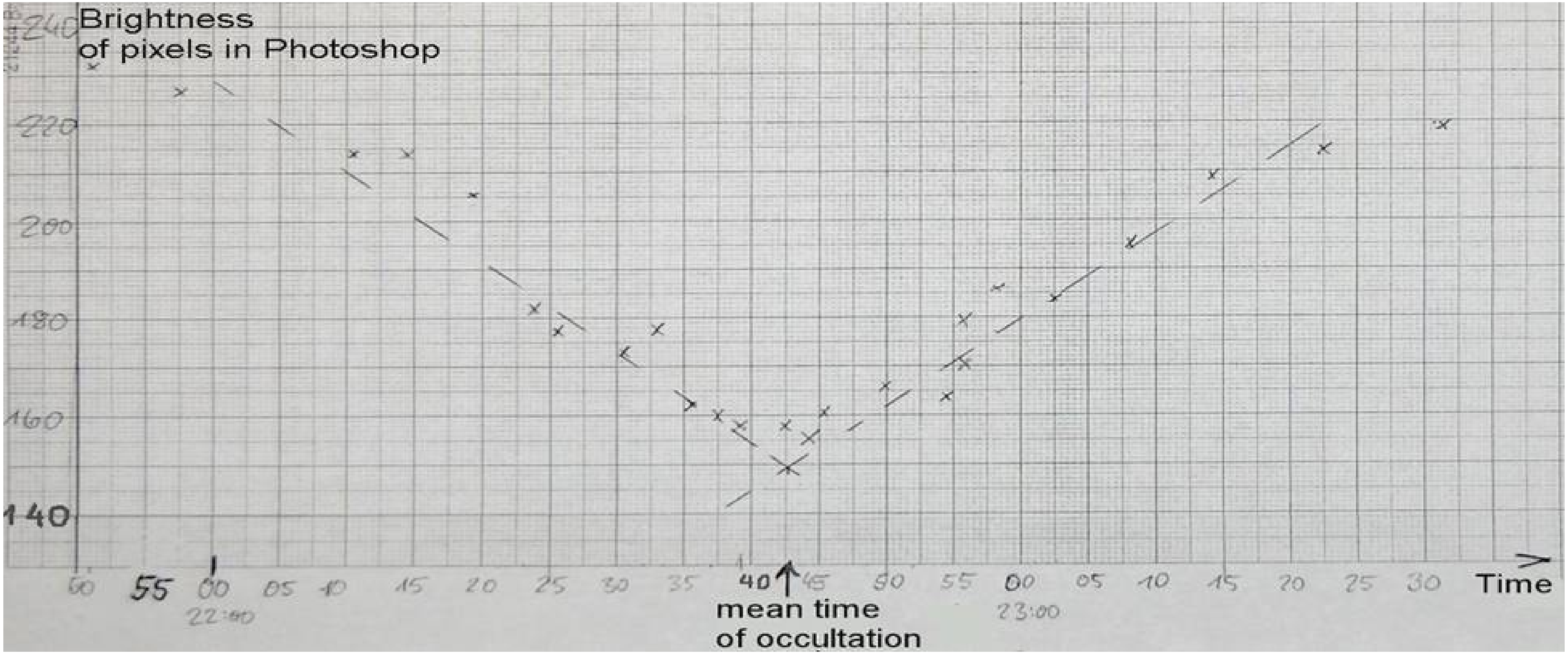
- ISO 1600 (maximum possible sensitivity to light)
- 10 seconds exposures (for minimum possible airy-discs and for a high contrast of the principal and the third component)
- The timer of the camera was synchronised with the Internet time (for exact timing of the minimum after conversion into the Julian date)

5.3 Software

In order to analyse the photographs, we primarily worked with Adobe Photoshop. The many tools allow to measure and compare distances by pixel co-ordinates and the brightness in (grey) colours of the pixels. We made use of a comparative star (Tycho 1763-02015-1 among others), whose parameters were taken from the Red Shift 4 astronomy program. A cross-check by means of CCD Night XP software offered no better results.

