Scientific Report. GREAT - Exchange Grant

Visit of Maria Czekaj to Institute UTINAM, Besançon Observatory,
1 - 10 February 2012
13 - 30 March 2012

Title: Galaxy modelling for preparing the Gaia analysis

Supervisors: Annie Robin, Francesca Figueras, Xavier Luri

Purpose of the visit: The objective of this thesis is to develop a new version of the Besançon Galaxy Model able to handle variations of the star formation rate in different populations, initial mass function and evolutionary tracks, as well as binaries and improved kinematical description. This visit of Maria Czekaj to the UTINAM Institute in Besançon was dedicated to intensive discussions with Annie Robin, the improvement of the model, derivation of the final conclusions for the thesis.

Description of the work carried out during the visit:

Binarity implementation.

During these two visits we have implemented the binarity in our model. For that the Besançon Galaxy Model is not any more a generator of single stars only, but it produces binary systems as well. This step is considered by us as a great improvement, because neglecting the fact that many of the stars in the Galaxy are double was a an obvious disadvantage.

We have followed a scheme proposed by Frederic Arenou in his paper *The simulated multiple stars* and applied in the Gaia simulator. The procedure is quite straightforward, see the core of the thin disc treatment in Fig. 1. The age, mass and metallicity of an object are drawn and then it is placed on the evolutionary tracks. If the star is found to be alive, we calculate its intrinsic parameters and decide if it is single or a primary component of a double system. This decision is made according to the probability, which depends only on the object's mass. If the star is on the main sequence F. Arenou proposes in his paper following function

$$f(M_1) = 83.88 \tanh(0.688 M_1 + 0.079). \quad (1)$$

Through the private communication we have updated it to the form

$$f(M_1) = 0.85 \tanh(0.55 M_1 + 0.095). \quad (2)$$

If a star is a giant we set the probability to be constant and equal to 60 %. At this stage a star is marked by a flag if it is single or double. Then its observables are calculated and it is written to the catalogue. If the star just created was a primary, in the subsequent step we create its secondary. First, the separation of the system is estimated as it proposes F. Arenou. Then, using a first guess secondary mass the period of the system is calculated. Knowing the period and the M_1 mass of the primary we derive the M_2 mass of the secondary and assign it the same age and metallicity. Similarly like for the primary component, the secondary is placed on the evolutionary tracks and its intrinsic parameters are determined. Then we derive the observables and save the secondary star in an additional catalogue. In our scheme merging of systems is done outside the model in the post processing. That is why if the binarity option is switched on by the user two catalogues will be created, one with single and primary stars and other with secondary components. The stars in binaries will have no extinction effect and photometric errors added. This is done by an independent merging code. In the future the merging part can be interpolated into the model, making it more consistent tool. At the moment such an arrangement has a quite convininet advantage, namely it allows us to apply several catalogue resolutions to one simulated sample.

It must be emphasized that we have implemented binarity remaining in the agreement with the total mass in stars. It is a big advantage of the new Besançon Galaxy Model's scheme that the total mass is constrained previously to simulations, throughout the dynam-

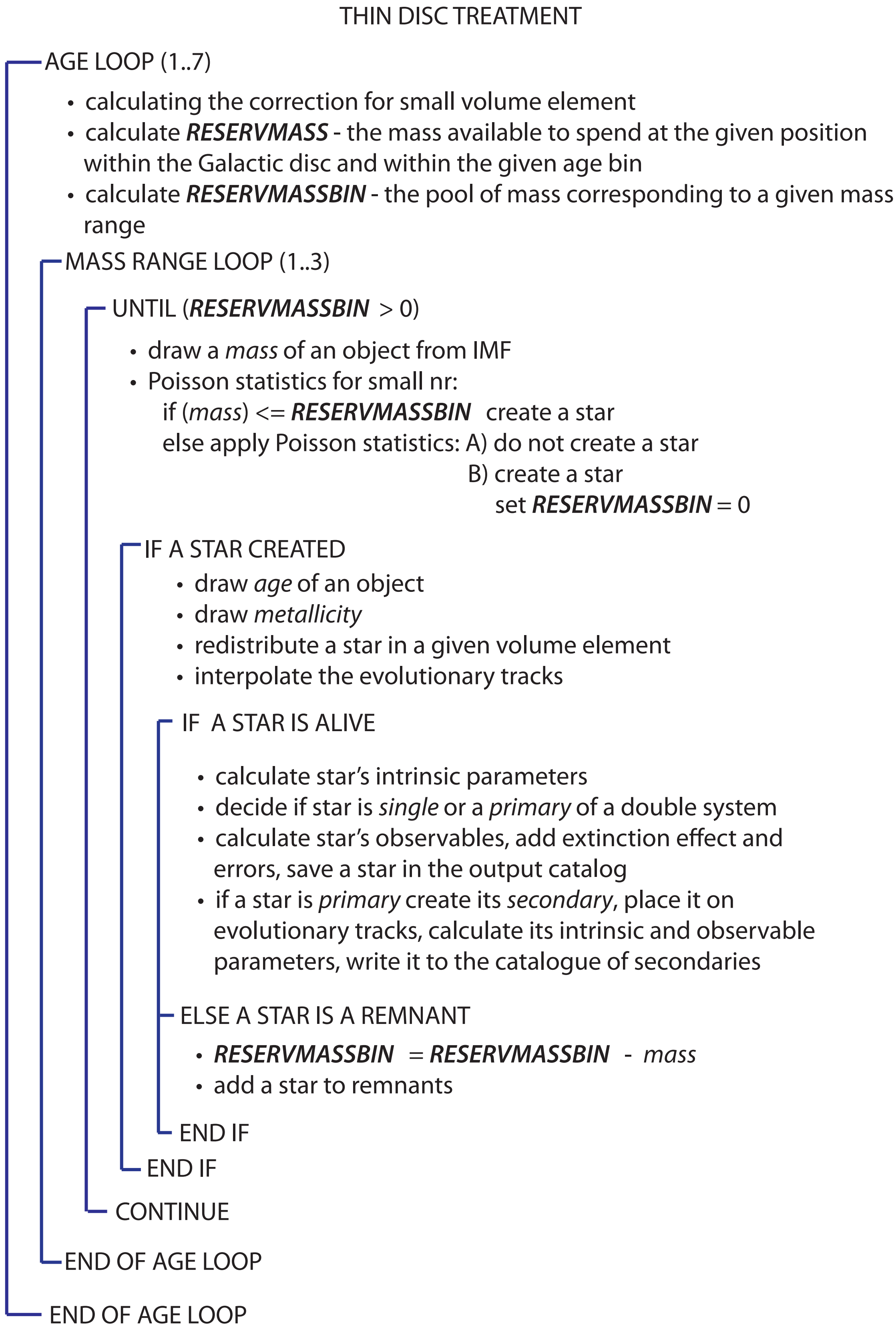


Figure 1: The organigram of the new model's thin disc treatment.

ical self-consistency calculations. That means that the mass is established before and the stars, single or double, are created from the available pool. This is the part which the Gaia simulator lacks.

BINARITY TESTS.

We have performed many tests of our new algorithm to confirm its correctness. Then we were especially interested what is the impact of binarity and flux merging on the resulting color distributions of the samples. It is because in our research we compare BV colour distributions of the model and Tycho-2 data and detect significant discrepancies. Until now we have investigated many possible scenarios, which could be responsible for them and binarity effect was one of the studied cases. We asked ourselves if merging of a significant fraction of a given sample can cause a shift in a corresponding giant peak. Here we present the undertaken analysis for two regions, the Galactic North Pole and the low latitudes field. The resolution of binary systems for Tycho-2 catalogue was taken from the literature and assumed to be 0.8 arc sec.

