2020

Internship Report

Arthur C. Clarke Institute for Modern Technologies

AS2016509

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STUDENT DECLARATION

I Kavindu Sellahewa, hereby declare that the presented report of internship titled "**AlphaTg: A code for computing synthetic stellar magnitudes**" of **Arthur C. Clarke Institute for Modern Technologies (ACCIMT)** is a record of an original work done by me under guidance of Mr. Janaka Adassuriya, the senior research scientist, astronomy division of Arthur C. Clarke institute for modern technologies. The project report is uniquely prepared by me after the completion of 12 Weeks work at ACCIMT, Katubedda.

I also confirm that, the report is only prepared for my academic requirement not for any other purpose.

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ABSTRACT

Asteroseismology is an unprecedent way of probing the stellar interior. This technique is entirely depending on determination of oscillation frequencies and their modes. These modes can be radial or non-radial. Among the methods of mode identification, the amplitude ratio method i.e. the comparison of observed amplitudes of UBVR color bands with the theoretical amplitudes is widely used. Since there are millions of data to process, the problem is the computation of theoretical amplitudes very complex and time consuming.

Automating this procedure is the best way to overcome this problem. In this task, it was done by creating a software application which can do this process easily for everyone. Then whoever the user does not need to calculate the theoretical amplitudes manually. Instead of that, this application program has created in such a way that processes over 1 million of data at a time to return the theoretical amplitudes automatically. Also, it allows users to calculate theoretical amplitudes by just clicking on a single button according to UBVR color bands separately. Furthermore, it also includes a graphical representation of the created models to get an idea about it. Additionally, it allows to compute Alpha (rate of change in flux) and Beta (limb darkening coefficient) components at any gravity or any temperature value. This application is now internationally available and anyone interest in asteroseismology can use it for their calculations.

ACKNOWLEDGEMENT

The internship opportunity I had with Arthur C. Clarke Institute for Modern Technologies was a great chance for learning and professional development. Therefore, I consider myself as a very lucky individual as I was provided with an opportunity to be a part of it. I am also grateful for having a chance to meet so many wonderful people and professionals who led me though this internship period.

Bearing in my mind previous I am using this opportunity to express my deepest gratitude and special thanks to Mr. Janaka Adassuriya, a senior research scientist of Arthur C. Clarke institute for modern technologies who in spite of being extraordinarily busy with his duties, took time out to hear, guide and keep me on the correct path and allowing me to carry out my project at their esteemed institute and extending during the training.

I express my deepest thanks to Mr. Saraj Gunasekara, head of the Astronomy Division of ACCIMT for taking part in useful decision & giving necessary advices and guidance and arranged all facilities to make life easier. I choose this moment to acknowledge his contribution gratefully.

I perceive as this opportunity as a big milestone in my career development. I will strive to use gained skills and knowledge in the best possible way, and I will continue work on their improvement, in order to attain desired career objectives. Hope to continue cooperation with all of you in the future.

Sincerely,

Kavindu Sellahewa,

Department of Physics,

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University of Sri Jayewardenepura.

CONTENTS

INTRODUCTION ABOUT INSTITUTE

The Arthur C. Clarke Institute for Modern Technologies continued to be one of a leading research and development institute in the country within the areas of its expertise and performs a pivotal role in development of national capabilities in space and several other identified core technology domains. In the process institute initiated several pioneering projects.

This institute consists 6 major divisions, which are:

01.) Communication and Engineering
02.) Electronic and Mobile Electronic
03.) Industrial Services
04.) Information Technology
05.) Space Applications
06.) Astronomy

Astronomy division was established in ACCIMT with the commencement of largest optical telescope facility in Sri Lanka, GOTO 45cm Cassegrain telescope. The division is responsible in the operation of telescope facility and carryout observations and education programs. Astronomers in the division are working in close collaboration with foreign entities and local universities to carry out basic research in astronomy. In addition, outreach programs for astronomy and space science popularization are also conducting for public and school children

Institute Facilities:

In 1996, ACCIMT hosted the UN/ESA workshop on Basic Space Science which resulted the commissioning of the GOTO 45cm Cassegrain telescope donated by the Japanese Government. This is the largest optical telescope facility available in Sri Lanka which is meant for carrying out basic research studies in astronomy as well as for teaching astronomy to school and university students.

This telescope facility is equipped with a spectrograph, photometer and Apogee ASPEN (3056×3056 pixels) and Apogee ALTA U47 (1024×1024 pixels) CCD cameras. The spectra in the wavelength region from 4000 A to 9000 A can be obtained with this system. The photometer of the telescope has RCA IP21 photomultiplier tube with pulse counting system and Johnson and Morgan UBVRI filters.[1]

[1] www.accimt.ac.lk

Figure 01: The Largest Telescope in Sri Lanka

Research carried by the institute:

ACCIMT conducts research under 4 main categories. Which are,

- Detecting Exoplanets
- Asteroseismology
- Solar Radio Bursts
- Cataclysmic Variables

A brief introduction about these categories are mentioned below.

Detecting Exoplanets:
Exoplanetary Astronomy is the study of planetary systems around stars other than our sun. Although the study of exoplanets has only been around for about 25 years, rapid progress had been made within the field with respect to the detection and characterization of new planets. This is mainly due to the presence of new instruments such as the Kepler space telescope and its immediate successor TESS (Transiting Exoplanet Survey Satellite).

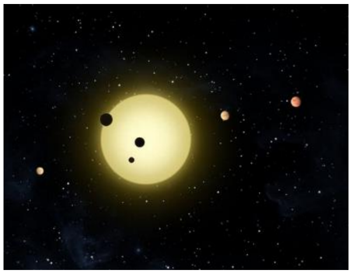


Figure 02: Exoplanets (image credit – NASA)

Asteroseismology:

Asteroseismology allows an unprecedented way to determine the internal structure of stars by studying their oscillations. Recent efforts have been performed allowing the detection of many frequencies in different kinds of pulsating stars. The pulsation is caused by stellar oscillations in three orthogonal directions, radial distance, co-latitude and longitude of the stellar structure.

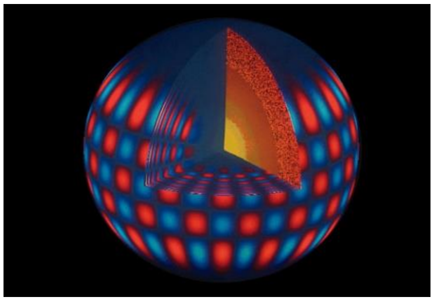


Figure 03: Variable Star Oscillation

Solar Radio Bursts

Solar Radio Bursts are measured using the CALLISTO system at ACCIMT. CALLISTO stands for Compound Astronomical Low-cost Low Frequency Instrument for Spectroscopy and Transportable Observatory. It is a programmable heterodyne receiver built in the framework of IHY2007 and ISWI (International Space Weather Initiative) by former Radio and Plasma Physics Group at ETH Zurich, Switzerland. Generally, this is applicable for observation of solar radio bursts and rfi – monitoring for astronomical science, education and outreach.

Figure 04: CALLISTO System Antenna @ACCIMT (Image Credit ACCIMT)

Cataclysmic Variables:

Cataclysmic variables are interacting binary stars comprising a white dwarf accreting matter from a companion star. ACCIMT carrying out researches about these areas also.

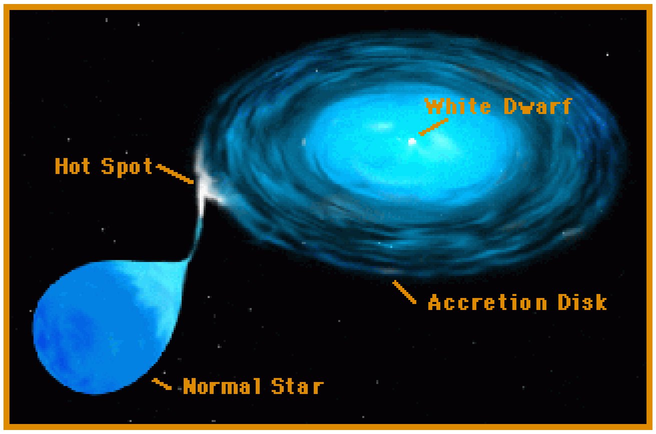


Figure 05: Cataclysmic Variables (image credit NASA)

Vision and Mission:

Vision:
To be a leading innovation center for Modern Technologies in the region

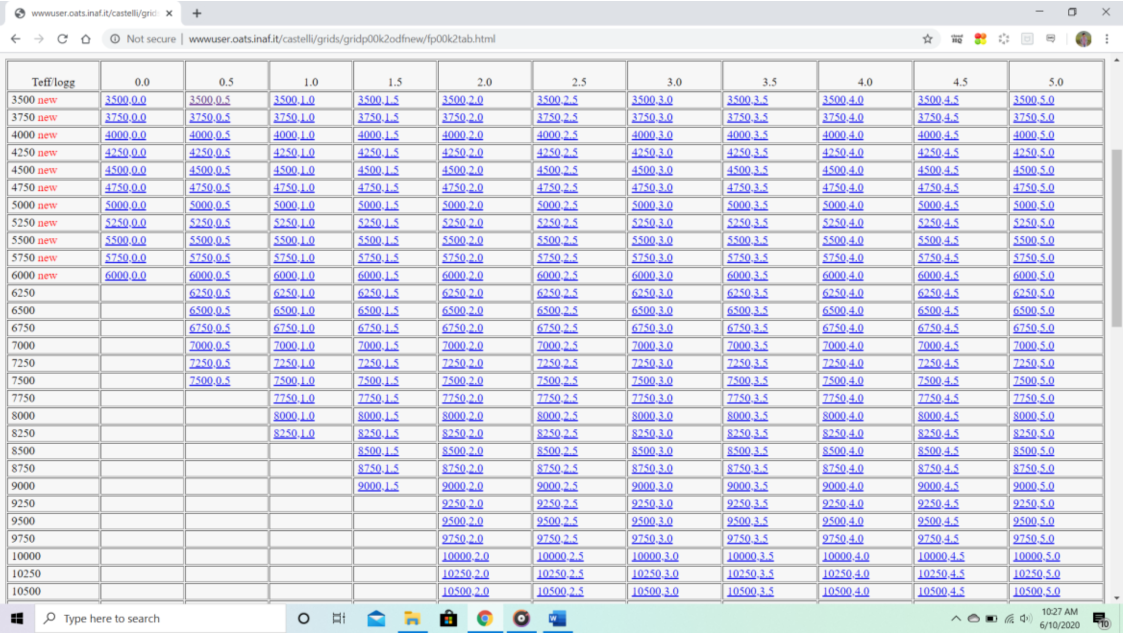
Mission:
To develop, foster and facilitate the domestic base of modern technological capabilities through innovation, R & D, training, industrial services and international collaboration”

INTRODUCTION TO THE TASK

Asteroseismology allows an unprecedented way to determine the internal structure of stars by studying their oscillations. This technique is entirely depending on determination of oscillation frequencies and their modes. These modes are initially classified as radial or non-radial and further narrow down to mode discrimination by assigning the quantum numbers n, l and m; n is related to the number of radial nodes and is called the overtone of the mode; l is the degree of the mode and specifies the number of surface nodes that are present; m is the azimuthal order of the mode, where m specifies how many of the surface nodes are lines of longitude. Among the methods of mode identification, the amplitude ratio method i.e. the comparison of observed amplitudes of UBVR color bands with the theoretical amplitudes is widely used. But there are 2 major challenges occur when calculating theoretical amplitudes. Those are,

01.) The computation of theoretical amplitudes very complex and time consuming.
02.) Computation of derivatives of color indices should be accurate enough for mode identification in pulsating stars.

