science_age_and_distance

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1 Calculating Age and Distance of NGC3201 using Isochrones

1.1 Science!

Written by Maria Funcich

[1]:
```python
import os
import numpy
import matplotlib.pyplot as plt
from matplotlib.colors import LogNorm
```

1.2 HR Diagrams

1.2.1 ⋆ Collecting the data set of magnitudes for each filter

[2]:
```python
cwd = os.getcwd()                          # saving current directory
os.chdir("../060_find_magnitudes/data")    # changing directory

file = open("magnitudes.csv", "r")         # opening the file (.csv) with all␣
 ↪the calculated magnitudes

# reading lines of the document
lines = file.readlines()[1:]               # skipping the first line as it␣
 ↪contains the heading (string)
lines_ = []
B = []                                     # creating empty arrays for each␣
 ↪filter
V = []
R = []
I = []

for i in lines:
    lines_.append(i.strip())               # removing '\n'

# note to self: data is represented as string
for x in lines_:
```

```
    B.append((x.split(',')[2]))            # adding all B magnitude data to␣
 ↪array 'B'...
    V.append((x.split(',')[3]))
    R.append((x.split(',')[4]))
    I.append((x.split(',')[5]))

file.close()                               # close magnitudes.csv
os.chdir(cwd)                              # returning to the defined current␣
 ↪directory
```

1.2.2 ⋆ Plotting HR diagram

[3]:
```
B_mag = []
V_mag = []

# removing rows that are empty (no magnitude for specific filter)
val = 0
for idx, a in enumerate(V):
    if V[idx] != '' and B[idx] != '':       # a null value is given by an empty␣
 ↪string... therefore ignore ''
        B_mag.append(float(B[idx]))         # append the magnitude as a float␣
 ↪value if both B and V mags are present
        V_mag.append(float(V[idx]))
        val = idx

# checking that it works and has only removed the necessary columns for both␣
 ↪specified mags
#print(B_mag)
#print(V_mag)
#print(len(B_mag))
#print(len(V_mag))

BV = numpy.array(B_mag)-numpy.array(V_mag)  # colour: B minus V mags

# plotting HR
plt.rcParams['figure.figsize'] = [14, 10]   # define plot size

plt.axis([-0.7, 3, 20.5, 11])                 # axes ranges
plt.scatter(BV, V_mag)                      # scatter plot

ax = plt.gca()
ax.scatter(BV, V_mag, color = "b")

# axis labels
plt.rcParams.update({'font.size':14 })
```

```
plt.xlabel('B-V colour')
plt.ylabel('Absolute V-band Magnitude ')
plt.title('NGC3201')
plt.grid(True)

plt.show()
```