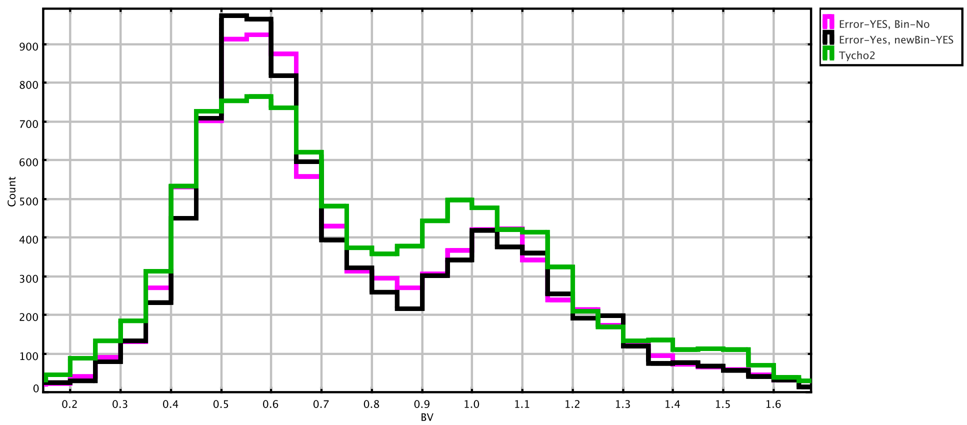
Npole region.

The sample statistics (when binarity applied):

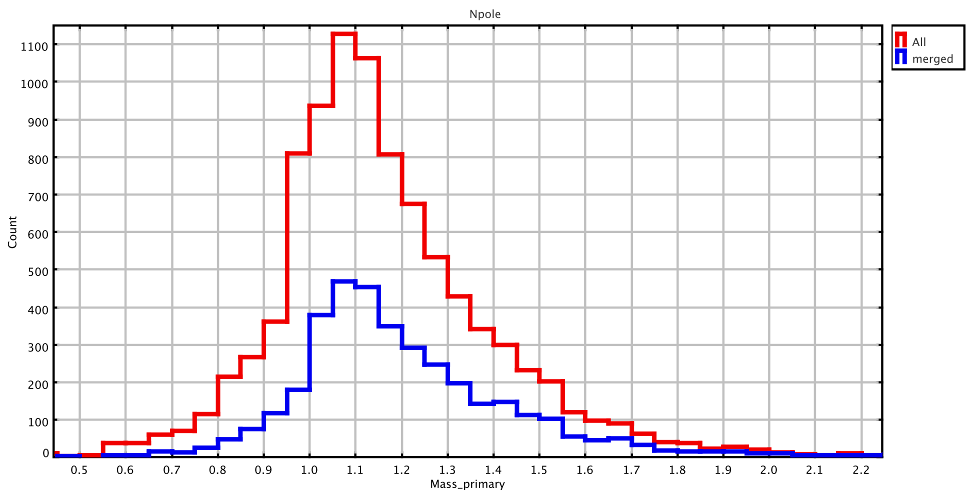
1. All: 9195 - 100 %
2. single: 3744 - 41 %
3. thick: 467 - 5%
4. merged: 3631 - 39%
5. separated: 1353 - 15%

The sample statistics (without binarity applied):

1. All: 9439 - 100 %
2. single: 8936 - 95 %
3. thick: 503 - 5%

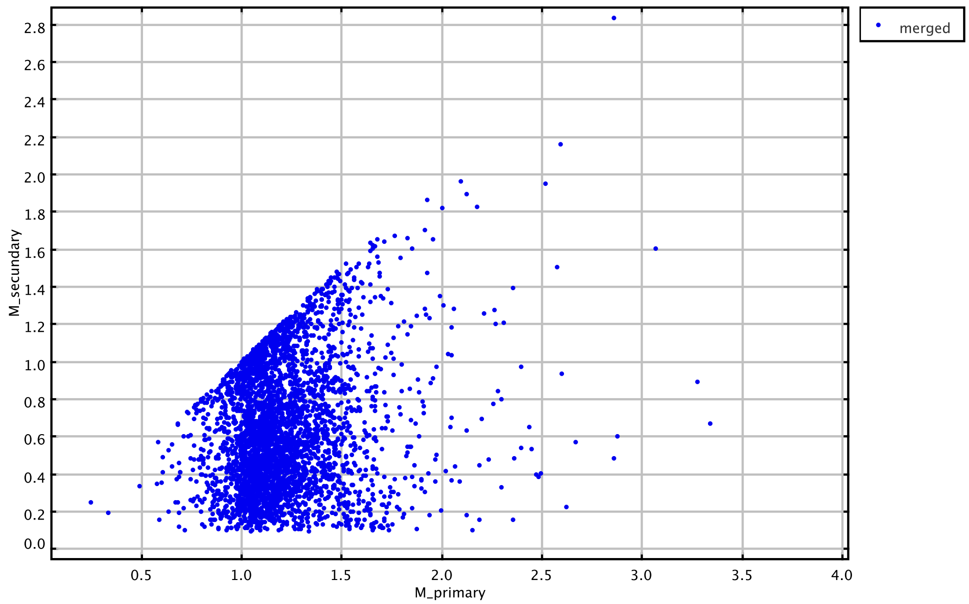


a) BV distribution

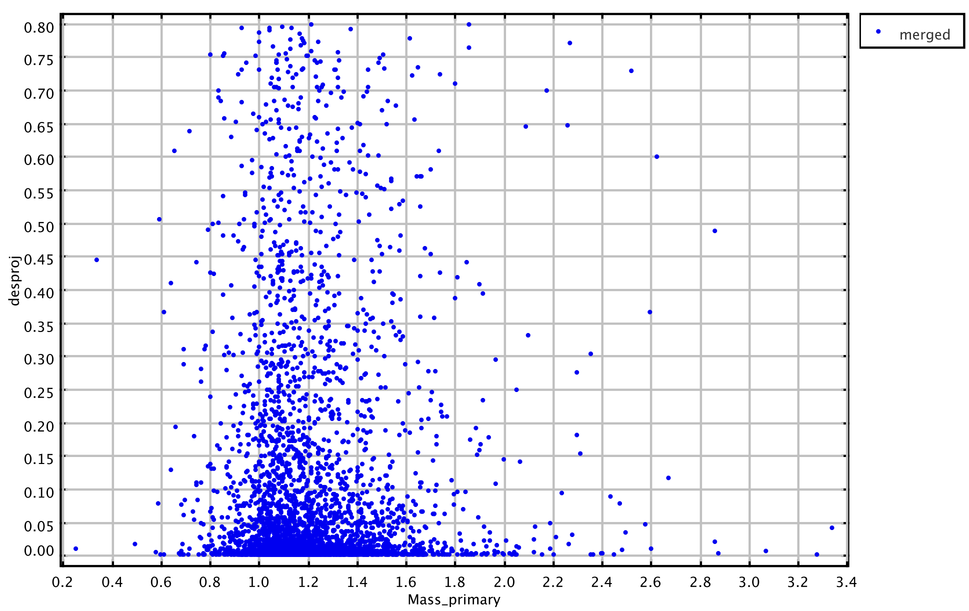


b) M-primary mass distribution

Figure 2: North Galactic Pole after applying binarity. a) simulations with binarity in black, without binarity in magneta, in green Tycho-2. b) the mass distribution of all and merged stars.