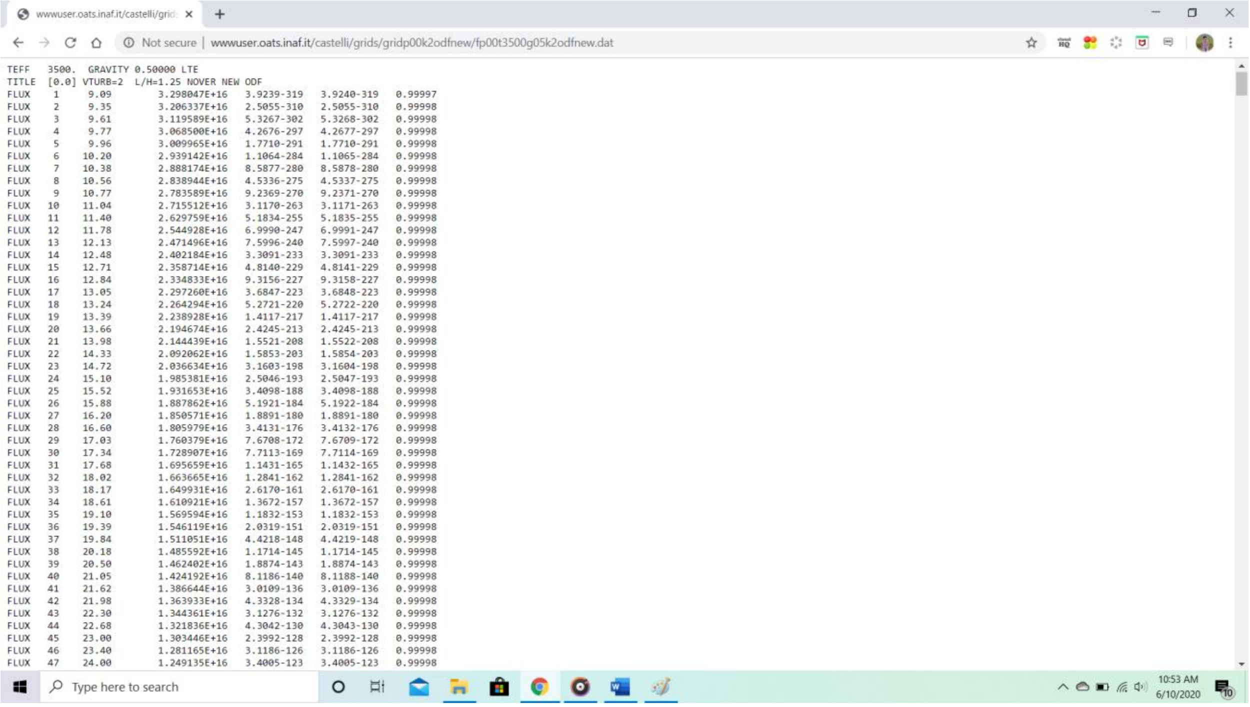
The reason for time waste is the flux values, which are used in calculations to obtain theoretical amplitudes are arranged in a huge grid as shown in the Figure 06. Every cell consists two unique values which are the temperature and the gravity of the star.



Teff/logg	0.0	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0
3500 new	3500,0.0	3500,0.5	3500,1.0	3500,1.5	3500,2.0	3500,2.5	3500,3.0	3500,3.5	3500,4.0	3500,4.5	3500,5.0
3750 new	3750,0.0	3750,0.5	3750,1.0	3750,1.5	3750,2.0	3750,2.5	3750,3.0	3750,3.5	3750,4.0	3750,4.5	3750,5.0
4000 new	4000,0.0	4000,0.5	4000,1.0	4000,1.5	4000,2.0	4000,2.5	4000,3.0	4000,3.5	4000,4.0	4000,4.5	4000,5.0
4250 new	4250,0.0	4250,0.5	4250,1.0	4250,1.5	4250,2.0	4250,2.5	4250,3.0	4250,3.5	4250,4.0	4250,4.5	4250,5.0
4500 new	4500,0.0	4500,0.5	4500,1.0	4500,1.5	4500,2.0	4500,2.5	4500,3.0	4500,3.5	4500,4.0	4500,4.5	4500,5.0
4750 new	4750,0.0	4750,0.5	4750,1.0	4750,1.5	4750,2.0	4750,2.5	4750,3.0	4750,3.5	4750,4.0	4750,4.5	4750,5.0
5000 new	5000,0.0	5000,0.5	5000,1.0	5000,1.5	5000,2.0	5000,2.5	5000,3.0	5000,3.5	5000,4.0	5000,4.5	5000,5.0
5250 new	5250,0.0	5250,0.5	5250,1.0	5250,1.5	5250,2.0	5250,2.5	5250,3.0	5250,3.5	5250,4.0	5250,4.5	5250,5.0
5500 new	5500,0.0	5500,0.5	5500,1.0	5500,1.5	5500,2.0	5500,2.5	5500,3.0	5500,3.5	5500,4.0	5500,4.5	5500,5.0
5750 new	5750,0.0	5750,0.5	5750,1.0	5750,1.5	5750,2.0	5750,2.5	5750,3.0	5750,3.5	5750,4.0	5750,4.5	5750,5.0
6000 new	6000,0.0	6000,0.5	6000,1.0	6000,1.5	6000,2.0	6000,2.5	6000,3.0	6000,3.5	6000,4.0	6000,4.5	6000,5.0
6250		6250,0.5	6250,1.0	6250,1.5	6250,2.0	6250,2.5	6250,3.0	6250,3.5	6250,4.0	6250,4.5	6250,5.0
6500		6500,0.5	6500,1.0	6500,1.5	6500,2.0	6500,2.5	6500,3.0	6500,3.5	6500,4.0	6500,4.5	6500,5.0
6750		6750,0.5	6750,1.0	6750,1.5	6750,2.0	6750,2.5	6750,3.0	6750,3.5	6750,4.0	6750,4.5	6750,5.0
7000		7000,0.5	7000,1.0	7000,1.5	7000,2.0	7000,2.5	7000,3.0	7000,3.5	7000,4.0	7000,4.5	7000,5.0
7250		7250,0.5	7250,1.0	7250,1.5	7250,2.0	7250,2.5	7250,3.0	7250,3.5	7250,4.0	7250,4.5	7250,5.0
7500		7500,0.5	7500,1.0	7500,1.5	7500,2.0	7500,2.5	7500,3.0	7500,3.5	7500,4.0	7500,4.5	7500,5.0
7750			7750,1.0	7750,1.5	7750,2.0	7750,2.5	7750,3.0	7750,3.5	7750,4.0	7750,4.5	7750,5.0
8000			8000,1.0	8000,1.5	8000,2.0	8000,2.5	8000,3.0	8000,3.5	8000,4.0	8000,4.5	8000,5.0
8250			8250,1.0	8250,1.5	8250,2.0	8250,2.5	8250,3.0	8250,3.5	8250,4.0	8250,4.5	8250,5.0
8500				8500,1.5	8500,2.0	8500,2.5	8500,3.0	8500,3.5	8500,4.0	8500,4.5	8500,5.0
8750				8750,1.5	8750,2.0	8750,2.5	8750,3.0	8750,3.5	8750,4.0	8750,4.5	8750,5.0
9000				9000,1.5	9000,2.0	9000,2.5	9000,3.0	9000,3.5	9000,4.0	9000,4.5	9000,5.0
9250					9250,2.0	9250,2.5	9250,3.0	9250,3.5	9250,4.0	9250,4.5	9250,5.0
9500					9500,2.0	9500,2.5	9500,3.0	9500,3.5	9500,4.0	9500,4.5	9500,5.0
9750					9750,2.0	9750,2.5	9750,3.0	9750,3.5	9750,4.0	9750,4.5	9750,5.0
10000					10000,2.0	10000,2.5	10000,3.0	10000,3.5	10000,4.0	10000,4.5	10000,5.0
10250					10250,2.0	10250,2.5	10250,3.0	10250,3.5	10250,4.0	10250,4.5	10250,5.0
10500					10500,2.0	10500,2.5	10500,3.0	10500,3.5	10500,4.0	10500,4.5	10500,5.0

Figure 06 – Temperature, Gravity grid

As shown in the Figure 06 there are hundreds of temperature and gravity cells and **each cell** consists theoretical flux values of the entire visible spectrum as shown in Figure 07.



```
TEFF   3500.  GRAVITY 0.50000 LTE
TITLE  [0.0] VTURB=2  L/H=1.25 NOVER NEW ODF
FLUX    1     9.09          3.298047E+16   3.9239-319   3.9240-319   0.99997
FLUX    2     9.35          3.206337E+16   2.5055-310   2.5055-310   0.99998
FLUX    3     9.61          3.119589E+16   5.3267-302   5.3268-302   0.99998
FLUX    4     9.77          3.068500E+16   4.2676-297   4.2677-297   0.99998
FLUX    5     9.96          3.009965E+16   1.7710-291   1.7710-291   0.99998
FLUX    6    10.20          2.939142E+16   1.1064-284   1.1065-284   0.99998
FLUX    7    10.38          2.888174E+16   8.5877-280   8.5878-280   0.99998
FLUX    8    10.56          2.838944E+16   4.5336-275   4.5337-275   0.99998
FLUX    9    10.77          2.783589E+16   9.2369-270   9.2371-270   0.99998
FLUX   10    11.04          2.715512E+16   3.1170-263   3.1171-263   0.99998
FLUX   11    11.40          2.629759E+16   5.1834-255   5.1835-255   0.99998
FLUX   12    11.78          2.544928E+16   6.9990-247   6.9991-247   0.99998
FLUX   13    12.13          2.471496E+16   7.5996-240   7.5997-240   0.99998
FLUX   14    12.48          2.402184E+16   3.3091-233   3.3091-233   0.99998
FLUX   15    12.71          2.358714E+16   4.8140-229   4.8141-229   0.99998
FLUX   16    12.84          2.334833E+16   9.3156-227   9.3158-227   0.99998
FLUX   17    13.05          2.297260E+16   3.6847-223   3.6848-223   0.99998
FLUX   18    13.24          2.264294E+16   5.2721-220   5.2722-220   0.99998
FLUX   19    13.39          2.238928E+16   1.4117-217   1.4117-217   0.99998
FLUX   20    13.66          2.194674E+16   2.4245-213   2.4245-213   0.99998
FLUX   21    13.98          2.144439E+16   1.5521-208   1.5522-208   0.99998
FLUX   22    14.33          2.092062E+16   1.5853-203   1.5854-203   0.99998
FLUX   23    14.72          2.036634E+16   3.1603-198   3.1604-198   0.99998
FLUX   24    15.10          1.985381E+16   2.5046-193   2.5047-193   0.99998
FLUX   25    15.52          1.931653E+16   3.4098-188   3.4098-188   0.99998
FLUX   26    15.88          1.887862E+16   5.1921-184   5.1922-184   0.99998
FLUX   27    16.20          1.850571E+16   1.8891-180   1.8891-180   0.99998
FLUX   28    16.60          1.805979E+16   3.4131-176   3.4132-176   0.99998
FLUX   29    17.03          1.760379E+16   7.6708-172   7.6709-172   0.99998
FLUX   30    17.34          1.728907E+16   7.7113-169   7.7114-169   0.99998
FLUX   31    17.68          1.695659E+16   1.1431-165   1.1432-165   0.99998
FLUX   32    18.02          1.663665E+16   1.2841-162   1.2841-162   0.99998
FLUX   33    18.17          1.649931E+16   2.6170-161   2.6170-161   0.99998
FLUX   34    18.61          1.610921E+16   1.3672-157   1.3672-157   0.99998
FLUX   35    19.10          1.569594E+16   1.1832-153   1.1832-153   0.99998
FLUX   36    19.39          1.546119E+16   2.0319-151   2.0319-151   0.99998
FLUX   37    19.84          1.511051E+16   4.4218-148   4.4219-148   0.99998
FLUX   38    20.18          1.485592E+16   1.1714-145   1.1714-145   0.99998
FLUX   39    20.50          1.462402E+16   1.8874-143   1.8874-143   0.99998
FLUX   40    21.05          1.424192E+16   8.1186-140   8.1188-140   0.99998
FLUX   41    21.62          1.386644E+16   3.0109-136   3.0109-136   0.99998
FLUX   42    21.98          1.363933E+16   4.3328-134   4.3329-134   0.99998
FLUX   43    22.30          1.344361E+16   3.1276-132   3.1276-132   0.99998
FLUX   44    22.68          1.321836E+16   4.3042-130   4.3043-130   0.99998
FLUX   45    23.00          1.303446E+16   2.3992-128   2.3992-128   0.99998
FLUX   46    23.40          1.281165E+16   3.1186-126   3.1186-126   0.99998
FLUX   47    24.00          1.249135E+16   3.4005-123   3.4005-123   0.99998
```