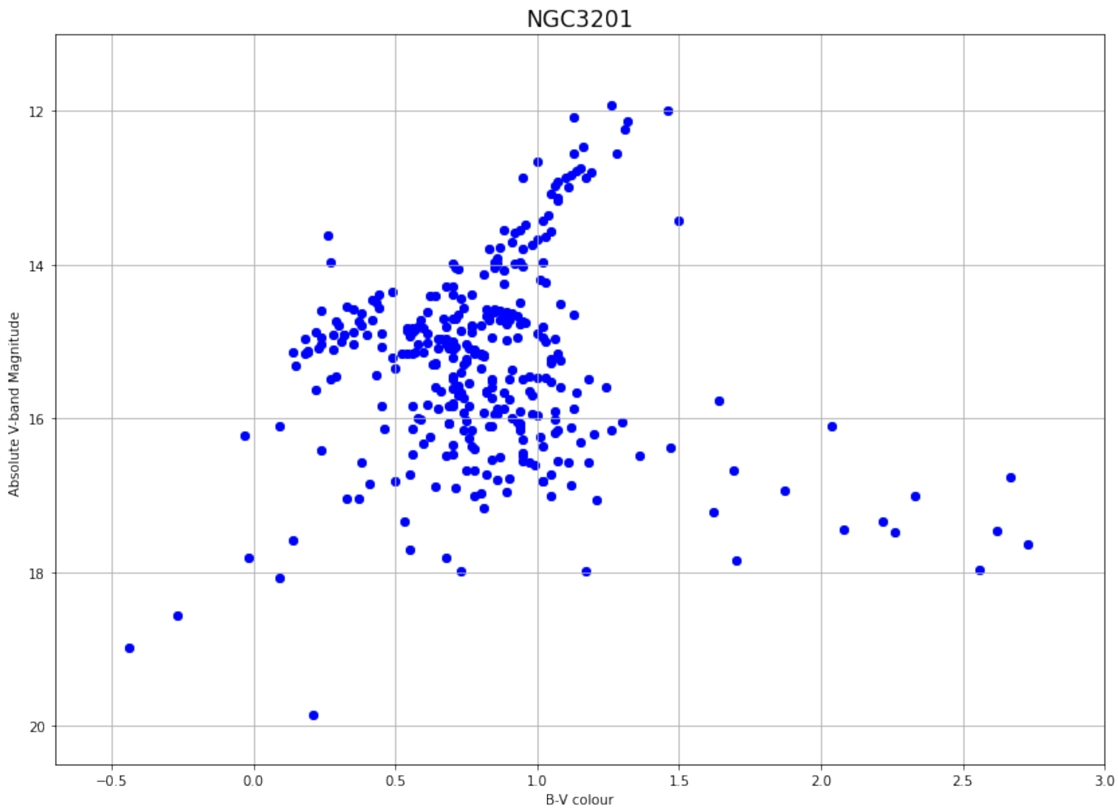


Figure 1. HR Diagram of NGC3201: is absent of a mainsequence, this is likely due to the fact that the faint stars weren't picked up - We can see that there's a red giant branch, this works to our advantage as we can fit red giant isochrones to this.

1.2.3 ⋆ Creating function for magnitudes

[4]:
```
# function collects magnitudes for a pair of specific bands and only appends␣
 ↪when magnitude is available for both
## 2 arguments --> band1: is minused from band2
##              --> band2: the band plotted on the y-axis

def magnitudes(band1, band2):
    band1_mag = []
```

```
    band2_mag = []

    val = 0
    for idx, a in enumerate(band1):
        if band1[idx] != '' and band2[idx] != '':
            band1_mag.append(float(band1[idx]))
            band2_mag.append(float(band2[idx]))
            val = idx

        colour = numpy.array(band1_mag) - numpy.array(band2_mag)

    return band2_mag, colour
```

[5]:

```
# function creates colour magnitude diagrams (HR diagrams)
## 8 arguments --> band1: is minused from band2
##             --> band2: the band plotted on the y-axis
##             --> sb1, sb2: strings of the name band1 and band2... couldn't␣
↪figure out how to implement the letter into a string :/
##             --> x_min, x_max, y_min, y_max: axis scaling

def plot(band1, band2, sb1, sb2, x_min, x_max, y_min, y_max):
    mag = magnitudes(band1,band2)
    colour = mag[1]
    band2_mag = mag[0]

    # define plot size
    plt.rcParams['figure.figsize'] = [13, 10]

    plt.axis([x_min, x_max, y_min, y_max])              # Axes ranges
    plt.scatter(colour, band2_mag, color = 'b')            # Scatter plot

    #ax = plt.gca()
    #ax.scatter(colour, band2_mag, color = "b")

    # axis labels
    plt.rcParams.update({'font.size':14 })
    plt.xlabel('{}-{} colour'.format(sb1,sb2))
    plt.ylabel('Absolute {}-band Magnitude'.format(sb2))
    plt.grid(True)

    #plt.show()
```