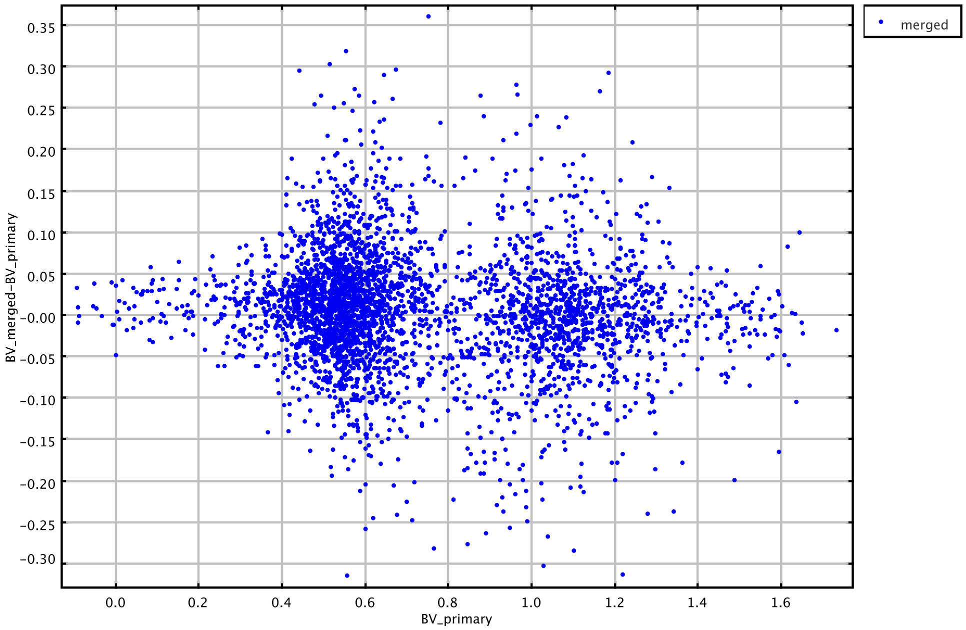


a) M-secondary(M-primary) of merged stars

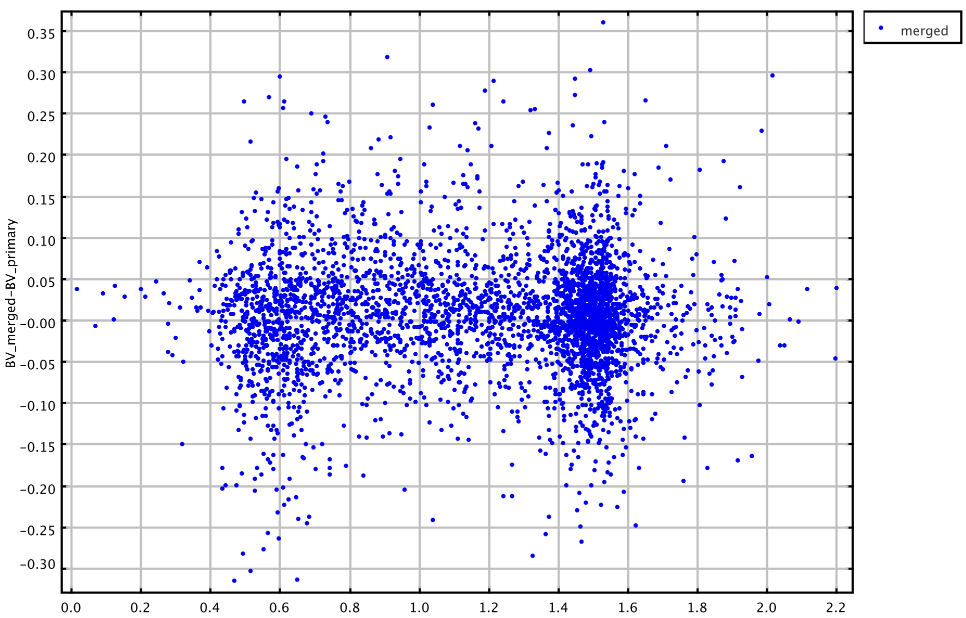


b) projected separation(M-primary) of merged stars

Figure 3: Npole after applying binarity and the correct error assignment.

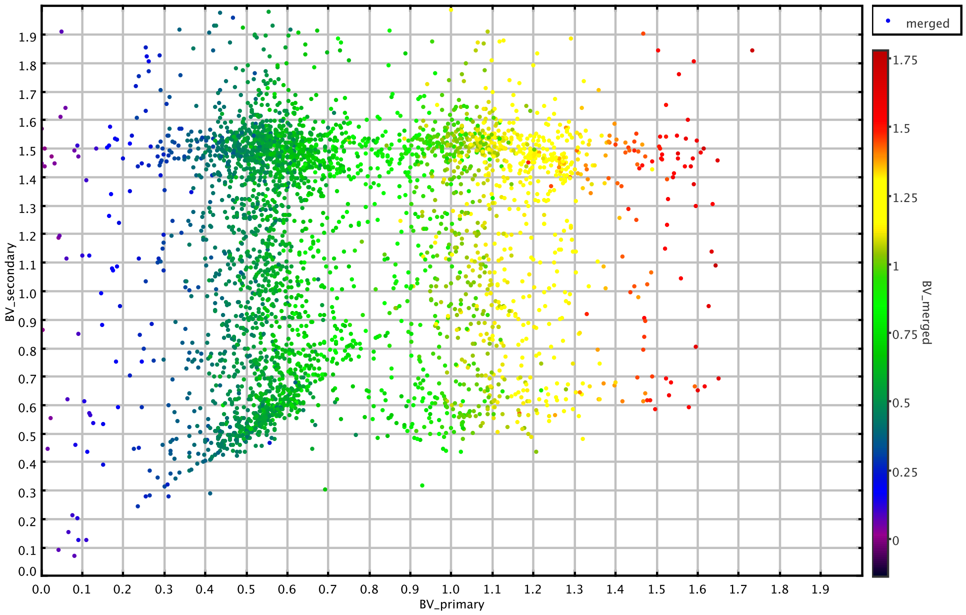


a) (BV-merged-BV-primary) as a function of (M-primary) errors added

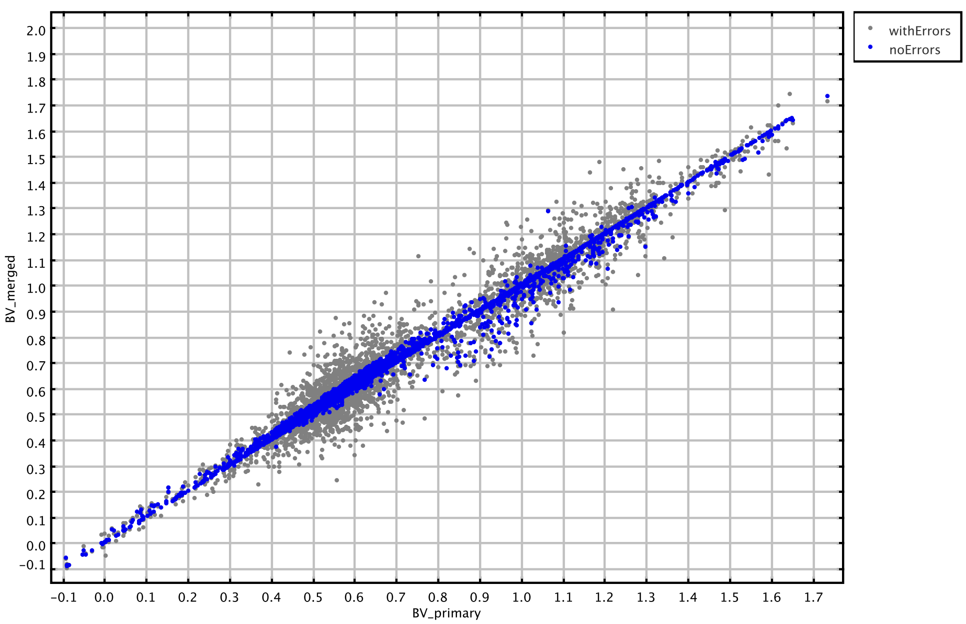


b) (BV-merged-BV-primary) as a function of (M-secondary) errors added

Figure 4: Npole after applying binarity and the correct error assignment.



a) BV-secondary (BV-primary) and in color scale BV-merged



b) BV-secondary(BV-primary) with and without errors

Figure 5: Npole after applying binarity and the correct error assignment.