Figure 07 (inside of the cell, T = 3500 K, g = 0.5)

When calculating theoretical amplitudes, it is necessary to calculate 2 terms known as α_T and α_g which consists in amplitude equation (see the appendix) under two main categories. Which are

01.)Keep the temperature as a constant in a certain value and change the gravity to obtain flux values to calculate α_g

02.)Keep the gravity as a constant in a certain value and change the temperature to obtain flux values to calculate α_T

As an example, if the gravity is kept as a constant at 5.0 LTE to calculate α_T by obtaining flux values, then there are total number of 76 cells (from 3500 Kelvin to 50000 Kelvin) according to that grid (see the grid: http://wwwuser.oats.inaf.it/castelli/grids/gridp00k2odfnew/fp00k2tab.html) and each cell consists flux values of entire range of visible wavelength spectrum as shown in Figure 07. As one cell nearly contains 1224 flux values, only for gravity value 5.0 it has nearly 1224x76 (=93024) flux values to process. But that is only for 5.0 value. Gravity varies from 0.0 to 5.0! and this is just one case. In the other hand as mentioned above, it has to keep temperature as a constant and obtain flux values by varying gravity as same as earlier. After obtaining every single flux value it needs to categories them into UBVR color bands according to their wavelengths. (see the wavelength ranges in appendix)

But that is just a part of the equation. Then it needs to calculate limb darkening coefficients known as β_T and β_g which also consists in amplitude equation. (see the appendix) Limb darkening means the stars are getting darker when the brightness is measured away from its center. This also depends on the temperature and the gravity of the star. This procedure is same as the previous to obtain data values. But the problem is now this has over 1 million data to process to obtain the α and β components which need to calculate theoretical amplitudes.

The grid shown in the Figure 06 is not the only grid! According to metallicity, there are different number of grids. Figure 06 represents grid only for metallicity 0.0 and there are other values also such as 0.5, 1.0, 1.5, -0.5 etc. If the observed amplitudes are not matching with theoretical amplitudes, users must change the metallicity and do the same procedure for other metallicity values also. Then the problem is getting more complex!

The task is not only to give an innovative solution to obtain these data by creating an automated system, but also do all the complex calculations automatically in order to return the final results. After creating the system, it will simply return the calculated α and β components according to temperature and gravity values which entered by a user by just clicking on a single button. It must also allow users to analyze them according to UBVR filters as they wish. Basically, the system must do the all calculations by processing those over 1 million data by hiding its complexity. Users may only see the result that they need.

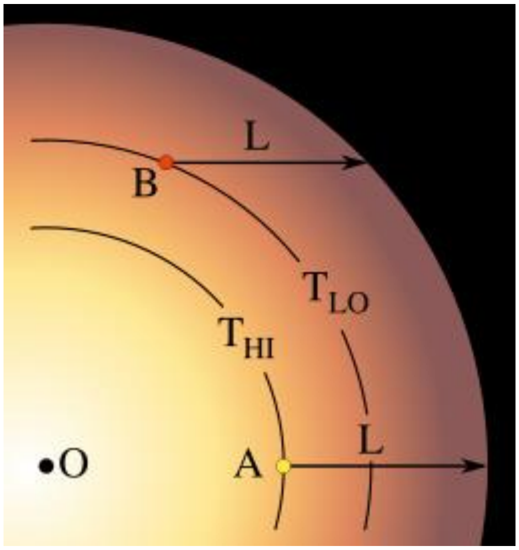


Figure 08 – Limb Darkening of a star

OBJECTIVES

- Create an automated solution to calculate α and β components without wasting time.
- Allow users to analyze results according to different kind of filters (i.e. according to different wavelengths of the visible spectrum.
- Return more accurate results in order to predict the theoretical amplitudes.
- Create a user-friendly system to release this project internationally.

METHODOLOGY

Identifying Theory Concepts

First thing was to identify the theory concepts. According to the amplitude equation, there are some terms called α_T, α_g, β_T, β_g. Where,

- α_T – The rate of change of flux with temperature
- α_g – The rate of change of flux with gravity
- β_T – Limb darkening with respect to the temperature
- β_g – Limb darkening with respect to the gravity

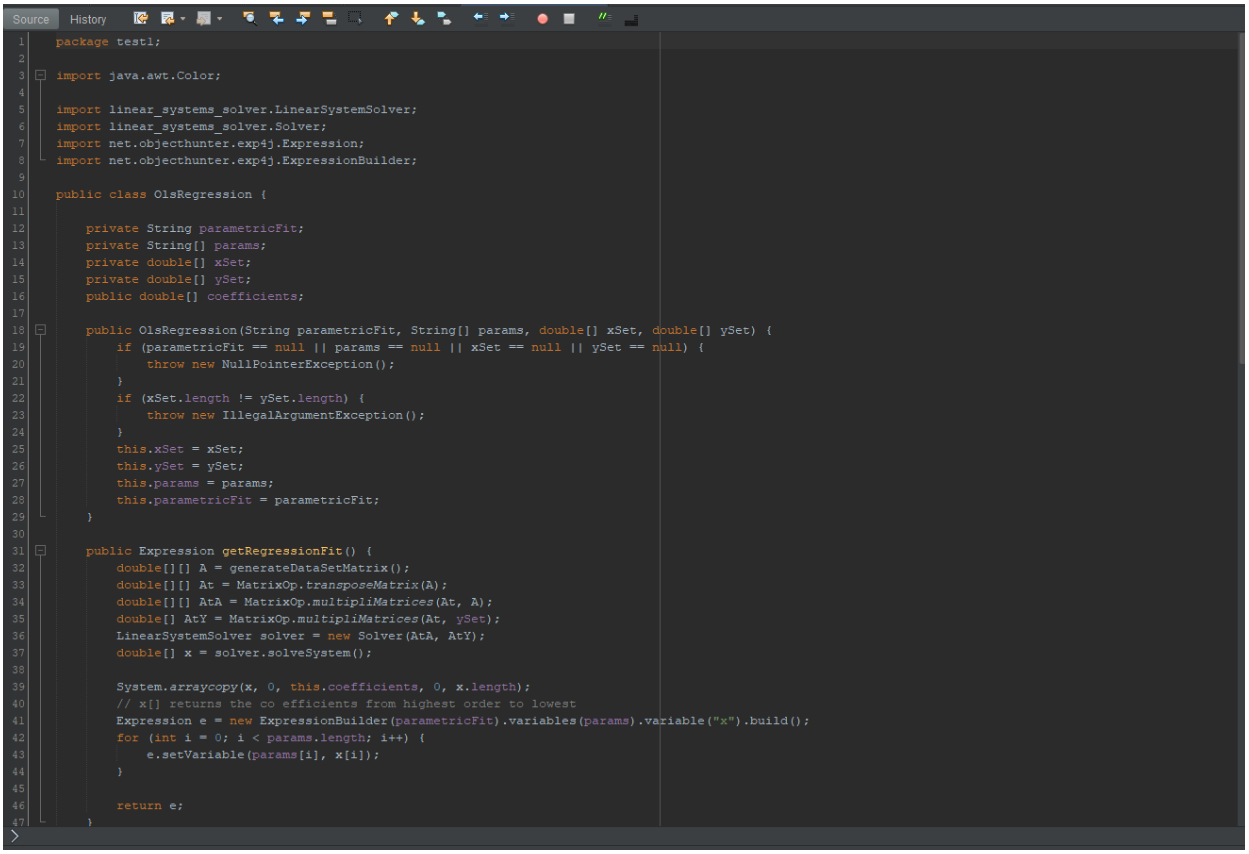
After getting knowing these terms, the theory behind these terms was identified in order to calculate them. To calculate these values, it is necessary to plot the flux values which were extracted from databases with respect to the temperature or gravity (plotting flux values with respect to the temperature and gravity to calculate both α and β values). After plotting, it has to fit those points by using a suitable mathematical model in order to obtain the graph equation. Then the rate of change of that mathematical model at a specific temperature or gravity value is known as α or β. (will discuss in detail in calculating α and β sections) In order to create a suitable mathematical model, another program was developed using OLS Regression Method.

Creating OLS Regression Code

OLS regression is a mathematical technique which is used to determine coefficients of a created mathematical model by using matrix multiplication. The program was created in such a way, that supports up to 9th order fitting polynomials. In the other words, if the fitting polynomial function is f(x), it is given by,

$$f(x) = ax^9 + bx^8 + cx^7 + dx^6 + ex^5 + fx^4 + gx^3 + hx^2 + ix + j$$

Finding coefficients from “a” to “j” is done by using OLS (Ordinary Least Squares) regression method in statistics. It finds the coefficients of the fitting polynomial which minimize the “sum of squared errors”. This relates only to the properties of the stochastic part, not to the functional part of the model. This means that the relationship between polynomial’s variables can have any form (linear, quadratic, etc.) that does not matter. For an example, if the best fitting polynomial is 8th order for some data points, x^9 coefficient (which is “a” in above equation) is nearly equal to zero. Then the rate of change of flux (α and β) can be obtained by substituting the desired temperature or gravity value from the derivate function of the fitted polynomial.