1.2.4 ⋆ Plotting HR Diagrams using different bands

[6]:
```
#plot(B,V,"B","V",-0.7, 3, 20.5, 11)
```

[7]:
```
plot(B,I,"B","I",-0.5, 3.8, 18.1, 9.5)
```

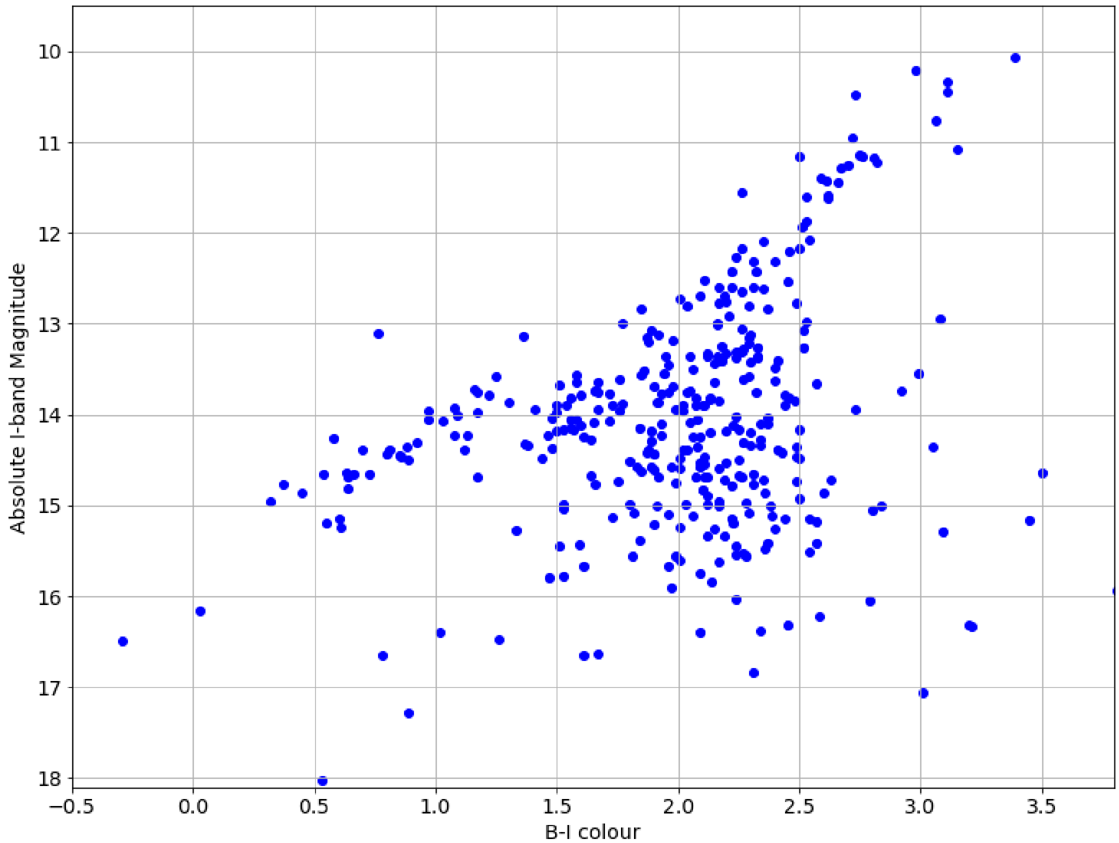


Figure 2: Absolute I-band magnitude as a function of (B-I) colour

[8]:
```
plot(B,R,"B","R",-0.5, 3.6, 19, 10.5)
```

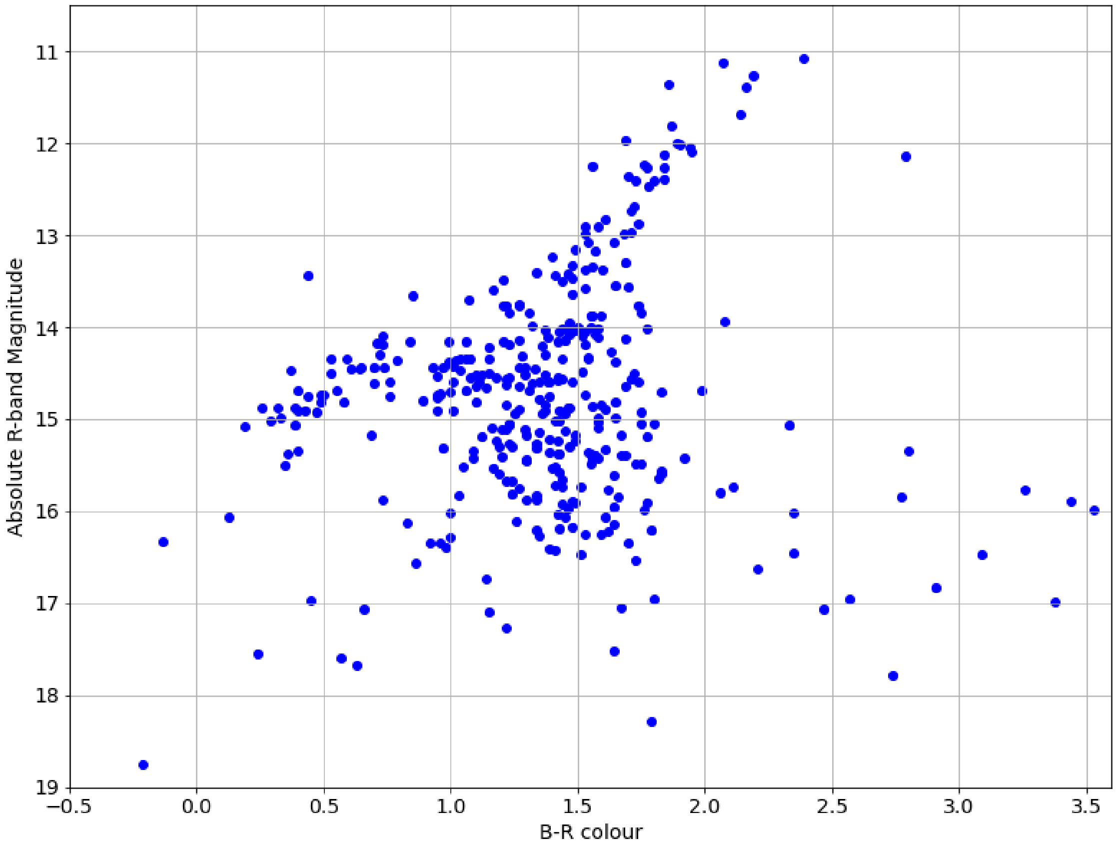


Figure 3: Absolute R-band magnitude as a function of (B-R) colour

[9]:
```
plot(V,R,"V","R",-0.5, 3, 20.5, 10.5)
```

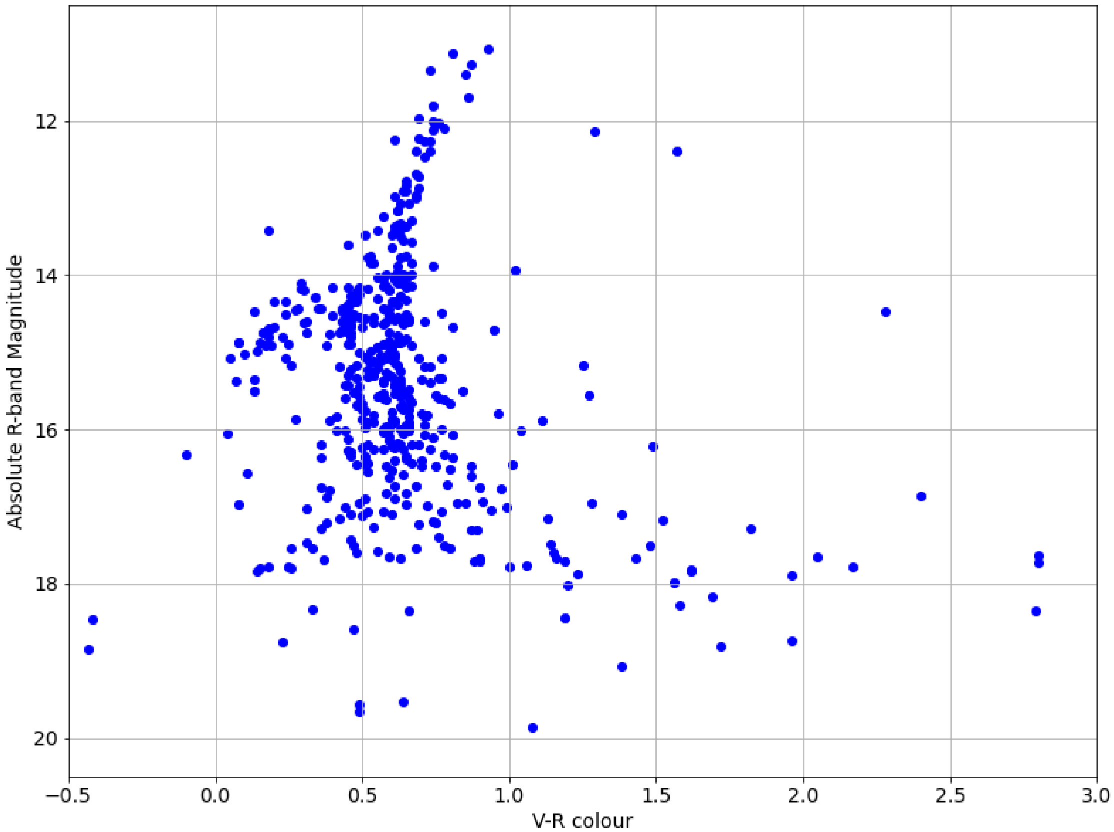


Figure 4: Absolute R-band magnitude as a function of (V-R) colour

[10]:
```
plot(V,I,"V","I",-0.5, 3.4, 20.5, 9.5)
```

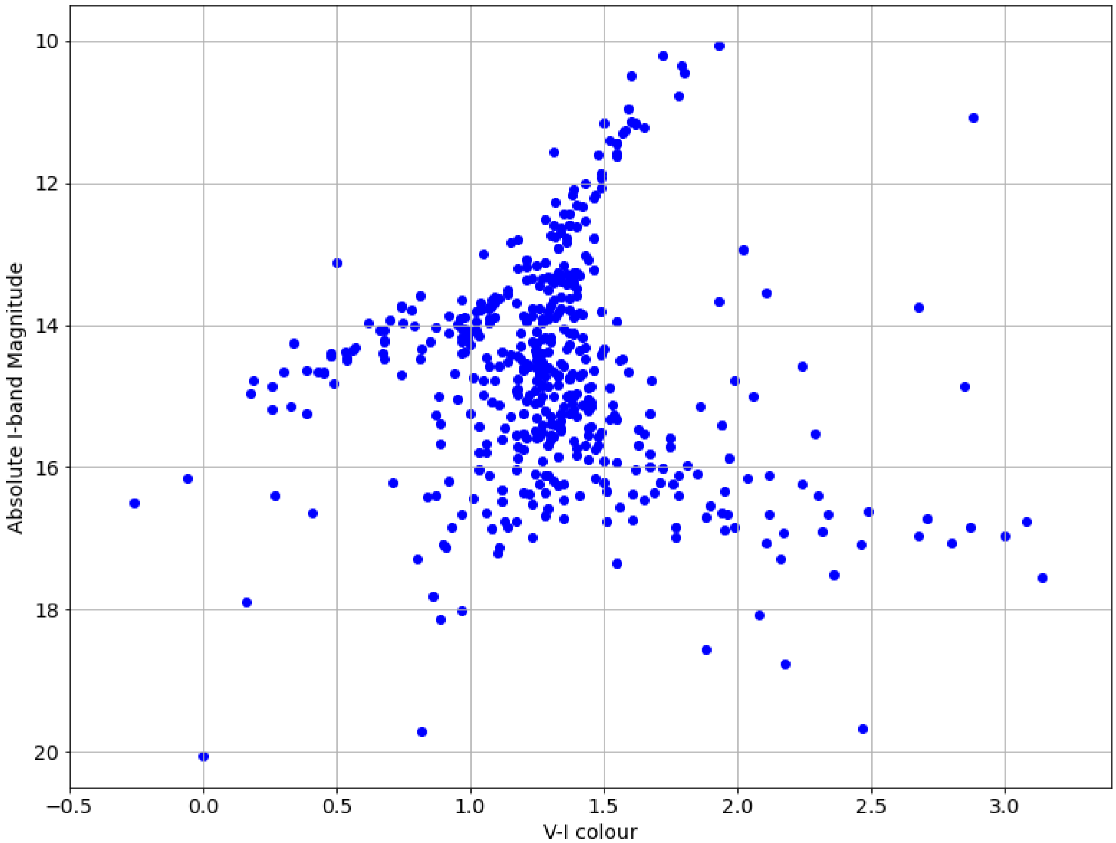