5.4 Photographic results

A (handmade) graph of the light curve of about 25 photographs taken on 2005-10-29 – 21:51-23:31 local time:



In comparison to other amateur light-curves of X Tri our one looks a bit rough. Reasons might be the non-cooled CCD-chip and heavy scintillation caused by the long way for starlight through the atmosphere in Northern Germany.

6. The Motion of the Third Companion

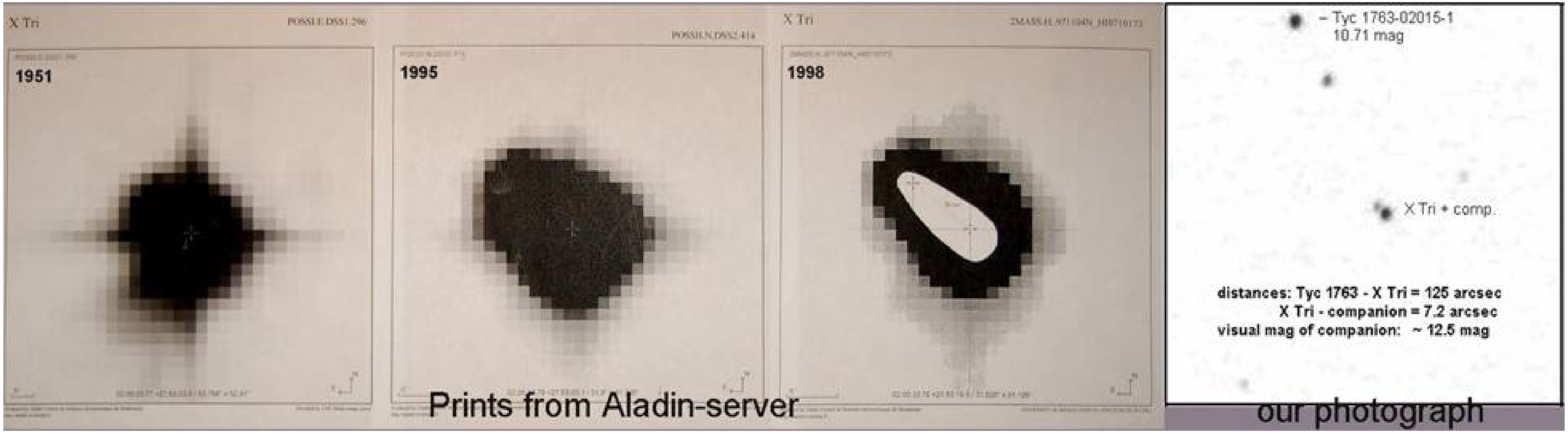
6.1 Long-term Observations

Our photos of December, 1st were primarily taken to look out for another variation in period. But the extra-ordinary clear view on the third component made us concentrate on this tiny star, (compared to the stellar map in Red Shift 4) in a distance of 7,2 arc seconds, which fits to the data of 6.8 –7 arcsec from literature. The star itself does not appear in the Tycho-satellite data after which the stellar map was made – although the distance was sufficient in times of the satellite measurements. Probably the contrast in brightness with the principal component exceeded the resolution limits of the satellite. That is why there are no Tycho-data about the third companion.