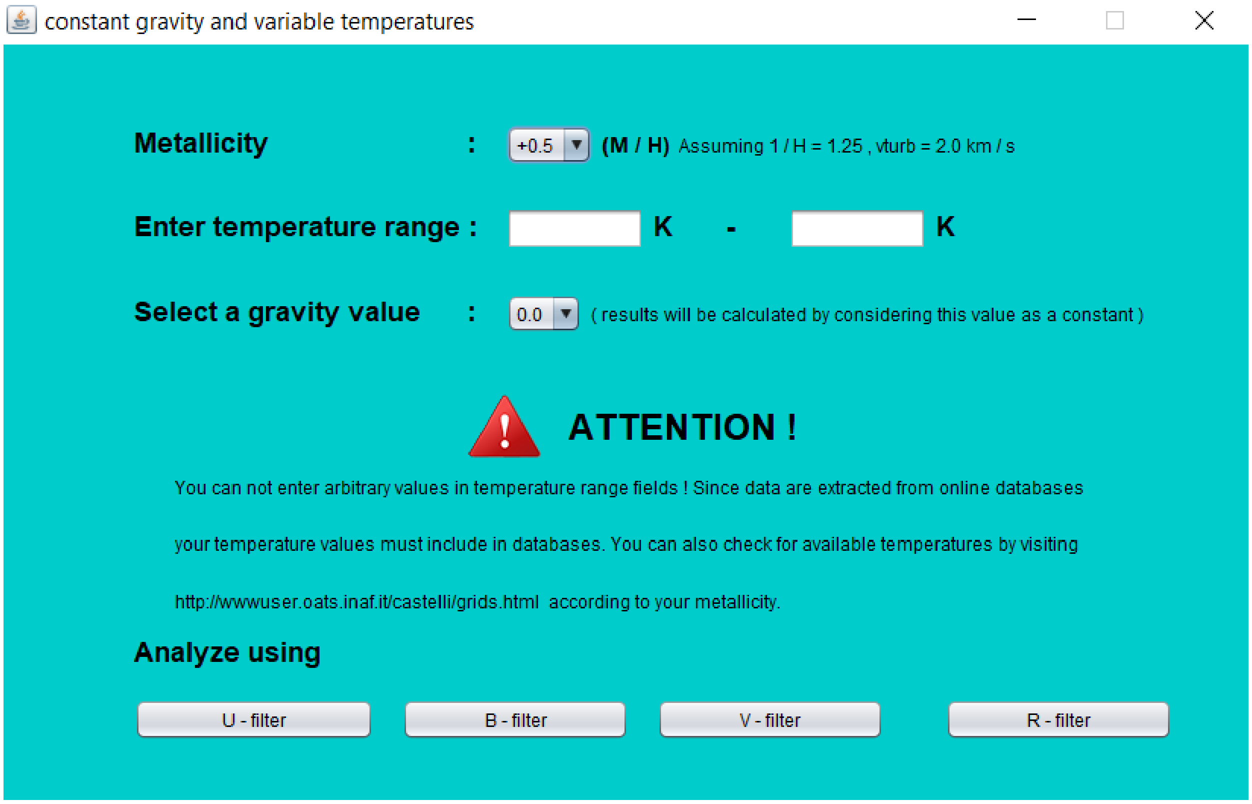


```
package test1;

import java.awt.Color;

import linear_systems_solver.LinearSystemSolver;
import linear_systems_solver.Solver;
import net.objecthunter.exp4j.Expression;
import net.objecthunter.exp4j.ExpressionBuilder;

public class OlsRegression {

    private String parametricFit;
    private String[] params;
    private double[] xSet;
    private double[] ySet;
    public double[] coefficients;

    public OlsRegression(String parametricFit, String[] params, double[] xSet, double[] ySet) {
        if (parametricFit == null || params == null || xSet == null || ySet == null) {
            throw new NullPointerException();
        }
        if (xSet.length != ySet.length) {
            throw new IllegalArgumentException();
        }
        this.xSet = xSet;
        this.ySet = ySet;
        this.params = params;
        this.parametricFit = parametricFit;
    }

    public Expression getRegressionFit() {
        double[][] A = generateDataSetMatrix();
        double[][] At = MatrixOp.transposeMatrix(A);
        double[][] AtA = MatrixOp.multipliMatrices(At, A);
        double[] AtY = MatrixOp.multipliMatrices(At, ySet);
        LinearSystemSolver solver = new Solver(AtA, AtY);
        double[] x = solver.solveSystem();

        System.arraycopy(x, 0, this.coefficients, 0, x.length);
        // x[] returns the co efficients from highest order to lowest
        Expression e = new ExpressionBuilder(parametricFit).variables(params).variable("x").build();
        for (int i = 0; i < params.length; i++) {
            e.setVariable(params[i], x[i]);
        }

        return e;
    }
```

Figure 09 – OLS Regression Method Program

Calculating α_T Value

α_T is the rate of change in flux values with respect to the temperature. (Note that gravity is constant in this case.) In this task users have to enter the temperature range that they wish to analyze. Also, they need to enter the gravity value which must keep as a constant. To do this task a user-friendly interface was developed as they can easily enter/select temperature range and constant gravity values as shown in Figure 10.



Metallicity : +0.5 ▼ **(M / H)** Assuming 1 / H = 1.25 , vturb = 2.0 km / s

Enter temperature range : ☐ **K** - ☐ **K**

Select a gravity value : 0.0 ▼ (results will be calculated by considering this value as a constant)

ATTENTION !

You can not enter arbitrary values in temperature range fields ! Since data are extracted from online databases your temperature values must include in databases. You can also check for available temperatures by visiting http://wwwuser.oats.inaf.it/castelli/grids.html according to your metallicity.

Figure 10 – calculate α_T (user interface)

In temperature range fields users have to enter the lower temperature range and upper temperature range and in gravity section they need to select gravity value which must keep as a constant to do further calculations. Additionally, it allows users to select the metallicity of the star also.

Analyzing with different filters

After entering the values in those fields displayed in Figure 10, users need to select the filter which they need to analyze. Because theoretical amplitudes can be obtained according to different filters (different wavelength ranges of the visible spectrum) and this program also allows to analyze according to different filters.

After obtaining values (from data tables as displayed in the Figure 07) from the websites a small calculation was done to calculate flux values (f_λ) using following equation. (Here Figure 07 shows only one table as an example. There are hundreds and each table are going to affect to the calculations.)

$$f_\lambda = \frac{4 \times Hnu \times C}{\lambda^2}$$

Where,

Hnu – 5th column of every single data set

C – Speed of Light

λ – Wavelength (3rd column of every single data set)

After calculating f_λ values they were categorized according to filters which user has selected. This was done by analyzing λ values. There are different wavelength ranges associated with different filters.

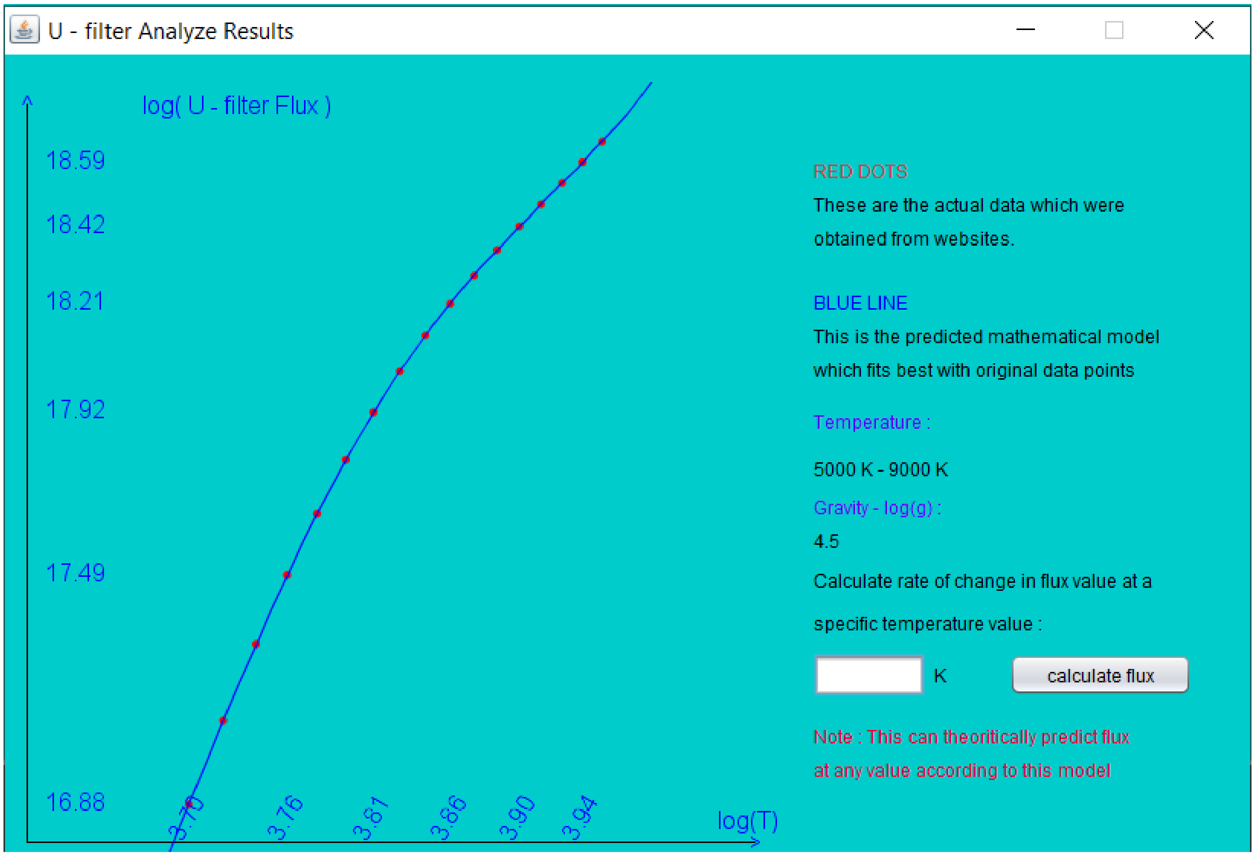
filter	Wavelength range (nm)
U filter	299 - 431
B filter	351 - 539
V filter	463 - 639
R filter	521 - 795

Then these categorized f_λ values were normalized by multiplying from the normalizing factor. Each wavelength has a unique normalizing factor. (see the appendix for the wavelengths and normalizing factors.) After doing all these calculations logarithm values of f_λ was obtained in order to display results. Because α_T is the rate of change of the graph which is drawn between log(f_λ) Vs temperature.

Displaying the Results

After user selecting the filter button another window was made to display results as shown in the figure 11. This also include a graphical representation of the created mathematical model. After studying the mathematical model users can enter any temperature value (in Kelvin) in the given text area as you can see in this figure. Red dots are the log values of the normalized flux (log[f_λ])

according to the filter (which selected by the user) with respect to the log temperature values. Blue curve is the predicted mathematical model which suits best with the red data points. As you can see in the figure 11 it is that much accurate!



RED DOTS

These are the actual data which were obtained from websites.