Figure 5: Absolute I-band magnitude as a function of (V-I) colour

1.3 Giradi Isochrones

[11]:
```
# function collects B and V magnitudes of the isochrone
## 1 argument --> file_name: the file name of the isochrone

def isochrone(file_name):
    os.chdir("giradi isochrones")
    fname = file_name

    f = open(fname,"r")
    lines = f.readlines()
    Bi = []
    Vi = []
    for x in lines:
        if x[0]!='#':
            Bi.append(float(x.split()[26]))
            Vi.append(float(x.split()[27]))
    f.close()
```

```
    os.chdir(cwd)

    BVi = numpy.array(Bi)-numpy.array(Vi)

    #print(B1)
    #print(V1)

    return Vi, BVi, Bi
```

1.3.1 ⋆ Plotting an isochrone

Generating a Girardi isochrone for specific ages using: http://stev.oapd.inaf.it/cgi-bin/cmd

Layden et al. gives an estimate of ~13Gyrs, therefore will use this value to approximate a model isochrone to calculate distance. Also using metallicity of [F/H] = -1.53 as given by Layden as well.

[12]:
```
iso = isochrone('13Gyr.txt')

plt.rcParams['figure.figsize'] = [15, 15] # define plot size
plt.axis([0.25, 2, 10, -3.20])            # axes ranges

ax = plt.gca()
ax.scatter(iso[1], iso[0], color = "r", label = "13.0 Gyr")

# axis labels
plt.rcParams.update({'font.size':14 })
plt.xlabel('B-V colour')
plt.ylabel('Absolute V-band Magnitude ')
plt.title('Giradri Isochrone')
plt.legend(loc='lower right');
plt.grid(True)

plt.show()
```