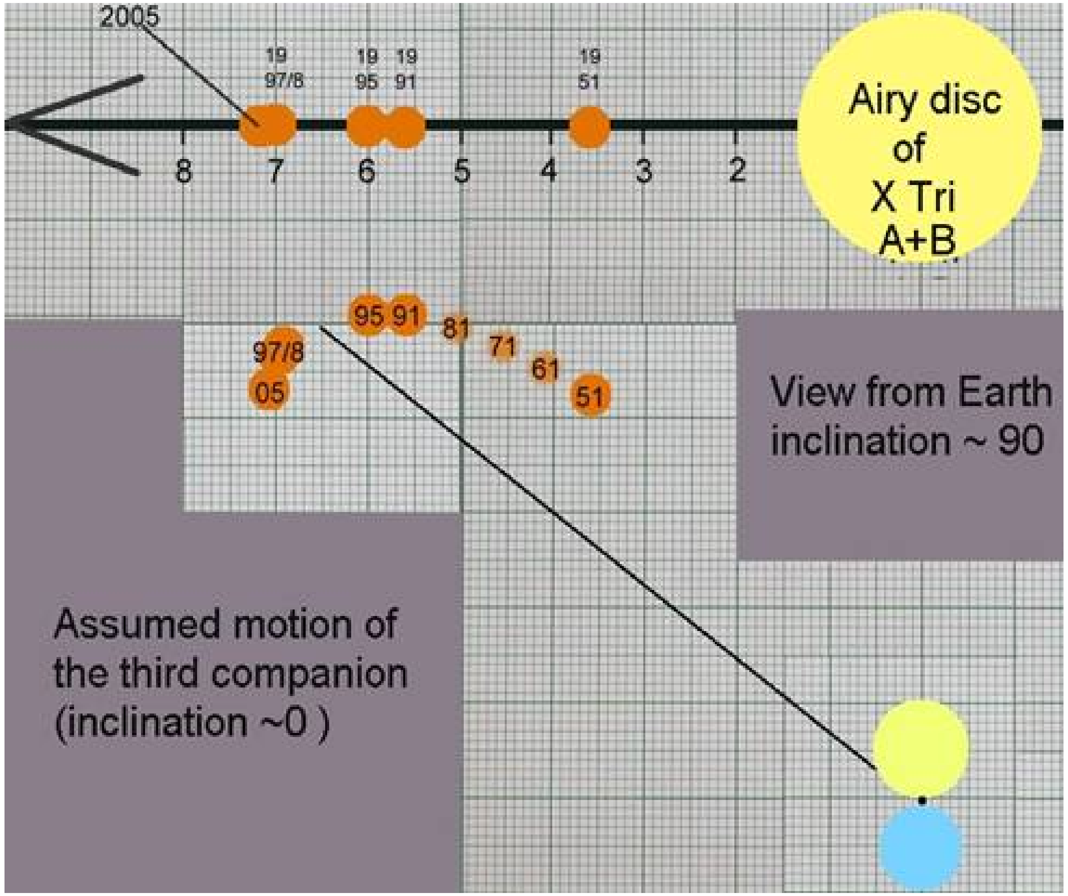
A comparison to older photographs of the celestial maps or surveys in high resolution, though, is possible via Internet with the “Aladin” data of the **University of Strasbourg (F)[3]. The Aladin-server** offers digitized surveys of the sky made by means of large telescopes with relevant data **-** in our case from 1951, 1991, 1993, 1995 and 1997/8. We found a fine selection of photographs of X Tri and its small companion, including all necessary data to determine its physical behaviour throughout these years in addition to our photographs.
Concerning all pictures of the third companion, we chose the red-filter-photos, since in this wavelength the small (red) star emerges stronger. With the given scale of magnification (16 times) and the interpolation of the pixel brightness, both objects – principal components A and B and the third companion in north-eastern direction– are easily measurable.
The data concerning the measurement of motion, gained in this piece of work, were ascertained by focal point determinations of the pixel area on the print-out of the “Aladin” –server pictures. This astrometric method appeared to be a bit more precise than the “Aladin”-tool, because of the jumping cursor, due to the high magnification. In the same way we proceeded with our own photos. Our measurements are afflicted with an error caused by the pixels which we estimated to be roughly 0,5 arc seconds.

Anyway, a definite increase of the distance is to be noted.

Also in view of the proper motion of the principal components in about 55 years by ~1.7 arcsec to the east and ~0.7 arcsec to the south (this is within the error sphere of the single pictures) the distance of the third component must have increased.
We have finally found **a tangential motion** (in a right angle to the line of sight) **of the third companion of ~3,6 arc seconds in 55 years.**
Our findings are roughly summarized by a collection of the following photographs:



When we analysed this motion throughout the years **we noticed an increase from 1991 to 1998 with a following decrease.**
By neglecting the above mentioned error this motion can graphically be interpreted like this:



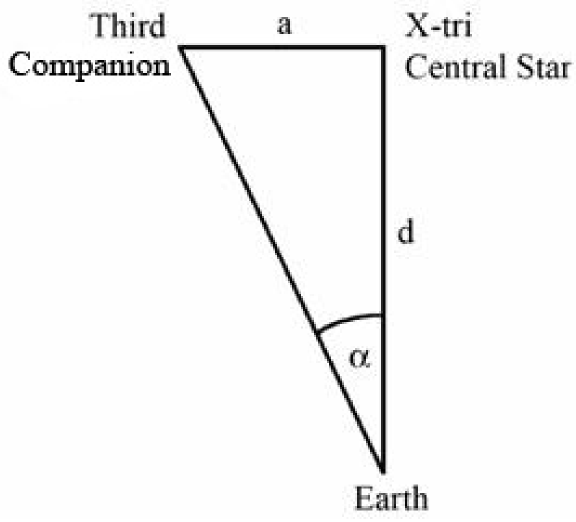
We soon discovered the problem of a high-speed star and have tried to find out possible explanations. Based on all accessible data we calculated the stellar parameters of this strange object.

[3] http://vizier-u.strasbg.fr/viz-bin/

6.2 Mass and orbital velocity of the third companion

For calculating the parameters of the third component we used values from literature **under the assumption that our star is a member of the X Tri system. The distance "Earth-X Tri" is:** d=165,8pc=540,7Ly

The third component's visual magnitude is, according to Rovithis, about 13mag. After comparing it with several similar stars whose magnitudes were taken from Red Shift 4 we determined a visual brightness of **12,5mag**.The distance (a) between X Tri and the third component can approximately be calculated.



We measured an angle of:

$$\alpha \approx 7{,}2'' = \frac{7{,}2°}{3600} = 0{,}002°$$

With $\tan \alpha = \frac{a}{d}$ we get a distance of about

$$a = d \cdot \tan \alpha = 540{,}7Lj \cdot \tan \frac{7{,}2°}{3600} \approx 0{,}01887Lj \approx 1{,}78 \cdot 10^{11} km$$

In order to calculate the mass of the third component we need its absolute magnitude (M) first.

$M = m + 5 - 5 \cdot \lg d$; (m) is the visual magnitude of 12,5mag and (d) the distance from earth in parsec.

$M = 12{,}5mag + 5 - 5 \cdot \lg 165{,}8pc \approx 6{,}4$ mag

Its luminosity (L) compared to the sun's (L_0) can be determined:

$$L = 10^{1{,}88-0{,}4M} \cdot L_0 = 10^{1{,}88-0{,}4 \cdot 6{,}4} \cdot L_0 \approx 0{,}2089 \cdot L_0$$

The third component's mass (m2) is related to its luminosity:

$L \approx m^{3{,}5} \Rightarrow m_2 \approx \sqrt[3{,}5]{L} = \sqrt[3{,}5]{0{,}2089 \cdot L_0} = 0{,}6393 \cdot m_0$; (m_0) is the mass of the sun.

The time (T) the object needs to orbit the centre of mass can be calculated:

$$m_1 + m_2 = \frac{a^3}{T^2} \Rightarrow T = \sqrt{\frac{a^3}{m_1 + m_2}}$$

The mass of the central star (m1) consists of two components:

$$m_1 = m_A + m_B = 1{,}81 \cdot m_0 + 0{,}89 \cdot m_0 = 2{,}7 \cdot m_0$$

The distance (a) must be calculated in AE, (T) in years:

$$T = \sqrt{\frac{a^3}{m_1 + m_2}} = \sqrt{\frac{1193{,}32AE^3}{2{,}7 \cdot m_0 + 0{,}6393 \cdot m_0}} \approx 22558{,}37a$$

Consequently, one orbit of the third companion takes about 22500 years. This can hardly be of any influence on the O-C diagram of the star system, because Rovithis measured fluctuations in a period of about 20 years. Nor does the resulting motion meet our findings of its tangential velocity during the period of 1991 to 1998.