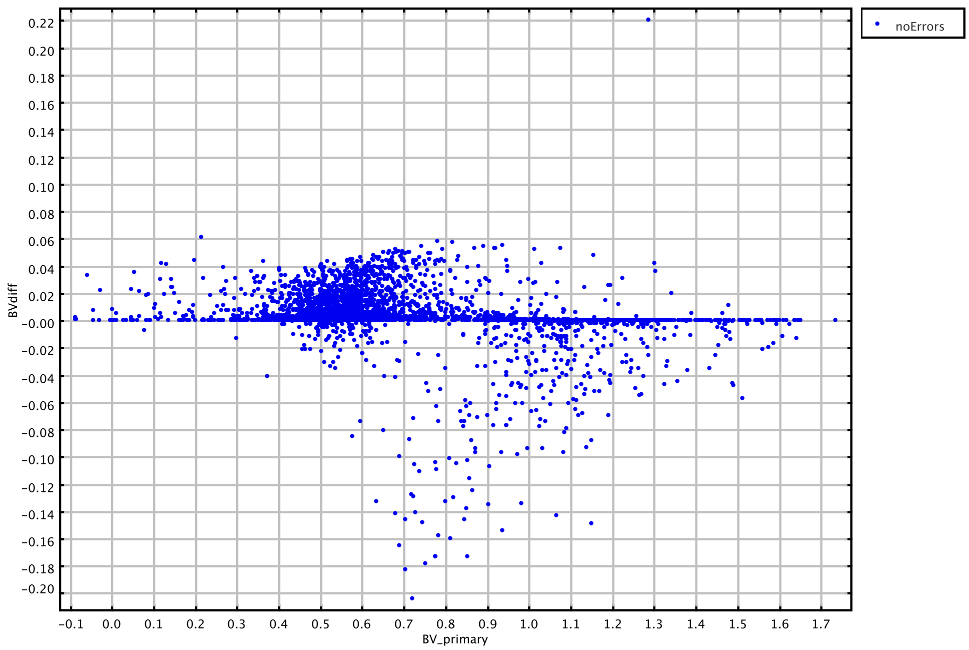


Figure 6: (BV-merged-BV-primary) as a function of (M-primary) errors added.

S099S100 region

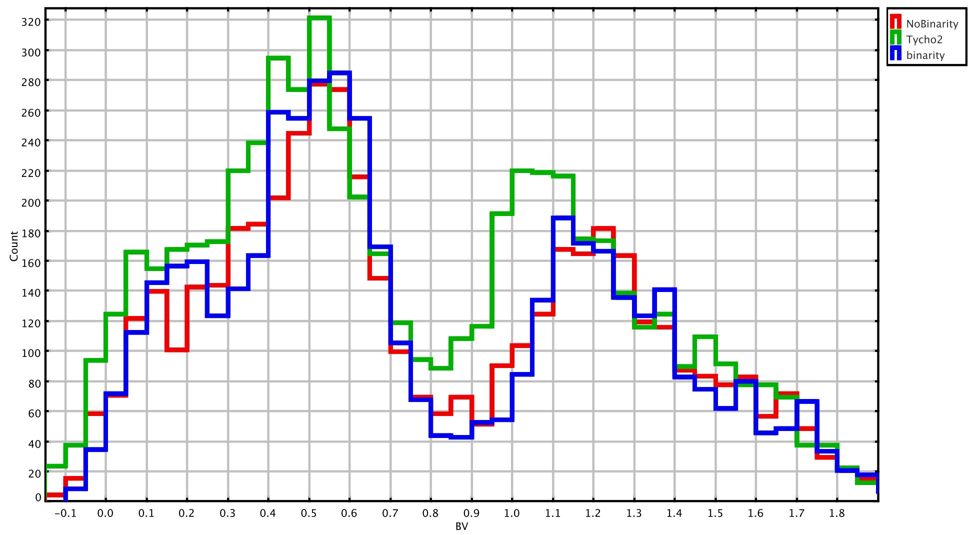
Longitudes : [260.0, 280.0] and Latitudes : [-20.0, -10.0]

The sample statistics:

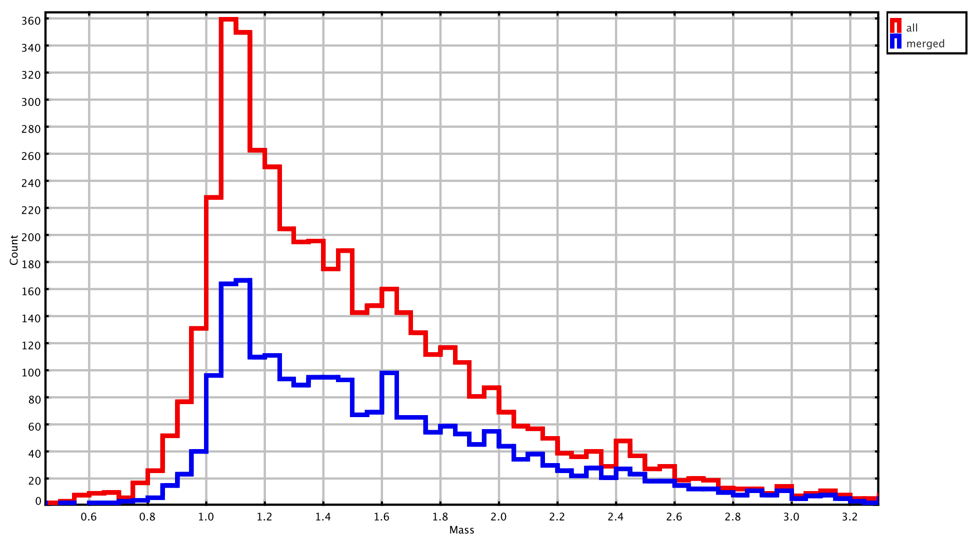
1. All: 4651 - 100 %
2. single: 1679 - 36 %
3. thick: 63 - 1%
4. merged: 2265 - 49%
5. separated: 644 - 14%

The sample statistics (without binarity applied):