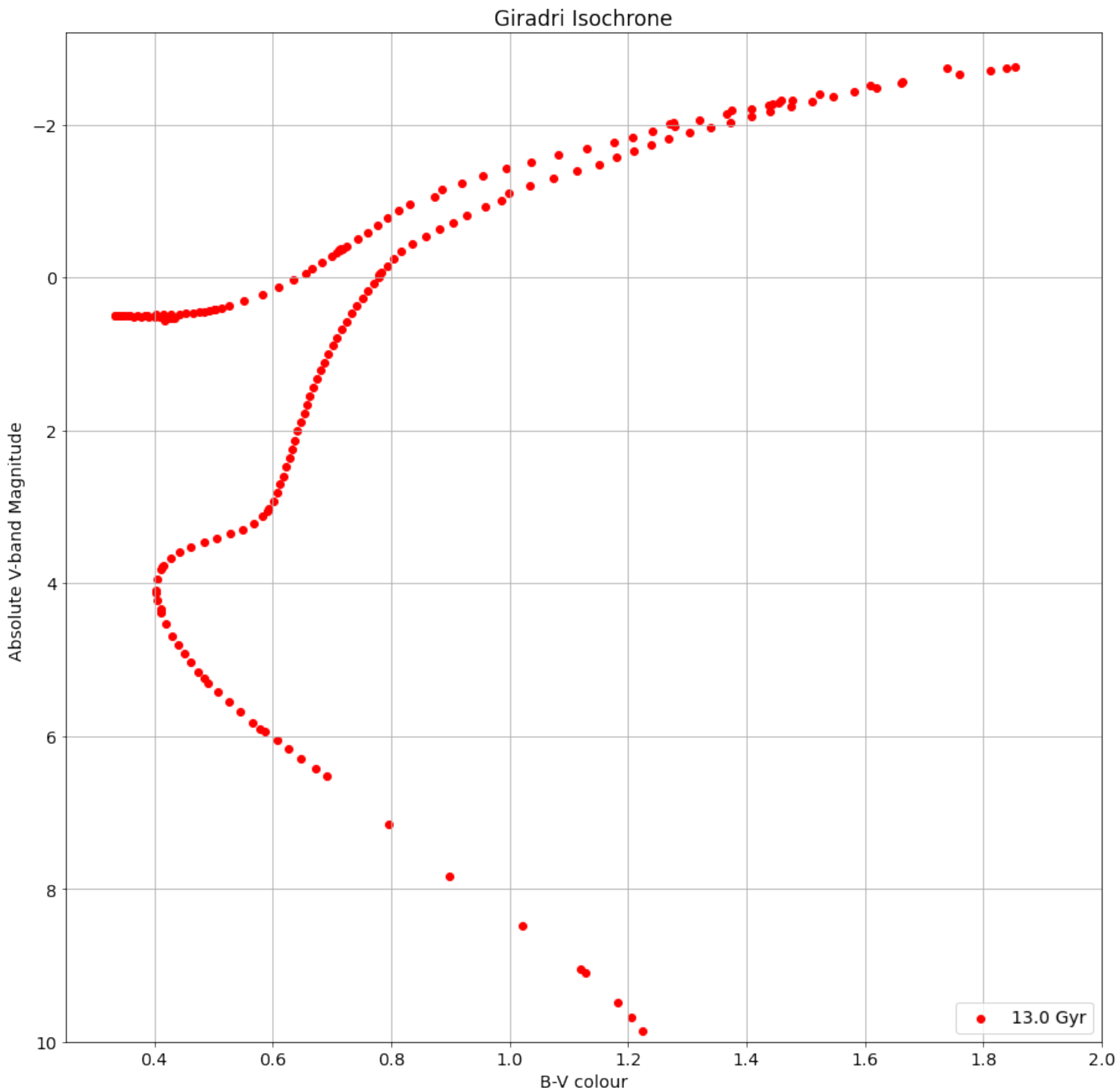


Figure 6: Giradi isochrone with a metallicity of [F/H] = -1.53 (Layden et al. 2003) and an age of ~13Gyr