BLUE LINE

This is the predicted mathematical model which fits best with original data points

Temperature :

5000 K - 9000 K

Gravity - log(g) :

4.5

Calculate rate of change in flux value at a specific temperature value :

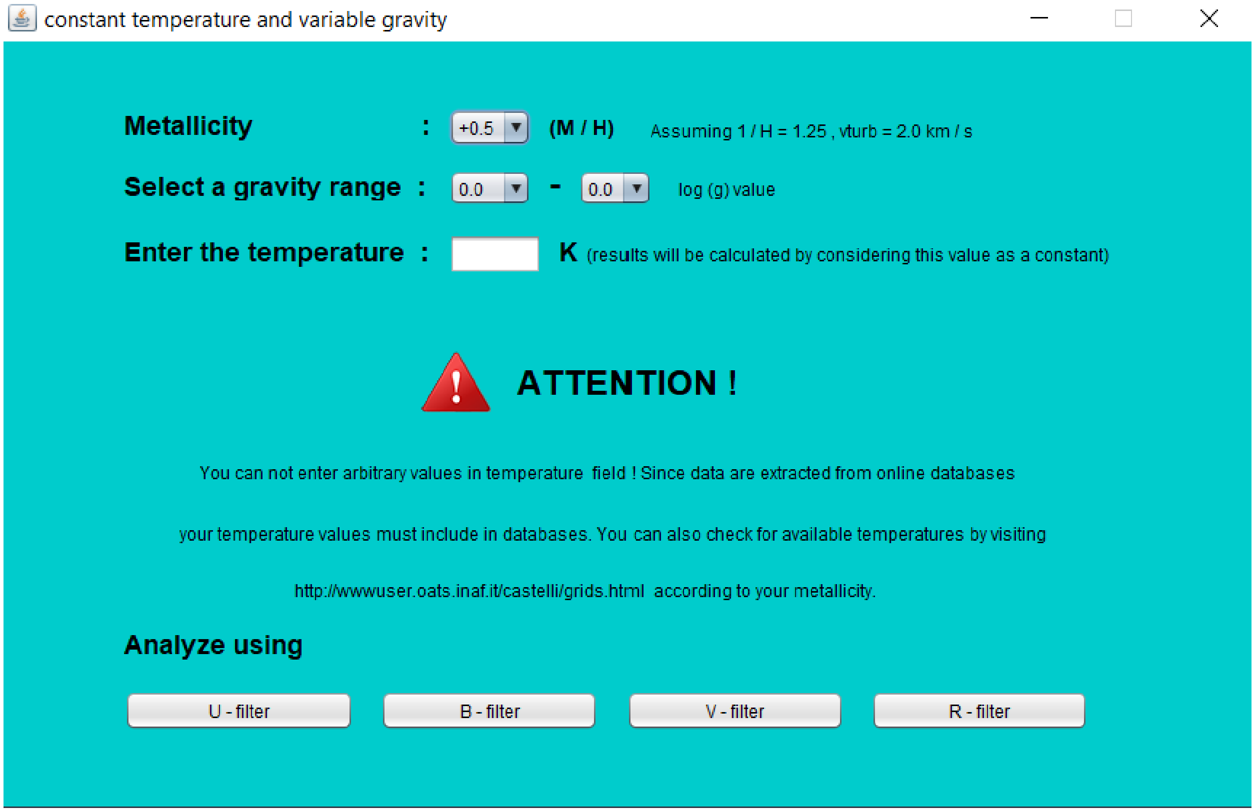
Note : This can theoritically predict flux at any value according to this model

Figure 11 – Display α_T results for u filter

In the right side it also displays the temperature range and the selected gravity value just to be clear. This was made in such a way, which simply returns the α_T when user enters the temperature. Which is the rate of change of the curve at any given temperature value. Then the entered temperature value was converted to log number and by using the mathematical model equation α_T was calculated and displayed.

Calculating α_g Value

α_g is rate of change in flux with respect to the gravity. Calculating α_g was done as same as α_T. But in this case temperature was kept as a constant. Then another interface was developed to select gravity range and to enter the temperature which must be kept as a constant as shown in the figure 12.



constant temperature and variable gravity

Metallicity : +0.5 (M / H) Assuming 1 / H = 1.25 , vturb = 2.0 km / s

Select a gravity range : 0.0 - 0.0 log (g) value

Enter the temperature : K (results will be calculated by considering this value as a constant)

ATTENTION !

You can not enter arbitrary values in temperature field ! Since data are extracted from online databases

your temperature values must include in databases. You can also check for available temperatures by visiting

http://wwwuser.oats.inaf.it/castelli/grids.html according to your metallicity.

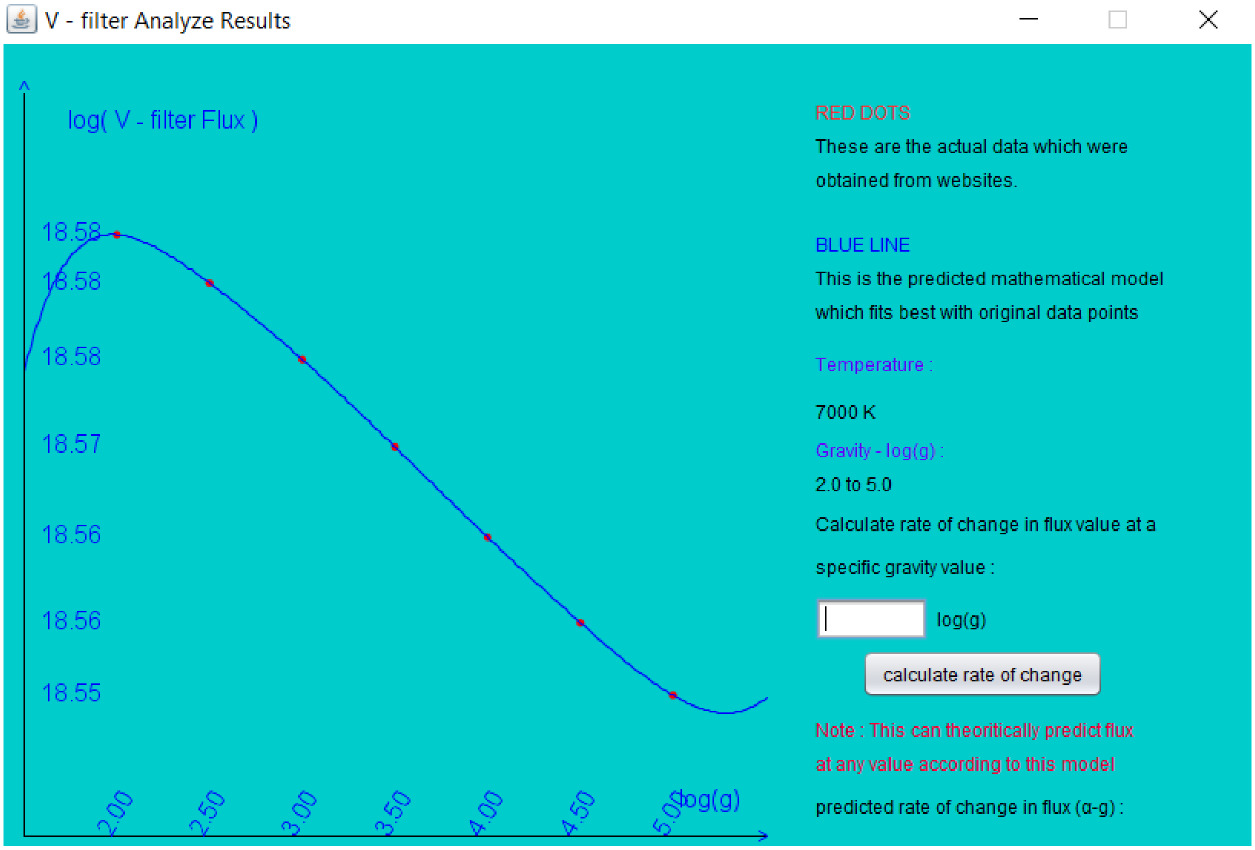
Analyze using

Figure 12 - calculate α_g (user interface)

In this section also, another option was developed by allowing users to select the metallicity of the star. After user has entered all the required fields again user need to select the filter. Another program was developed to do this task but the equation and the method is same as which was done in calculating α_T section. But the difference is in this case temperature is kept as a constant. Keeping the temperature as a constant program will search for every gravity value which was entered by a user. After extracting data from the website same procedure was done to categorize them according to different filters as did in α_T section.

Displaying the Results

To display the graph (which consists the graphical representation of the predicted mathematical model) an interface (just like the previous) was developed. Same instructions and labels were added to the interface like earlier. The difference is, a field was added to enter a gravity value instead of the temperature field since here users are wanted to calculate rate of change in flux with respect to the gravity, which is known as α_g.



RED DOTS

These are the actual data which were obtained from websites.

BLUE LINE

This is the predicted mathematical model which fits best with original data points

Temperature :

7000 K

Gravity - log(g) :

2.0 to 5.0

Calculate rate of change in flux value at a specific gravity value :

Note : This can theoritically predict flux at any value according to this model

predicted rate of change in flux (α-g) :

Figure 13 – Display results α_g for V filter (T = 7000K)

In log(g) field gravity value was taken from the user and according to the coefficients of the predicted mathematical model rate of change was calculated at that gravity value. Hence it was displayed at the bottom of the interface. This whole process is automatic and users just want to enter the gravity value that they need to calculate!

Calculating β components (Limb Darkening)

As shown in the figure 08, stars are getting darker when the brightness is measured away from its center. This is called as limb darkening of a star. This also depends on the temperature and the gravity of the star, but in a different way. In this scenario limb darkening integral was calculated by using following equation.

$$b_{l,f} = \int_0^1 \mu I(\mu) P_l(\mu) d\mu$$

Where,

b = limb darkening integral

$I(\mu) = \cos(\theta)$ – θ is the spherical angle measured from vertical axis

$P_l(\mu)$ = legendary polynomial (see the appendix)

l = spherical degree

μ = filter coefficient

In this case b (the limb darkening integral) was calculated according to different spherical degree and also according to different filters as previous cases. But this equation only for linear integrals. There are two other equation types known as quadratic and logarithm. Every equation type has a unique equation. They are much complicated.

In this section, two components were calculated known as β_T and β_g.