1. All: 5878 - 100 %
2. single: 5787 - 98 %
3. thick: 91 - 2%

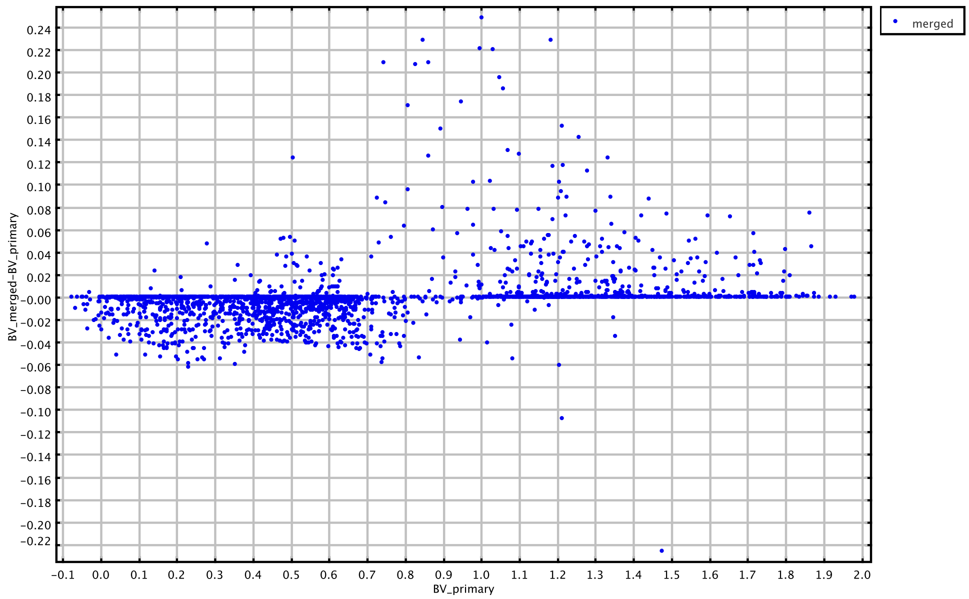


a) BV distribution, in red model with no binarity, in blue with binarity

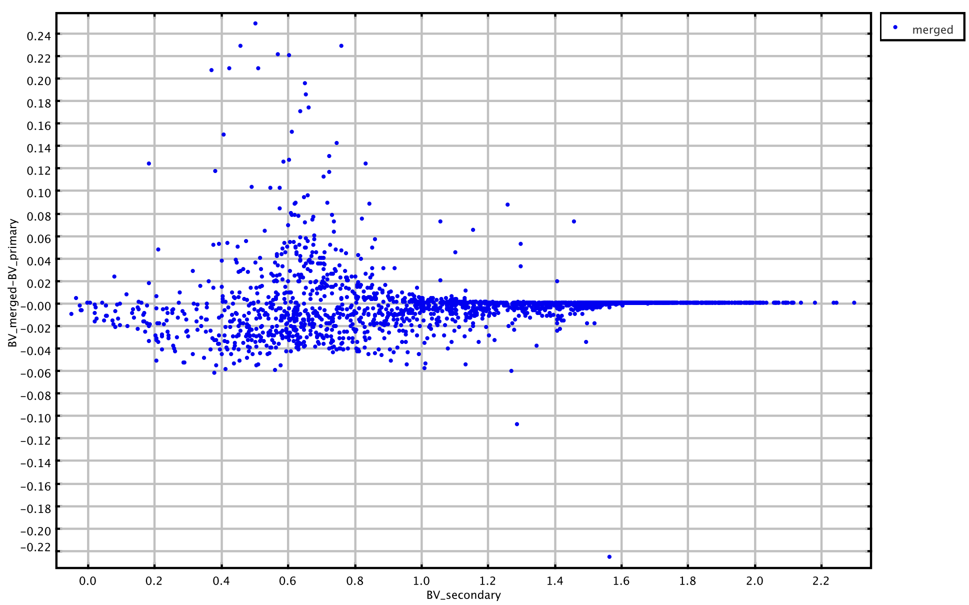


b) Mass distribution of all and merged stars

Figure 7: S099S100 after applying binarity and the correct error assignment.

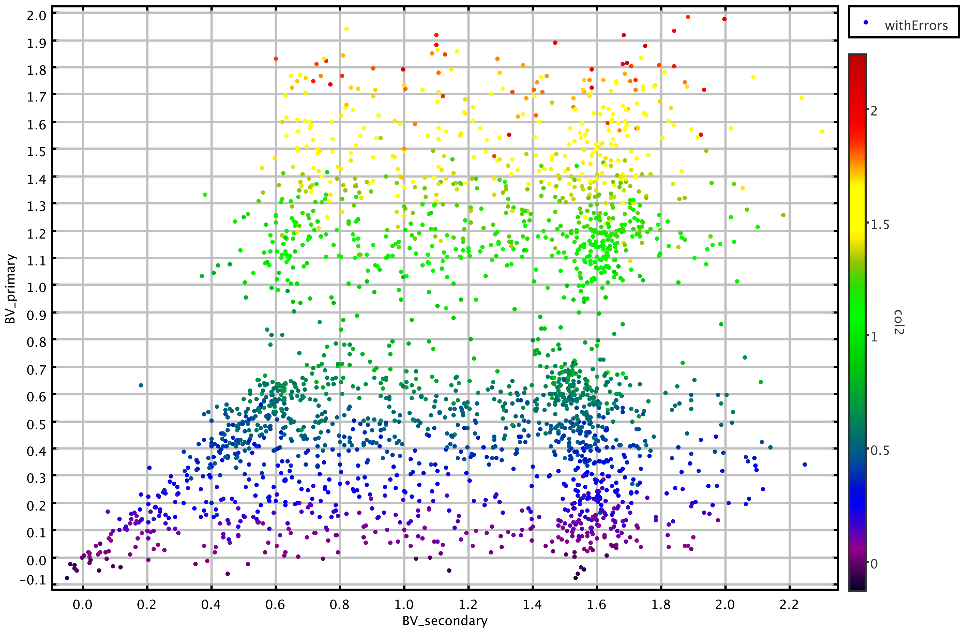


a) (BV-merged-BV-primary) as a function of (M-primary)

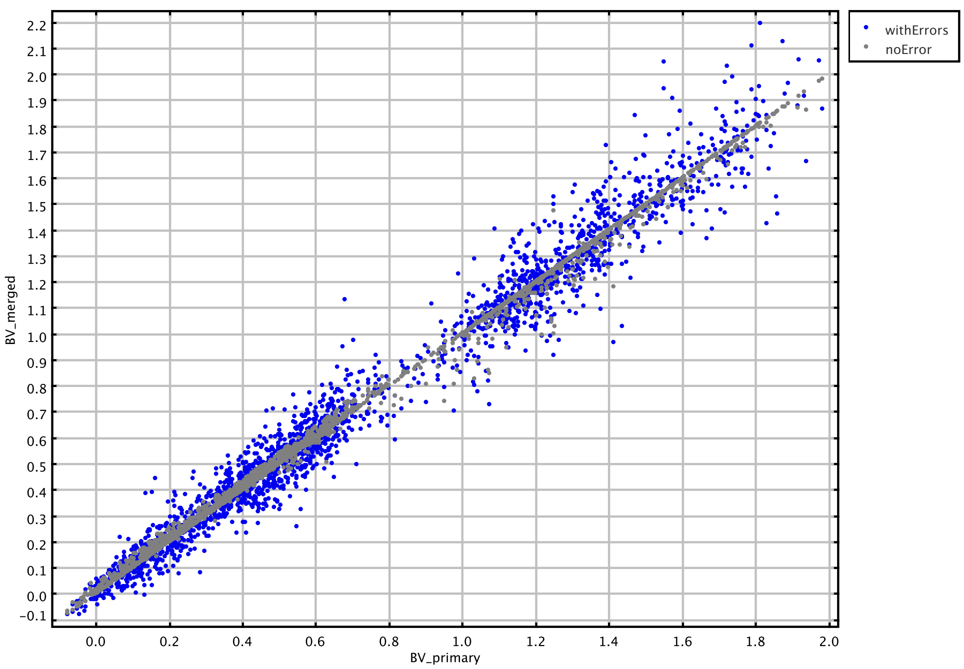


b) (BV-merged-BV-secondary) as a function of (M-primary) errors added s

Figure 8: S099S100 after applying binarity and the correct error assignment. In blue with errors, in grey without errors.



a) BV-secondary (BV-primary) and in color scale BV-merged



b) BV-secondary(BV-primary) with and without errors

Figure 9: S099S100 after applying binarity and the correct error assignment.