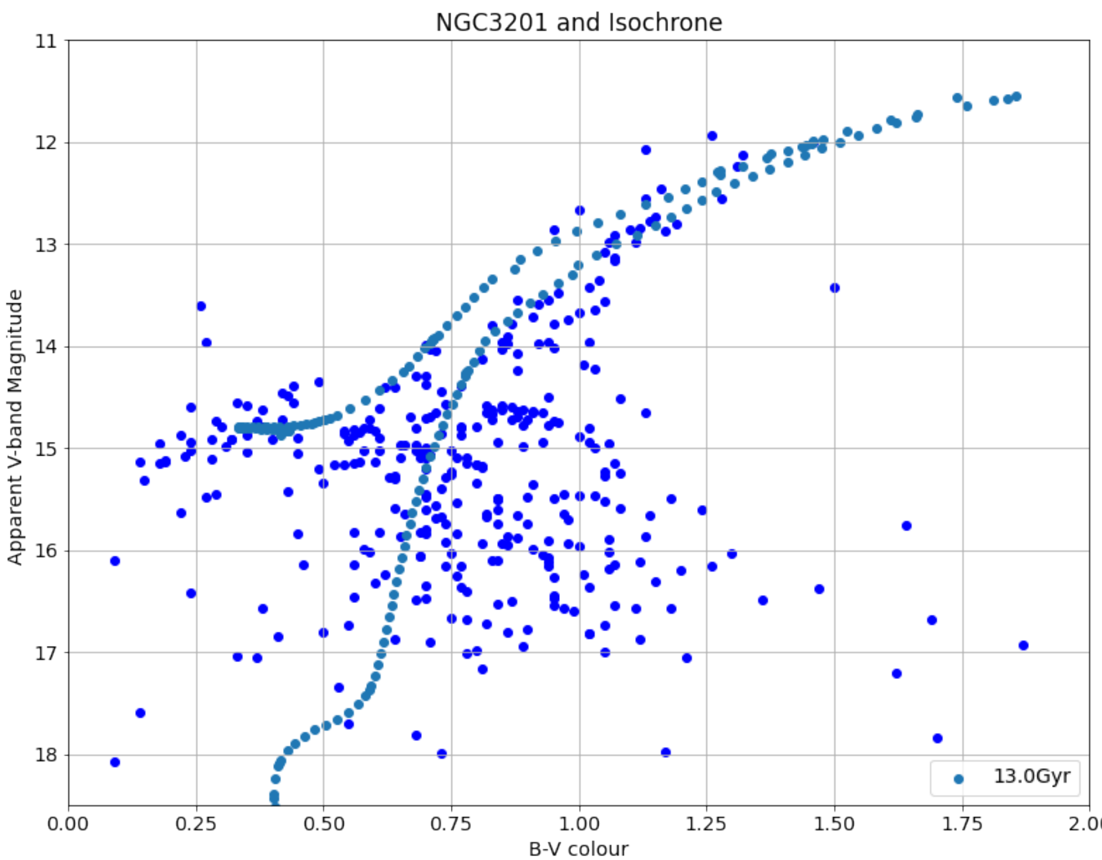
Looks good, move on to plotting more…

1.3.2 ⋆ Plotting isochrone over NGC3201

Using an estimated distance modulus that was calculated by 'eye' to fit isochrone over the HR diagram of NGC3201

[13]:
```
plot(B,V,"B","V",0 , 2, 18.5, 11)

DM = 14.3                                          # distance modulus
```

```
V_DM = numpy.array(iso[0]) + DM              # adding distance modulus to the␣
↪V magnitude of the isochrone
plt.scatter(iso[1], V_DM, label='13.0Gyr')      # scatter plot

# axis labels and grid
plt.xlabel('B-V colour')
plt.ylabel('Apparent V-band Magnitude ')
plt.title('NGC3201 and Isochrone')
plt.grid(True)
plt.legend(loc='lower right')

plt.show()

# calculating distance
distance=(10.0**(DM/5))*10
print("Distance:", distance/1000, "kpc")
```




```
Distance: 7.244359600749905 kpc
```

Figure 7: Plotting 13.0Gyr isochrone over HR diagram and correcting with a distance modulus of 14.3, thus giving a distance of ~7.2kpc

- The fit of the isochrone is not too bad
- The distance is ~2kpc greater than the expected literature values of ~5.1 ± 0.1 kpc (Monty et al. 2018). This is likely due to the dust/reddenning which we need to factor out to get a true value.

1.3.3 ⋆ Plotting various isochrones

[14]:
```python
# function plots isochrones
## 2 arguments --> filename: file name of isochrone
##             --> DM: distance modulus
##             --> age: age of isochrone

def plot_iso(file_name, DM, age):
    iso = isochrone(file_name)

    V_DM = numpy.array(iso[0])+DM
    ax = plt.gca()
    ax.scatter(iso[1], V_DM, label = age)                          # scatter plot

    # axis labels
    plt.xlabel('B-V colour')
    plt.ylabel('Apparent V-band Magnitude ')
    plt.title('NGC3201 and Isochrone')
    plt.grid(True)
    plt.legend(loc='lower left')
```

[15]:
```python
plot(B,V,"B","V",-0.5 , 2, 18.5, 11)
plot_iso('100Myr.txt', 14, '100Myr')
plot_iso('1Gyr.txt', 14, '1Gyr')
plot_iso('10Gyr.txt', 14, '10Gyr')
plot_iso('12Gyr.txt', 14, '12Gyr')
plot_iso('20Gyr.txt', 14, '20Gyr')

distance=(10.0**(DM/5))*10
print("Distance:", distance/1000, "kpc")
```

```
Distance: 7.244359600749905 kpc
```