Calculating β_T and β_g

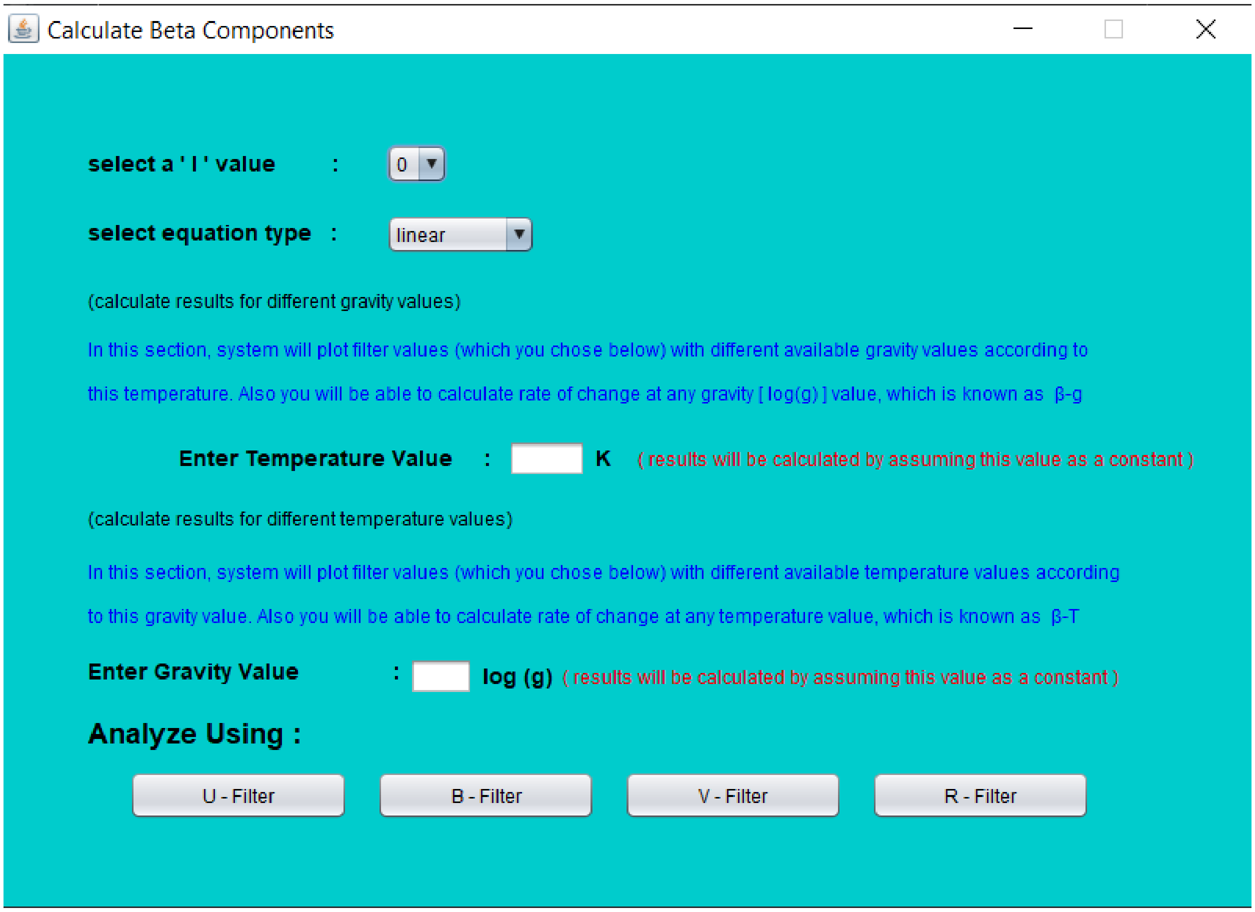
When calculating α components, data were extracted from those websites displayed in Figure 06. But, to calculate β components there is another website which contains temperature, gravity and μ values. Then a text file was created by downloading those data. When the software is installed, the file will also be saved to the computer.

To calculate β_T and β_g another window was developed as shown in the figure 14 by writing a script.

β_T and β_g is given by the following equation.

$$\beta_T = \frac{\partial(\ln b)}{\partial(\ln T)} \quad , \quad \beta_g = \frac{\partial(\ln b)}{\partial(\ln g)}$$

Where T is the temperature, g is the gravity.



select a ' l ' value : 0

select equation type : linear

(calculate results for different gravity values)

In this section, system will plot filter values (which you chose below) with different available gravity values according to this temperature. Also you will be able to calculate rate of change at any gravity [log(g)] value, which is known as β-g

Enter Temperature Value : K (results will be calculated by assuming this value as a constant)

(calculate results for different temperature values)

In this section, system will plot filter values (which you chose below) with different available temperature values according to this gravity value. Also you will be able to calculate rate of change at any temperature value, which is known as β-T

Enter Gravity Value : log (g) (results will be calculated by assuming this value as a constant)

Analyze Using :

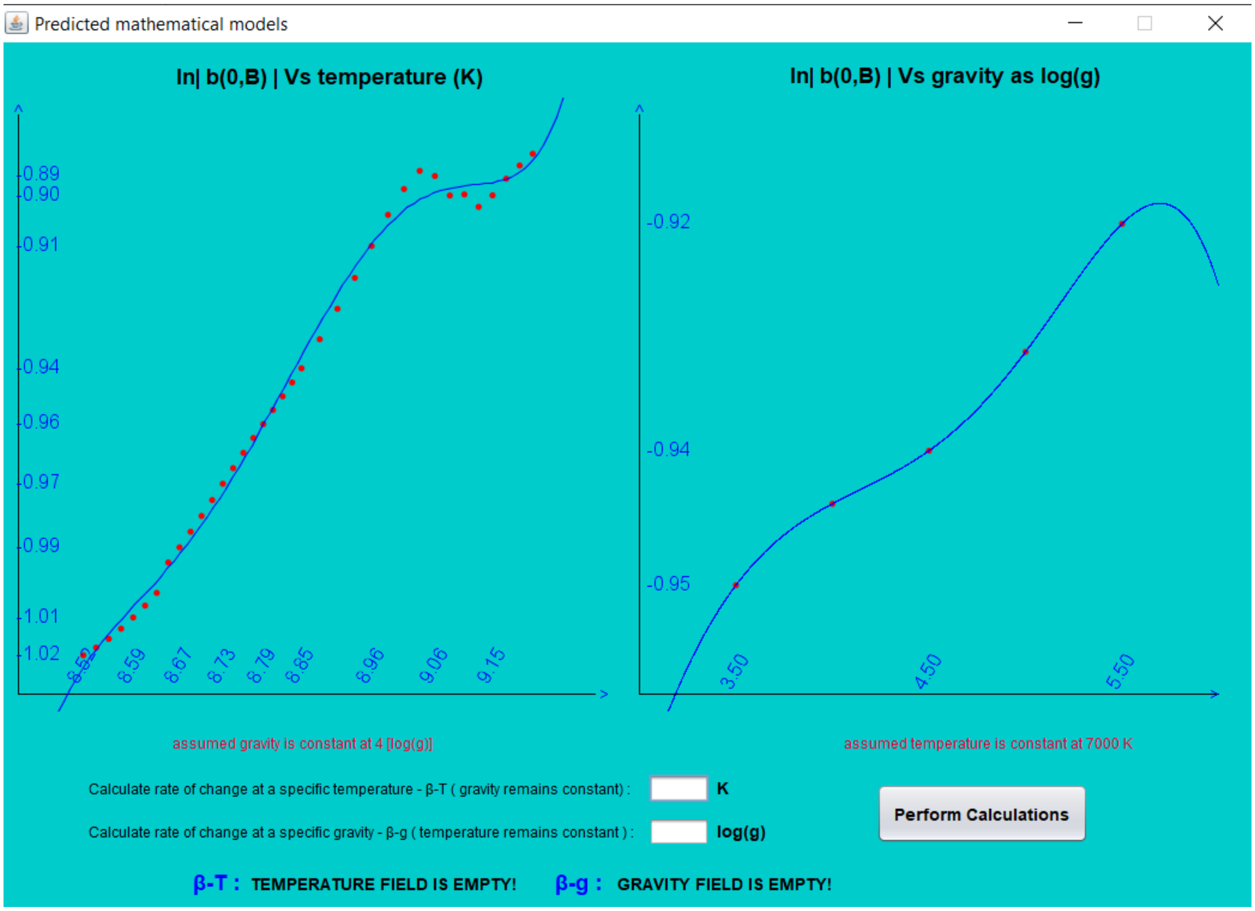
Figure 14 – calculating β components (user interface)

In this interface user need to select the spherical degree value and the equation type which they need to use. Hence calculations were done according to their selections by using above equation. Before that, they need to enter the temperature which should keep as a constant to calculate β_g and the next section the gravity value which should keep as a constant to calculate β_T value.

After entering these value data were extracted from the table which was saved earlier according to the filter that was selected by the user. Then the equation was applied according to the equation type selected by the user (linear, quadratic etc.) and the natural log of the limb darkening integral was taken according to the filter. In this case software do not asking to enter temperature and gravity values because, it will obtain all the available temperature and gravity values in the text file to do the calculations. According to the equation β values are the rate of changes of natural log values with respect to the natural log values of temperature or gravity values. Then the results were displayed by using another window.

Displaying Results

Results displaying window was created by writing another program as shown in the figure 15. In this window both graphs are shown which will used to calculate both β_T and β_g values. Because β_T is the rate of change of the graph between natural log of limb darkening integral and the natural log of temperature values that were selected from the saved text file. Similarly, β_g is the rate of change of the graph between natural log of limb darkening integral and the natural log of gravity values that were selected from the saved text file.



Calculate rate of change at a specific temperature - β-T (gravity remains constant) : K

Calculate rate of change at a specific gravity - β-g (temperature remains constant) : log(g)

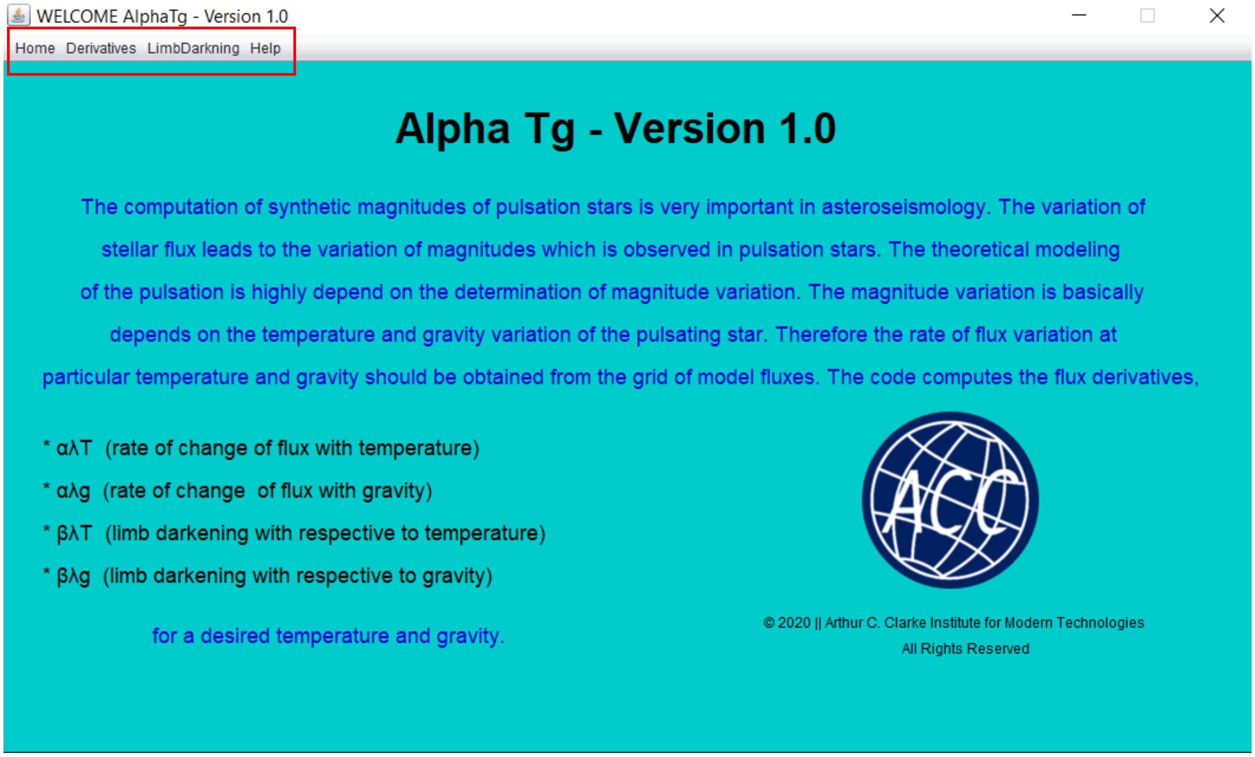
β-T : TEMPERATURE FIELD IS EMPTY! **β-g :** GRAVITY FIELD IS EMPTY!

Figure 15 – Results displaying window (*l = 0, eq*^{n} *type = linear, filter = B)*

After obtaining this window program was developed in such a way that allows users to enter the specific temperature and gravity value to calculate rate of change as they need. In this scenario also red dots represent the data which was obtained from the text file and blue curve represents the predicted mathematical model which suits best with these data points. After user entering the specific temperature and gravity value to calculate β components and pressing perform calculation button, program will automatically do the rest and quickly displays the results.