Photometric transformation

In the second part of the visit preparing the thesis and the resulting publication we have reviewed our approach to the photometry transformation.

We have followed four different approaches to the Tycho - Johson Cousin photometric transformation and compared their performance. We either transformed the data to the model space as well as our model to the space of observables.

In the guide to the Tycho-2 catalog there is presented the standard and well known transformation between the Tycho and Johnson Cousin photometric systems

$$\begin{aligned} V_J &= V_T - 0.090(B_T - V_T), \\ B_J - V_J &= 0.850(B_T - V_T). \end{aligned} \tag{3}$$

It was the first method we have applied. The authors recommend consulting the Vol. 1 of the Hipparcos and Tycho Catalogues (Sections 1.3 and 2.2) for more details. There they explain that these standard equations are a rough approximation because they impose the same transformation for all types of stars.

Thus they suggest a more sophisticated method of transformation, which is the linear interpolation of the values specified in their Table 1.3.4. copied here to Fig. 10.

Table 1.3.4. Transformation from the Tycho photometric system to Johnson. The points given can be used in a linear interpolation, with deviations less than 0.005 mag from a more accurate spline fit.

$(B-V)_T$	≤ -0.2	0.1	0.5	1.4	≥ 1.8	
$V_J - V_T + 0.090(B-V)_T$	0.014	0.000	−0.005	−0.005	−0.015	
$(B-V)_J - 0.85(B-V)_T$	−0.006	0.000	0.046	−0.008	−0.032	
G-factor	0.85	0.87	0.97	0.79	0.79	0.85

Figure 10:

This was our second approach and in this case the slope of the $(B-V)_J$ versus $(B_T - V_T)$ relation is different in each of the six presented colour intervals.

In reality the photometric transformation depends on the detailed spectrum of the star, especially on luminosity class and interstellar and circumstellar reddening. Different relations for various spectral ranges are also presented in the book and consequently one should use them to minimise errors of conversion if only one has information about star's luminosity.

In our case we did not have that information, so we have decided to make use of the following conclusion: âWhen no luminosity classification was available, the relation defined for luminosity class III gians was used.â Indeed we have checked that even if a star is a dwarf applying giant's equation provides us more accurate results than standard transformations. Thus our third approach was to use the following equations of giant-like stars for the whole sample

$B_T - V_T < 0.65$:

$$\begin{aligned} (B_J - V_J) &= (B_T - V_T) - 0.010 - 0.060z - 0.14z^3 \\ z &= B_T - V_T - 0.22 \end{aligned} \tag{4}$$

$0.65 < B_T - V_T < 1.10$:

$$\begin{aligned}(B_J - V_J) &= (B_T - V_T) - 0.113 - 0.258z + 0.40z^3 \\ z &= B_T - V_T - 0.95\end{aligned} \tag{5}$$

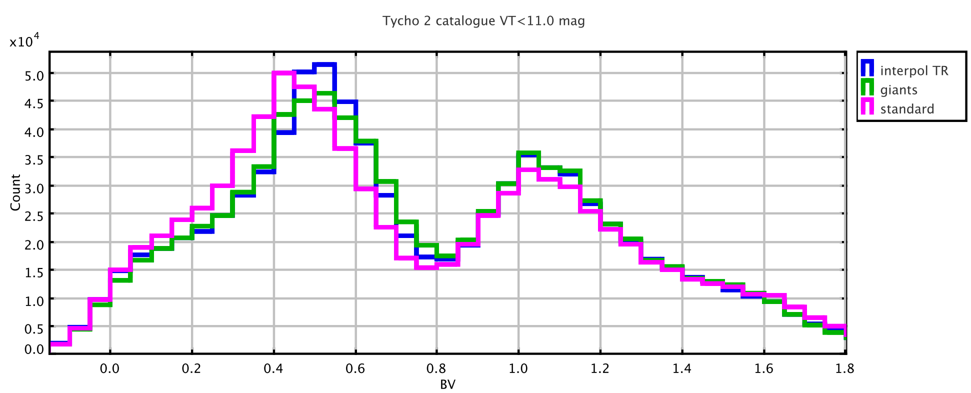
$1.10 < B_T - V_T$:

$$\begin{aligned}(B_J - V_J) &= (B_T - V_T) - 0.173 - 0.220z + 0.01z^3 \\ z &= B_T - V_T - 1.20\end{aligned} \tag{6}$$

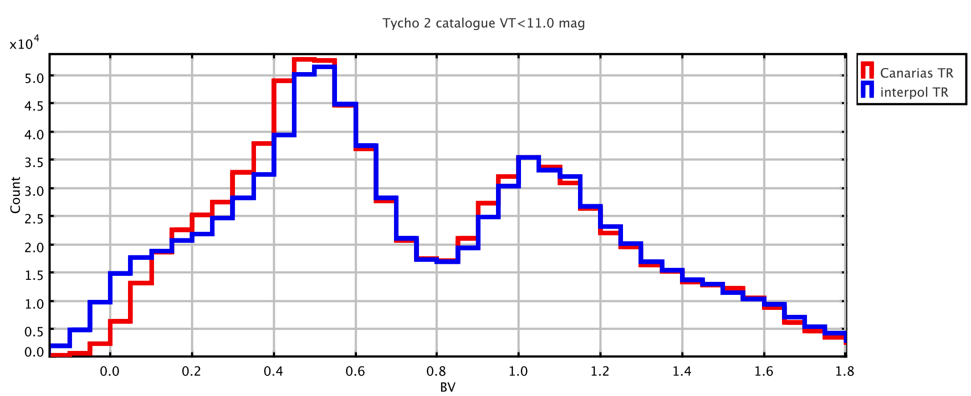
The fourth method of transformation comes from the study of Mark Kidger. On his website he derives the following relations

$$\begin{aligned}(B_T - V_T) &= 1.28899(B_J - V_J) - 0.1031 \\ V_J &= V_T - 0.016 - 0.0741 * (B_T - V_T)\end{aligned} \tag{7}$$

In the Fig. 11 we present the BV distributions our Tycho catalogue (cut at $V_T <= 11$ mag) transformed to Johson Cousin system by the four discussed methods.