7. Alternative calculations

The curious motion of the third companion seems to represent a curve, which cannot be explained as a proper motion of a tiny star in the foreground of X Tri. A curve or orbit needs a (big) mass which causes a small mass to move in an orbit.
Although there is a relatively high error in pixel interpretation we had assumed that X Tri consists of at least 3 components until we have succeeded in the following considerations:
By measuring the supposed tangential motion during the years of 1991 to 1998 we found a distance of 1.6 arcsec in 7 years, which is rounded to α = 0.22 arcsec per year. In the distance of X Tri (540 Ly) the body must have moved a distance (s):

$$\tan\alpha = \frac{s}{d} \Rightarrow s = d \cdot \tan\alpha = 540 Ly \cdot \tan\frac{0{,}22°}{3600} \approx 5{,}76 \cdot 10^{-4} Ly$$

The resulting orbital velocity (at least in this part of the orbit) is:

$$v = 5{,}76 \cdot 10^{-4} Lya^{-1} \approx 172{,}68 kms^{-1}$$

The mass in the centre of such an orbit can be estimated according to a formular derived from Newton's formula of Kepler's third law (which is used in the regular calculations above) and frequently used to determine mig masses in relation to tiny ones (which is the case when our solar system orbits the centre of our galaxy)[4]:

$M = a \cdot \frac{v^2}{G}$; with a distance $a \approx 0{,}018 Lj \approx 1{,}70 \cdot 10^{14} m$ and gravitational constant $G = 6{,}67 \cdot 10^{-11} m^3 /(kg \cdot s^2)$:

$$M = 1{,}70 \cdot 10^{14} m \cdot \frac{(172680 \frac{m}{s})^2}{6{,}67 \cdot 10^{-11} \frac{m^3}{kg \cdot s^2}} \approx 7{,}6 \cdot 10^{34} kg$$

The surprising (and somehow crazy) result is a mass concentration of roughly 38000 masses of our sun in the centre of the X Tri system.

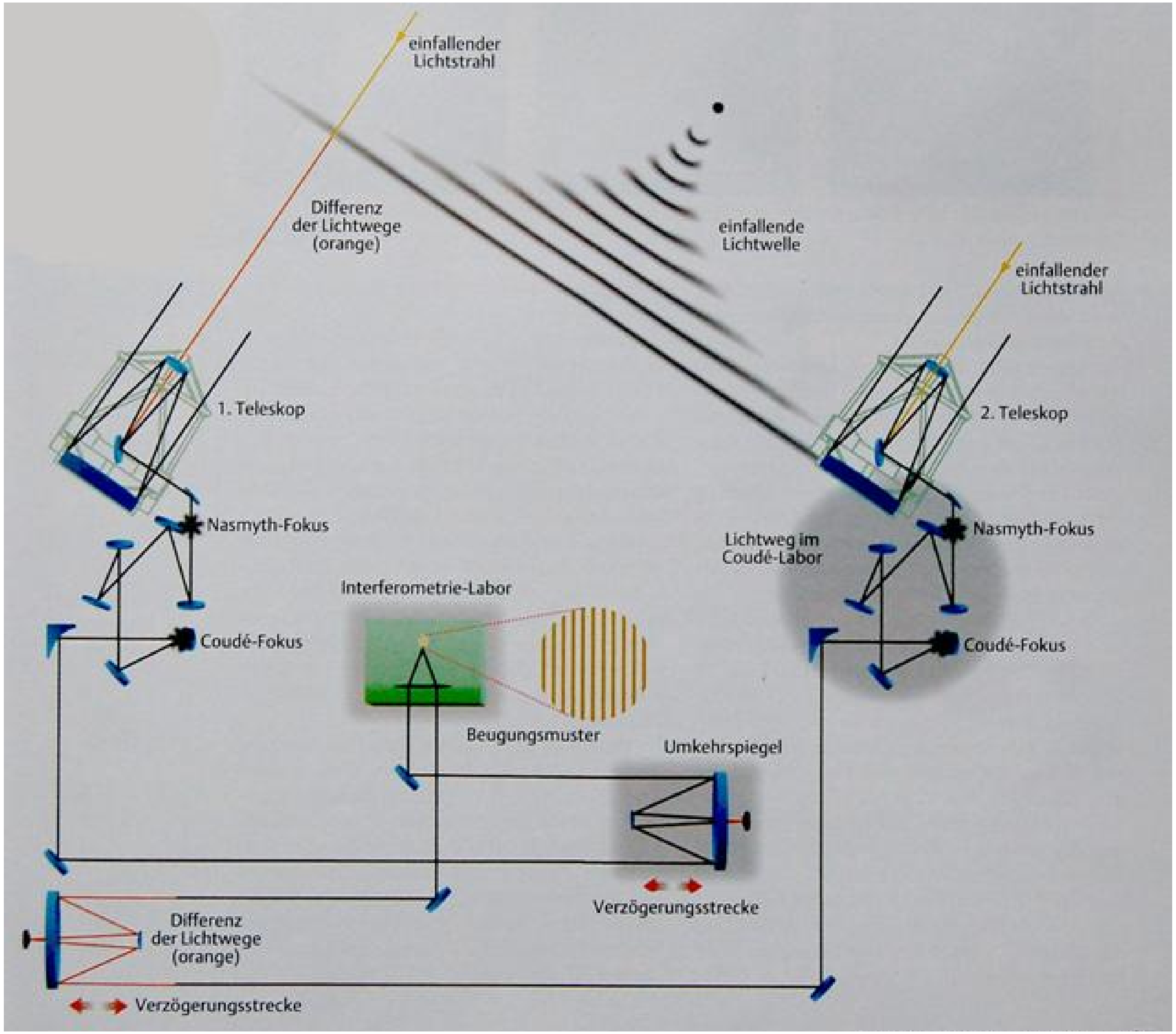
[4] Freedman, Roger A.; Universe ; New York 2002; p.575