Finalizing Work

Up to now all the calculation parts were done. Next step was to finalize these windows/ sections together by creating another window as shown in the figure 16. Then a menu was added so that users can easily select the window that they need to use.



Alpha Tg - Version 1.0

The computation of synthetic magnitudes of pulsation stars is very important in asteroseismology. The variation of stellar flux leads to the variation of magnitudes which is observed in pulsation stars. The theoretical modeling of the pulsation is highly depend on the determination of magnitude variation. The magnitude variation is basically depends on the temperature and gravity variation of the pulsating star. Therefore the rate of flux variation at particular temperature and gravity should be obtained from the grid of model fluxes. The code computes the flux derivatives,

* αλT (rate of change of flux with temperature)
* αλg (rate of change of flux with gravity)
* βλT (limb darkening with respective to temperature)
* βλg (limb darkening with respective to gravity)

for a desired temperature and gravity.

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Figure 16 – Main Screen (User Interface)

As displayed by using the red box in the figure 16, the menu was added at the top of the screen. Then a small description was added by showing the usage of the software. Also, a help tab was added to the menu that contains every single technical support which requires to handle the software. By now whole system has finished developing and ready to use!

Gantt Chart

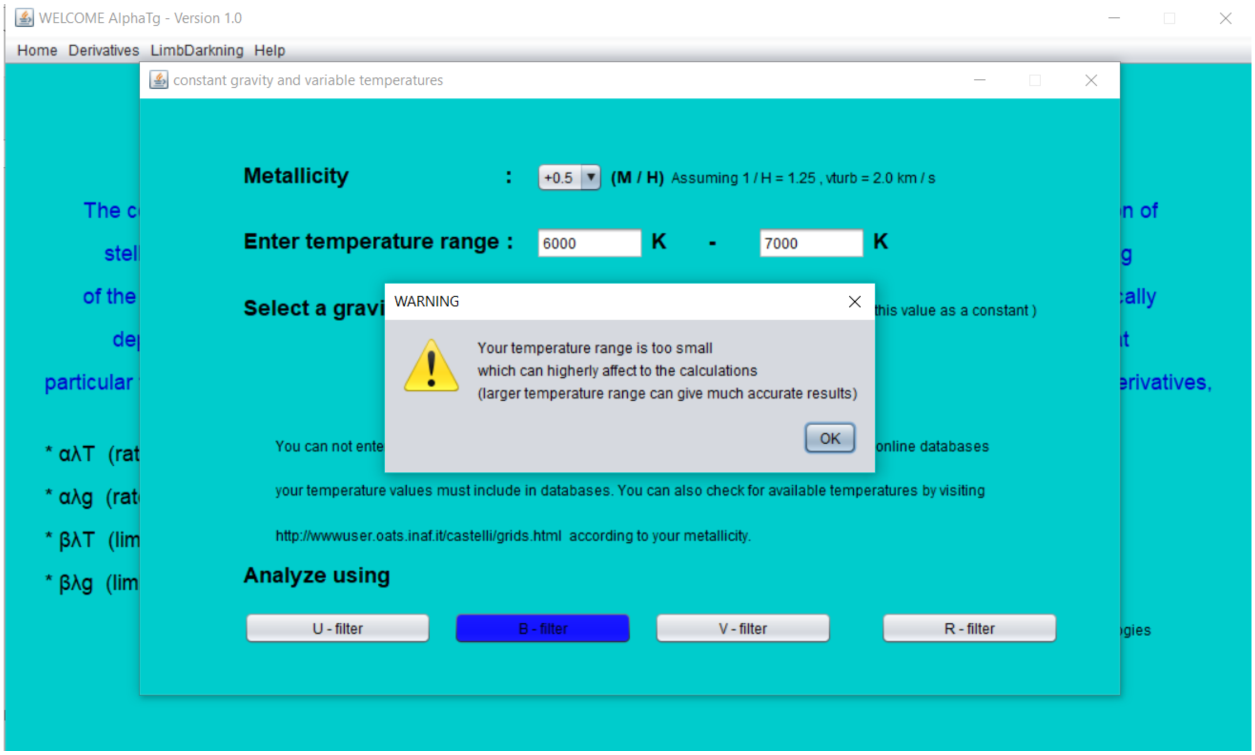
Week Work	1	2	3	4	5	6	7	8	9	10	11	12
Studying Theory concepts	■											
Creating data extracting method		■										
Creating polynomial regression method			■									
Creating α_T window			■	■								
Creating α_g window				■	■							
Creating β component window						■						
Creating welcome screen (main screen)							■					
Finalizing software and fixing errors			■		■	■		■	■			
Writing the journal paper to publish the project										■	■	■

Results and Discussion

Final result of the entire project was an automated software application which simply returns the necessary requirements as what need. The main objectives, which lead to do this project is fully completed. By creating the automated system, the main objective was completed which was to minimized time waste that could occur while doing huge calculation. This application can return the results in a time which is less than one minute even user wanted the hardest calculation to do. That was the main thing.

Next thing was the accuracy of the results. The software can return predicted values that accurate up to 15th decimal point. Also, the predicted mathematical models can return up to 9th order fitting polynomials which is much accurate. Almost every data point was covered by the mathematical model and that is the expected goal.

It is not just displaying the result. When the user selected temperature range or gravity range is too small it can highly affect to the calculation. Because when the number of data points is large error is minimized. In order to do that if the selected range is too small program will display a warning message by saying that as you can see in the figure 17.



Metallicity : +0.5 **(M / H)** Assuming 1 / H = 1.25 , vturb = 2.0 km / s

Enter temperature range : 6000 **K** - 7000 **K**

Select a gravi … this value as a constant)

Your temperature range is too small
which can higherly affect to the calculations
(larger temperature range can give much accurate results)

You can not ente … online databases

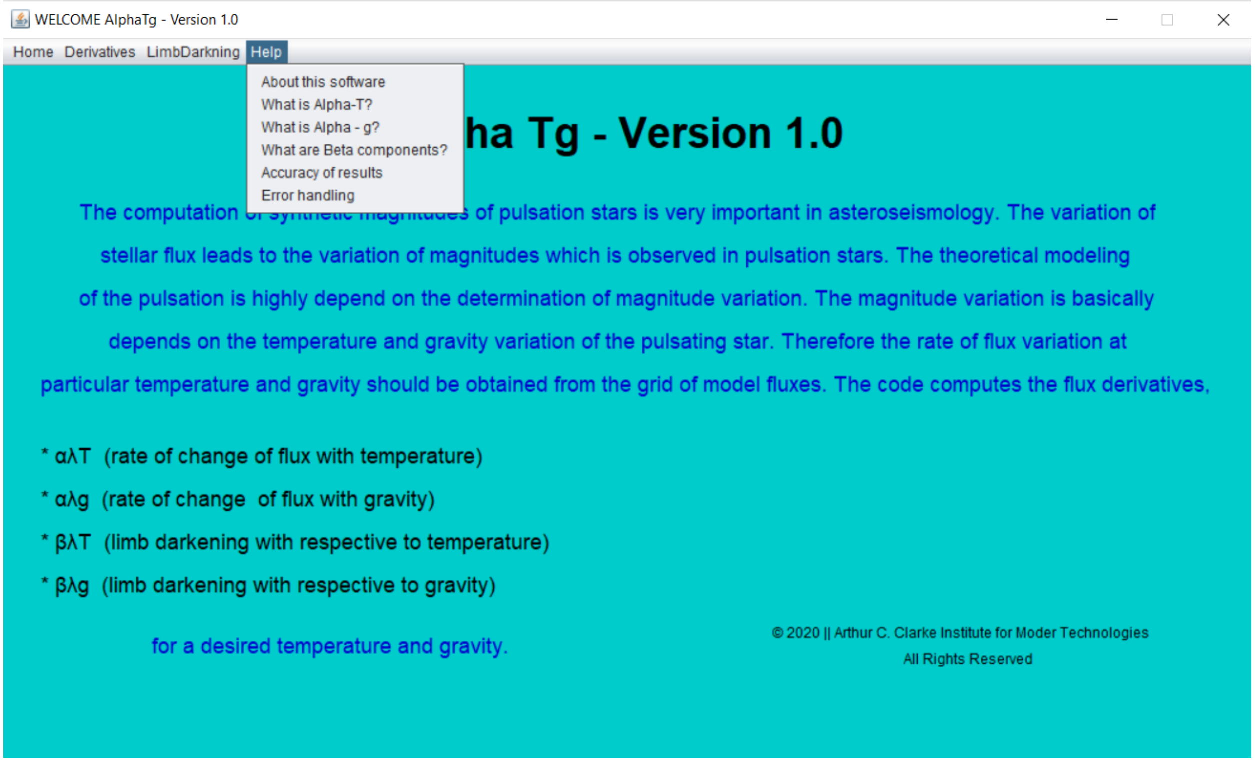
your temperature values must include in databases. You can also check for available temperatures by visiting

http://wwwuser.oats.inaf.it/castelli/grids.html according to your metallicity.

Analyze using

Figure 17 – Low number of data points warning

If the user does not know about the theory concept or the way how to use the software that will not be a problem. A detailed help section was added to the main menu as you can see in the figure 18. It explains every single part of the software application as well as the theory.



ha Tg - Version 1.0

The computation of synthetic magnitudes of pulsation stars is very important in asteroseismology. The variation of stellar flux leads to the variation of magnitudes which is observed in pulsation stars. The theoretical modeling of the pulsation is highly depend on the determination of magnitude variation. The magnitude variation is basically depends on the temperature and gravity variation of the pulsating star. Therefore the rate of flux variation at particular temperature and gravity should be obtained from the grid of model fluxes. The code computes the flux derivatives,

* αλT (rate of change of flux with temperature)
* αλg (rate of change of flux with gravity)
* βλT (limb darkening with respective to temperature)
* βλg (limb darkening with respective to gravity)

for a desired temperature and gravity.

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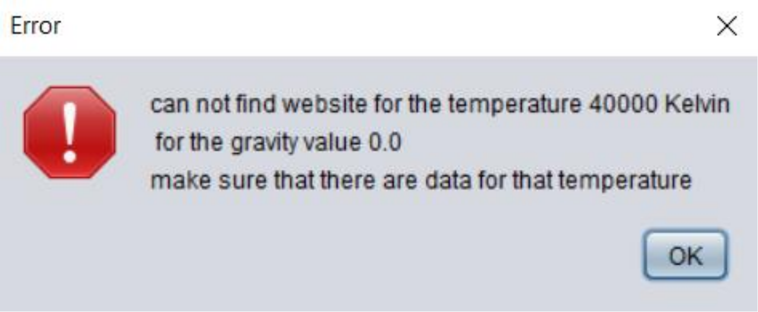
Figure 18 – Help Menu

Furthermore, it was developed with user friendly error handling system. Rather than saying “just an error occurred” it can display the error and where the error occurred. Then user can easily correct the error and can carry on the calculation. Additionally, the data are extracted from the online databases an active internet connection is required in order to run this program.