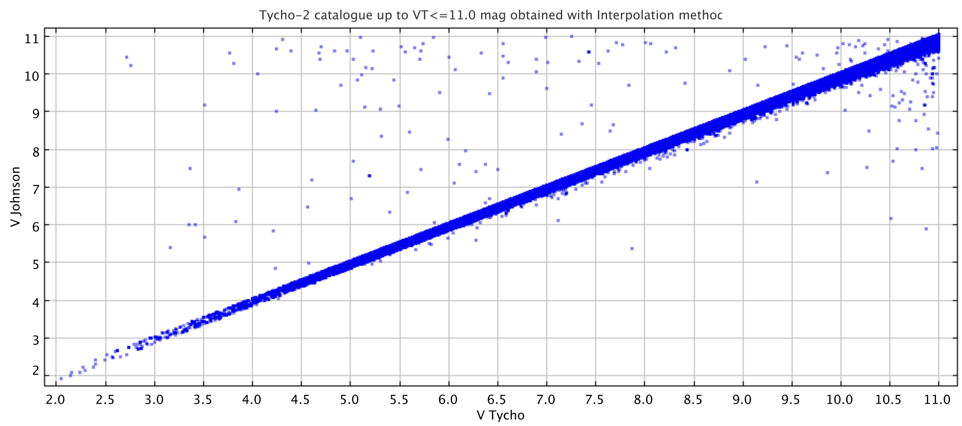
a) standard, interpolation and giants methods



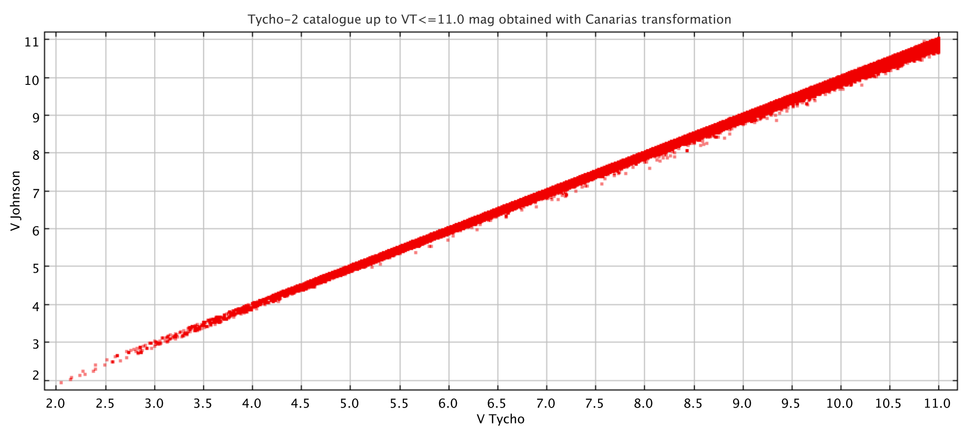
b) interpolation and Mark Kidger's methods

Figure 11: Our Tycho-2 catalogue after cuting at $V_T = 11$ mag.

In the Fig. 12 a) and b) we show the V_J versus V_T relation for the linear interpolation method and Mark Kidger's method respectively.



a) linear interpolation method

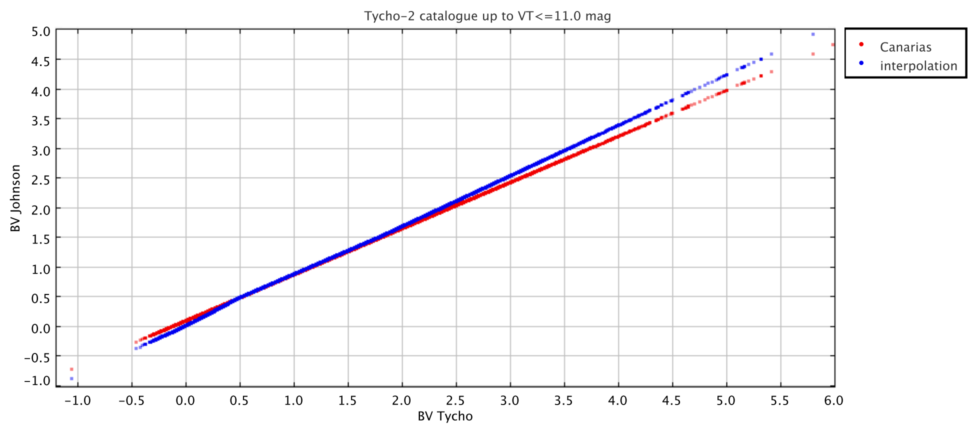


b) Mark Kidger's method

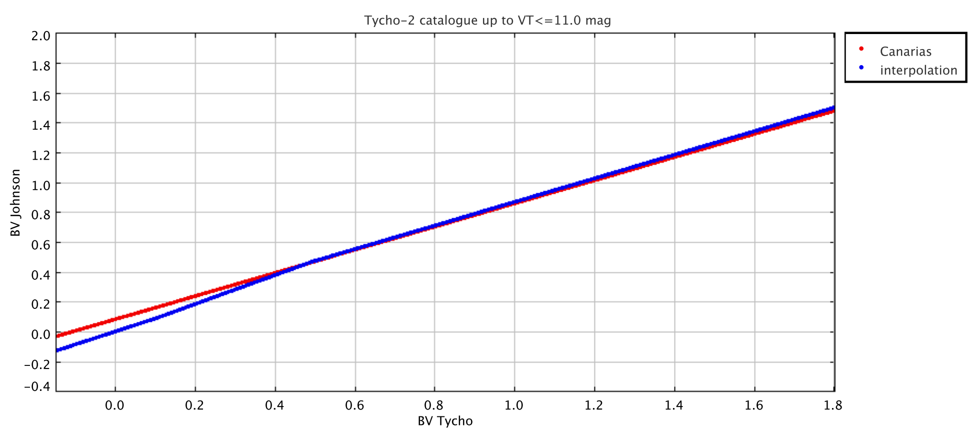
Figure 12: V_J versus V_T relation

In the Fig. 13 the comparison of the $(B-V)_J$ versus (B_T-V_T) relation for both methods.

Thus we see that those two methods differ on the blue end of the colour distribution, while for giant peak they provide very similar solution.



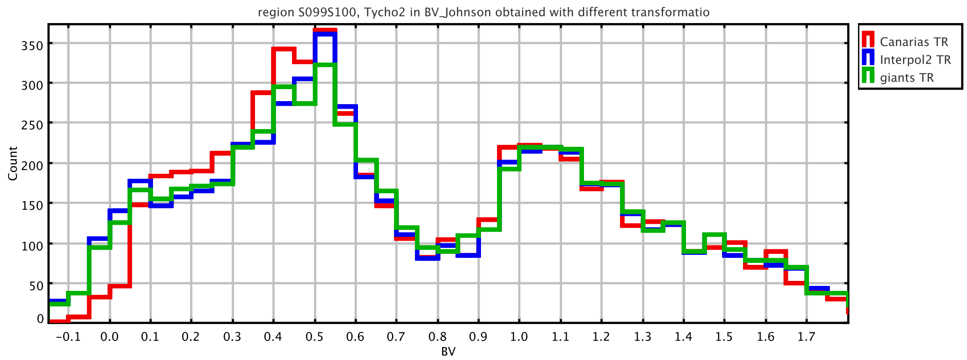
a)



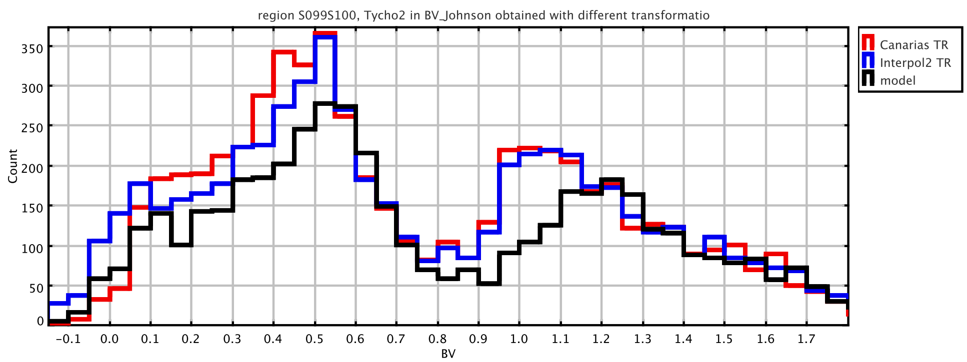
b)

Figure 13: the $(B-V)_J$ versus $(B_T - V_T)$ relation

In the Fig. 14 we compare the performance of the linear interpolation method and Mark Kidger's method in the region S099S100 and the same tests but in the North Pole direction in Fig. 15.