8. Summary: How ESO-telescopes can solve the riddle

Our findings are worth a few critical reflections:

A. A closer examination of the system with the help of bigger telescopes of the *Hamburg-Bergedorf Observatory* and the *Melle Observatory* which are situated in our "vicinity" has been spoiled by the weather of Northern Germany. Both telescopes of the 1-meter-size can easily verify the present distance of our tiny star from the main components in a much higher resolution. But this is only a fraction of the real big ones the **ESO** operates.

B. If we take into considerations that the **VLT-Interferometer is said to resolve two objects at a distance of 0.003 arcsec**[5] by means of Adaptive Optics, Speckles-Analysis and Interferometry the present proper motion can be verified within a short period of time-intervals by only short exposure-times due to the relatively high magnitudes of all objects in the X Tri system. This could be achieved within the following months when the Triangulum-constellation will still be observable for this season. (**The OWL data predict an angular resolution of even 0.001 arcsec**, so that many eclipsing binaries and other multiple star systems can directly be observed in their “merry-go-round”. But this will possibly be a waste of observation time for public relation business only). Nevertheless, the technique is so exciting that we place a diagram from our German publication just for reasons of attractivity here:

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[5] Sterne und Weltraum Special 3/03, p. 38

C. Then a **spectrum of the third companion** is required to determine its spectral class (supposingly a M-star) and its radial velocity, which must be negative (absorption lines should be blue-shifted), if our findings from the latest photographs are correctly interpreted. There is no need of a big telescope for a spectrum of a 12.5 mag star. Nevertheless, this can only be done by professional astronomers and their equipment.

D. Under the assumption that our tiny star is a “superfast giant” in the distant background of X Tri (which is randomly in the line of sight) orbiting a black hole of even more than 38000 solar masses, this mass concentration must have been detected by the effect of a gravitational lens, because there have to be “enough” star light behind the massive black hole to be deflected towards our line of sight. Interestingly this would help to identify the missing mass (dark matter) of galaxies.

E. What remains can be an awful mistake in our considerations. On the other hand could there be no big errors in the parameters of the main components of X Tri. An error of distance would mean that the spectral classes of the main components were wrong, which is not realistic.

The hypothetical other object orbiting the center of mass according to the findings of Rovithis et al could not have much influence on the mass relations. But it can be found by the **VLTI.**

If finally our small star is a foreground star, then what makes it move that curiously?

So dear ESO-astronomers – we really need your help!

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[1] Astronomy and Astrophysics, H. Rovithis, S.354 Study of the period changes of X Trianguli
[2] http://www.as.wsp.krakow.pl/minicalc/
[3] http://vizier-u.strasbg.fr/viz-bin/
[4] Freedman, Roger A.; Universe ; New York 2002; p.575
[5] Sterne und Weltraum Special 3/03, p. 38

Redshift 4 Professional Edition, München 2001, United Soft Media Verlag GmbH
Meyers Handbuch Weltall, Joachim Krauter und Erwin Sedlmayr, Mannheim 1994, 7. Auflage, Corman Verlag
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