We are hoping to add this software on to the official website of the Arthur C. Clarke Institute for Modern Technologies, then anyone who interest in asteroseismology can use it. Already we have received some international request to access this software and hope this will helpful for everyone who is going to use.



can not find website for the temperature 40000 Kelvin
for the gravity value 0.0
make sure that there are data for that temperature

Figure 19 – Displaying an error

Conclusion

- Amplitude ratio method is one of the best methods to study the internal structure of a variable star. But the amplitude depends on the different factors, mainly on the gravity and the temperature of the star. Even the brightness at the edge of a star also depends on the temperature and gravity.
- Computing theoretical amplitudes are very complex and time consuming.
- This software gives one of the best solutions to minimize the time waste.

Feedback

When the mathematical models are created in order to fit the data points to predict α and β components, knowledge obtained in computational physics course unit was much useful. That knowledge helped me to resolve some problems such as which order polynomial should take, and how to fit a polynomial to a function and whether the selected polynomial is the right one or not etc.

When the limb darkening integrals are calculated knowledge obtained in mathematical physics – II course unit was much useful. It helped me to take decisions such as, how to define spherical coordinates and how to take the integral all over the star which has a spherical surface etc.

Additionally, the programming knowledge and mathematical theories were very useful which I have learned within first two years in the university in order to do calculations and to create the software application.

With the help of these all theories and knowledge it was much easier to complete the task successfully within the given time period.

Summary

Asteroseismology is an unprecedent way of probing the stellar interior. Among the methods of mode identification, the amplitude ratio method i.e. the comparison of observed amplitudes of UBVR color bands with the theoretical amplitudes is widely used. Since there are millions of data to process, the problem is the computation of theoretical amplitudes very complex and time consuming. To overcome these difficulties a project was designed to create an automated system which could easily return the theoretical amplitudes. Then the task was successfully completed by creating a user-friendly software application which includes calculating, mathematical modeling and also error handling. Software allows to calculate theoretical amplitudes at any given temperature value or gravity value. Then the software was tested by using data which is already known. Results were positive and they are accurate up to 15th decimal point. Then the software was released among some people and currently hoping to release it internationally.

References

- Database – temperature and gravity grids

  http://wwwuser.oats.inaf.it/castelli/grids/gridp00k2odfnew/fp00k2tab.html
- Limb Darkening integral coefficients

  https://www.aanda.org/articles/aa/full/2003/47/aa4065/table6.html
- OLS Regression Method

  https://statisticsbyjim.com/regression/ols-linear-regression-assumptions/

Appendix

Amplitude Equation

The most general expression for the magnitude variation, $m\lambda$, at wavelength λ for a star pulsating with spherical harmonic degree, l, and angular frequency of pulsation, ω, with angle of inclination, i, is given by;

$$\Delta m_{\lambda} = A_0 P_{lm} (\cos i)\, bl_{\lambda} (T_1 + T_2 + T_3)\, e^{i\omega t}$$

Where,

$T_1 = (1 - l)\,(l + 2)$

$T_2 = f_T\,(\alpha_{T\lambda} + \beta_{T\lambda})\, e^{-i\psi T}$

$T_3 = -f_g\,(\alpha_{g\lambda} + \beta_{g\lambda})$

where P_{lm} is the associated Legendre function of degree l and azimuthal number m, A0 is related to the amplitude of oscillations of the photosphere, and i is the inclination angle between the stellar axis and the direction towards the observer. The component T_1 is the contribution of the magnitude variation due to the different pulsation modes. T_2 is the temperature dependent component of the magnitude which consists of f_T, the amplitude of temperature variation function relative to the normalized radial displacement at the photosphere and ψ_T, the phase difference between maximum temperature and maximum radial displacement.

Legendre Polynomials

If the Legendre Polynomial is $P_l(x)$

l value	polynomial
0	1
1	x
2	$(1/2) * (3x^2 - 1)$

UBVR Wavelengths and Normalizing Factors

(Each Table 1st column – wavelength, 2nd column – normalizing factor)

U filter:

299	-0.000669696
301	-0.001681827
303	-0.000375763
305	-0.00011534
307	0.001013109
309	0.000417459
311	0.006783938
313	0.038829271
315	0.156836003
317	0.473890275
319	1.149823904
321	2.334327698
323	4.155767918
325	6.623749256
327	9.731628418
329	13.30919456
331	17.29029274
333	21.48851585
335	25.75052452
337	29.99902916
339	34.11233902

341	37.94564438
343	41.55776978
345	44.86132431
347	47.92475128
349	50.7262001
351	53.1930809
353	55.42895126
355	57.35425949
357	59.07337189
359	60.49622345
361	61.73461533
363	62.70090866
365	63.40652084
367	63.86858368
369	64.07866669
371	63.94550705
373	63.44900131
375	62.55573654
377	61.19347382
379	59.30774307
381	56.81710815
383	53.6580925
385	49.89732361
387	45.50691223
389	40.58543015
391	35.23839569
393	29.71320152
395	24.24505234
397	19.07090569
399	14.45932579
401	10.51132298
403	7.342841625
405	4.922122955
407	3.178602457
409	1.970628142
411	1.18116641
413	0.679432094
415	0.382284015
417	0.209411562
419	0.112746552
421	0.05965177
423	0.031105801
425	0.015592914
427	0.008662422
429	0.003692987

431	0.002511696

B filter:

351	0.001189998
353	0.001959546
355	0.001335922
357	0.001544407
359	0.002317364
361	0.000944031
363	0.002325911
365	0.001689855
367	0.000339572
369	0.001767187
371	0.002168936
373	0.004561498
375	0.044999443
377	0.452859193
379	2.973155975
381	11.44234085
383	26.31748962
385	42.45031738
387	54.7177124
389	62.59383011
391	67.44042969
393	70.46337891
395	72.50675201
397	74.02620697
399	75.2188797
401	76.1701889
403	76.92060089
405	77.59502411
407	78.11906433
409	78.53395081
411	78.87051392
413	79.10342407
415	79.28269196
417	79.45341492
419	79.64757538
421	79.69796753
423	79.67707062
425	79.50920105
427	79.33563232

429	79.13903809
431	78.91230011
433	78.61769104
435	78.26279449
437	77.87546539
439	77.53175354
441	77.14750671
443	76.65423584
445	76.05338287
447	75.35453796
449	74.52497864
451	73.6526413
453	72.78461456
455	71.91506958
457	70.91161346
459	69.69960785
461	68.32331085
463	66.74669647
465	64.88441467
467	62.66930771
469	60.14781189
471	57.41687012
473	54.57733154
475	51.64573288
477	48.63081741
479	45.56961441
481	42.38645554
483	39.20676041
485	36.0572052
487	33.01993561
489	30.17393875
491	27.54945374
493	25.16630363
495	23.0478096
497	21.1842308
499	19.4687748
501	17.74962616
503	15.90761375
505	13.98432541
507	12.15857983
509	10.52681637
511	9.150234222
513	7.952643871
515	6.864009857
517	5.85759449

519	4.932483196
521	4.107953072
523	3.388067007
525	2.776194096
527	2.277125835
529	1.888394713
531	1.592131138
533	1.377410769
535	1.225167155
537	1.121748567
539	1.056008935

V filter:

463	0.006034468
465	0.007889393
467	0.010544402
469	0.017186783
471	0.031421557
473	0.059841137
475	0.122275144
477	0.261935234
479	0.578332484
481	1.307706118
483	2.872772217
485	5.919353485
487	11.14160156
489	18.89259338
491	28.77396965
493	39.77479172
495	50.73743439
497	60.68194962
499	69.21595001
501	75.99686432
503	81.2434845
505	85.16732788
507	88.03078461
509	90.10810089
511	91.5404129
513	92.57933807
515	93.25953674
517	93.69736481
519	93.93641663

521	94.10150146
523	94.09174347
525	93.98947144
527	93.84949493
529	93.63430023
531	93.38285828
533	93.021698
535	92.64871979
537	92.18958282
539	91.69980621
541	91.12490082
543	90.49147034
545	89.78933716
547	89.08204651
549	88.26218414
551	87.37770081
553	86.43718719
555	85.42190552
557	84.34403992
559	83.21211243
561	82.00279236
563	80.69631195
565	79.34845734
567	77.88956451
569	76.37065887
571	74.80906677
573	73.19715881
575	71.46160126
577	69.68399048
579	67.83309174
581	65.99272156
583	64.01839447
585	62.03679276
587	60.01616287
589	57.93376541
591	55.81464767
593	53.72424698
595	51.54794312
597	49.39841843
599	47.22030258
601	45.10167313
603	42.91197205
605	40.79430771
607	38.65452576
609	36.56022644

611	34.47874832
613	32.44970322
615	30.46535492
617	28.53107071
619	26.6454277
621	24.82754326
623	23.07086372
625	21.39551544
627	19.77576256
629	18.23073387
631	16.74389458
633	15.3572607
635	14.04292583
637	12.81057549
639	11.63498116

R filter:

521	0.002944848
523	0.002089794
525	0.003371919
527	0.005084066
529	0.008155693
531	0.008314351
533	0.015071834
535	0.022898281
537	0.036960699
539	0.067224726
541	0.120258078
543	0.22050184
545	0.402524889
547	0.726718903
549	1.293524623
551	2.235859156
553	3.738025904
555	6.007618904
557	9.232580185
559	13.57418156
561	19.00156403
563	25.50657463
565	32.62343597
567	40.21298981
569	47.59418106

571	54.32490158
573	60.39918518
575	65.64186096
577	69.91790771
579	73.34972382
581	76.03323364
583	78.06031036
585	79.51274872
587	80.58981323
589	81.29089355
591	81.69754791
593	81.91542053
595	81.95018005
597	81.82957458
599	81.59781647
601	81.33335876
603	80.92240906
605	80.49958038
607	79.99421692
609	79.46527863
611	78.88967133
613	78.2405014
615	77.59609222
617	76.90136719
619	76.17784882
621	75.41682434
623	74.64862061
625	73.8398056
627	73.02371216
629	72.16812134
631	71.29589844
633	70.42154694
635	69.5294342
637	68.64337158
639	67.71125793
641	66.79827881
643	65.86396027
645	64.92672729
647	63.96414566
649	62.99859238
651	62.03138733
653	61.04286957
655	60.07561111
657	59.11544418
659	58.12862396

661	57.15373611
663	56.13951111
665	55.15139771
667	54.15691757
669	53.15185165
671	52.14332199
673	51.12384415
675	50.07619095
677	49.00761032
679	47.93523407
681	46.8348999
683	45.75318909
685	44.63775635
687	43.55319595
689	42.45966339
691	41.37291336
693	40.27168655
695	39.19721985
697	38.11877441
699	37.07518768
701	36.02098465
703	34.98455429
705	33.95766068
707	32.95179749
709	31.95403481
711	30.99447823
713	30.01971626
715	29.07637596
717	28.13087082
719	27.22860336
721	26.3301754
723	25.46568489
725	24.59818649
727	23.7460537
729	22.90930748
731	22.11213303
733	21.31085587
735	20.53005981
737	19.75452805
739	19.00649261
741	18.28031158
743	17.5661602
745	16.87119675
747	16.18872833
749	15.51856232

751	14.87565899
753	14.23876286
755	13.62880516
757	13.03202057
759	12.45641041
761	11.88848495
763	11.34821129
765	10.81669521
767	10.31607437
769	9.822717667
771	9.352499962
773	8.896583557
775	8.463427544
777	8.033233643
779	7.632407665
781	7.241755009
783	6.872023582
785	6.509381294
787	6.172382832
789	5.844631195
791	5.529330254
793	5.22914505
795	4.94959259