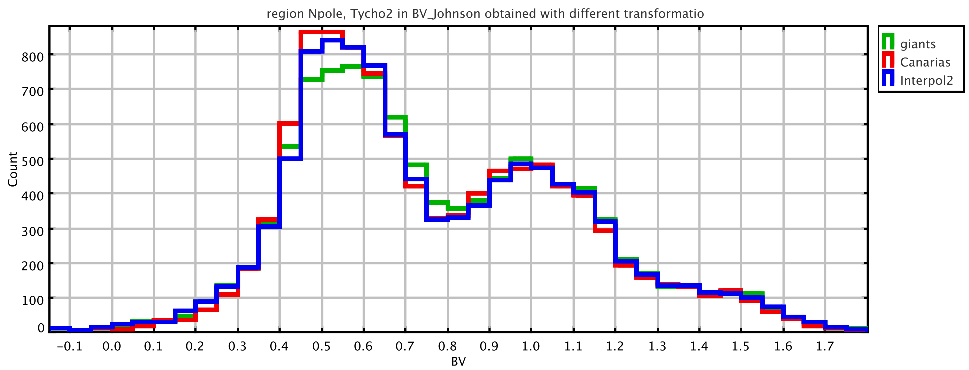


a)

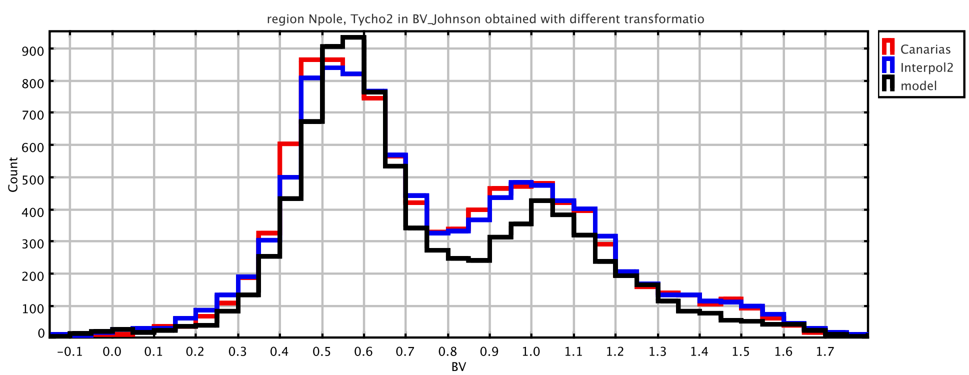


b)

Figure 14: S099S100 region. Comparing transformation methods.



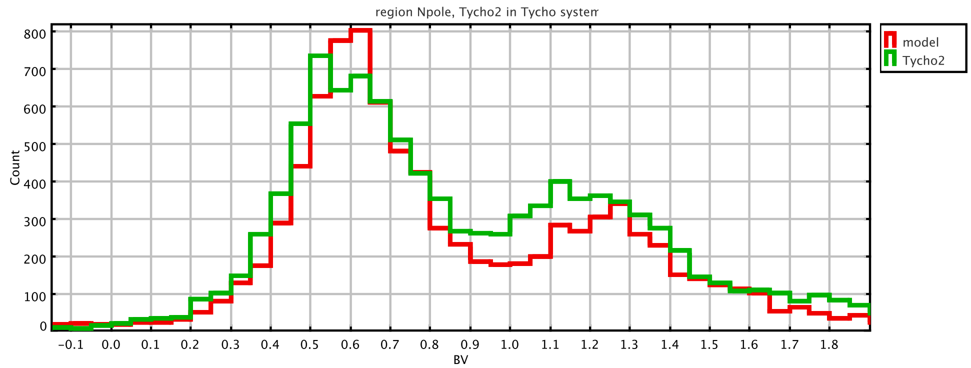
a)



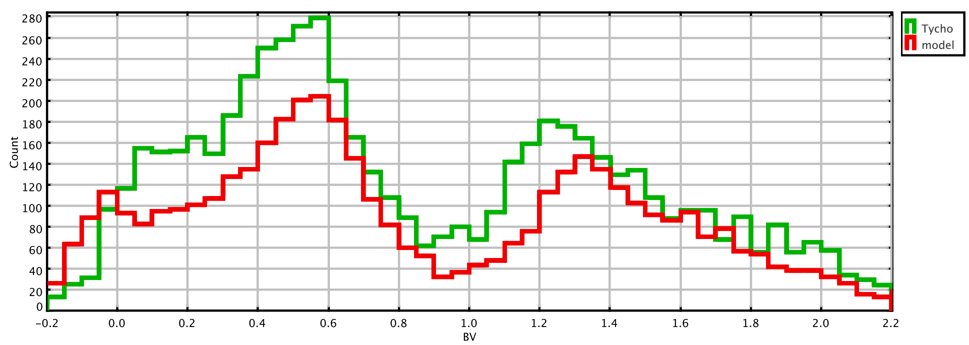
b)

Figure 15: North pole. Comparing transformation methods.

We have also implemented the inverted transformation inside the model, such that we get the simulations in the Tycho photometric system and they can be directly compared to data. The transformation method used was the Mark Kidger's one. In the Fig. 16 a) and b) the comparison of $B_T - V_T$ towards Galactic North pole and for the S099S100 region.



a) BV in Tycho system



b) BV in Tycho system

Figure 16:

The semiar at the UTINAM Institute in Besançon

Finally during the visit a student gave a seminar dedicated to the PhD project in question.

Tittle: The new version of the Besançon Galaxy Model: one step closer to Gaia

Authors: M. Czekaj, A. Robin, F. Figueras, X. Luri

Abstract:
The construction of a dynamical model of the Milky Way from the upcoming Gaia data will require a complex comparison between models and data in the space of the observables. To be ready for this challenge, in my PhD thesis, we have optimized the BesanÃ§on stellar population synthesis model. In this new version, almost ready, ingredients as critical as the IMF, the SFR, the binary fraction, the age-metallicity relation and the age-kinematic relation can be fitted to the observed data. That is this new version is not any more a single stars generator, but it considers binary systems maintaining constraints on the local mass density. The optimization includes also the use of most updated evolutionary tracks and model atmospheres. Various scenarios for those parameters have been checked against the Tycho-2 data.

During the seminar it was clearly mentioned that our work was supported by the European Space Foundation within the framework of Great activity.

CONCLUSIONS:

1. The new Besançon Galaxy Model is able to produce binary systems remaining in the agreement with the constraints on the local mass density in stars.

2. Applying binarity to our simulations we did not change significantly the BV distribution and did not explained the remaining discrepancies between Tycho and model. It is because merging of fluxes give a small change in the resulting magnitude and even if 50 % of the sample is merged any of the peaks in the colour distribution is shifted.

3. Four methods of photometry transformation between Johnson-Cousin and Tycho photometric systems were applied and compared. Small differences can be seen between them, however they do not explain our discrepancies. No significant differences in the BV colour distribution can be noticed when changing approach to the photometric transformation.

4. When the model photometry is transformed into the Tycho data photometric space, discrepancies in the BV colour remain, for that suggesting that the problem are not related to the transformation at all. In our studies we decided to work in the Johnson-Cousin system.

5. Thanks to the grant and the visit we have presented our work and the new Besançon Galaxy Model to the scientific community at the UTINAM Institute in Besançon.

Future collaboration with host institution:

The project is close to the finished. The student is writing the thesis and it should be ready within two months. Subsequently the defence is planned and the resulting publication. Continuous cooperation between both parties is being maintained.