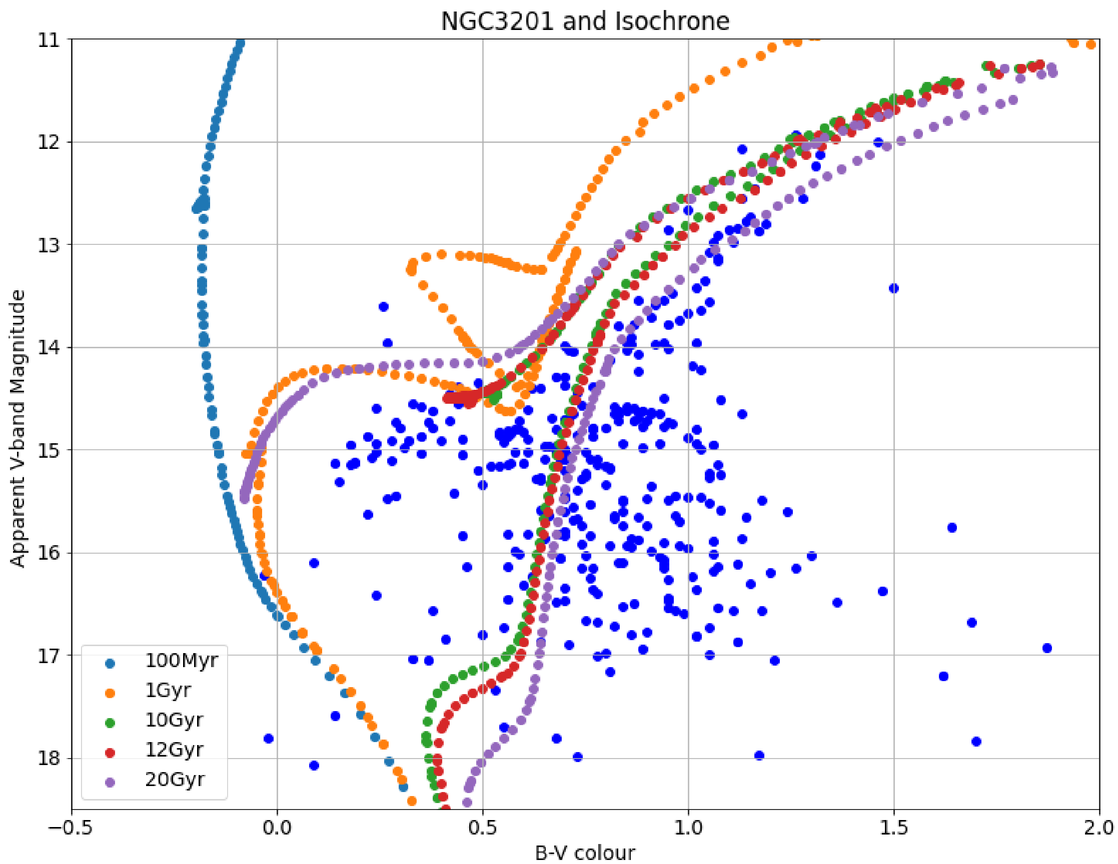


Figure 8: Plotting isochrones of 100Myr, 1Gyr, 10Gyr, 12Gyr and 20 Gyr over NGC3201 using V-band against (B-V) colour

By plotting 5 different aged isochrones we can get a good estimate of a good model for NGC3201.

- We can rule out 100Myr and 1Gyr as the red giant branches don't match as they are way off
- Using the distance modulus of 14 we get a distance of ~ 7.2kpc (this does not take into account dust/reddening)

1.4 Calculating distance by taking into account 'Dust'

1.4.1 ⋆ Calculating true distance modulus to add reddening to isochrones

$ (m - M)_0 = (m - M)_V - R_VE(B - V) $

Extracting values from literature given in 06_NGC_3201_factsheet. Reddenning is found in **Table 1** on the factsheet. We are using the values:

- $(m - M)_0$ our true distance modulus
- $(m - M)_V$ distance modulus, calculated by eye through shifting the magnitudes of the isochrones

- $R_V = 3.1$
- $E(B-V)$ is the extinction correction value (aka "reddening") of the (B-V) colour
- using $E(B-V)$ value of 0.25 as given by Monty et al. 2018

[18]:
```
EBV = 0.25
RV = 3.1*EBV

def true_mod(file_name, DM, age):
    iso = isochrone(file_name)
    BV_M = numpy.array(iso[2])-numpy.array(iso[0])+EBV   # adding reddening␣
 ↪value to (B - V) colour
    V_M = numpy.array(iso[0])+DM+RV                       # adding the distance␣
 ↪modulus and R_V value to V magnitude

    # define plot size
    plt.rcParams['figure.figsize'] = [15, 15]
    plt.scatter(BV_M, V_M, label = age)                   # scatter plot

    # axis labels
    plt.rcParams.update({'font.size':14 })
    plt.xlabel('B-V colour')
    plt.ylabel('Absolute V-band Magnitude ')
    plt.title('Giradri Isochrone')
    plt.legend(loc='upper right');
    plt.grid(True)

    # calculate new distance and print
    distance=(10.0**(DM/5))*10
    print("Distance:", distance/1000, "kpc")
```

Changing the Distance modulus to now fit the 'reddened' isochrone magnitudes

- The modulus now goes up by ~1 compared to the non reddened isochrones

[19]:
```
plot(B,V,"B","V",0 , 2, 18.5, 11)
true_mod('12Gyr.txt', 13.1, '12Gyr')
#true_mod('13Gyr.txt', 13.35, '13Gyr')
true_mod('12.7Gyr.txt', 13.1, '12.7Gyr')
#true_mod('15Gyr.txt', 13.35, '15Gyr')
```

```
Distance: 4.168693834703355 kpc
Distance: 4.168693834703355 kpc
```

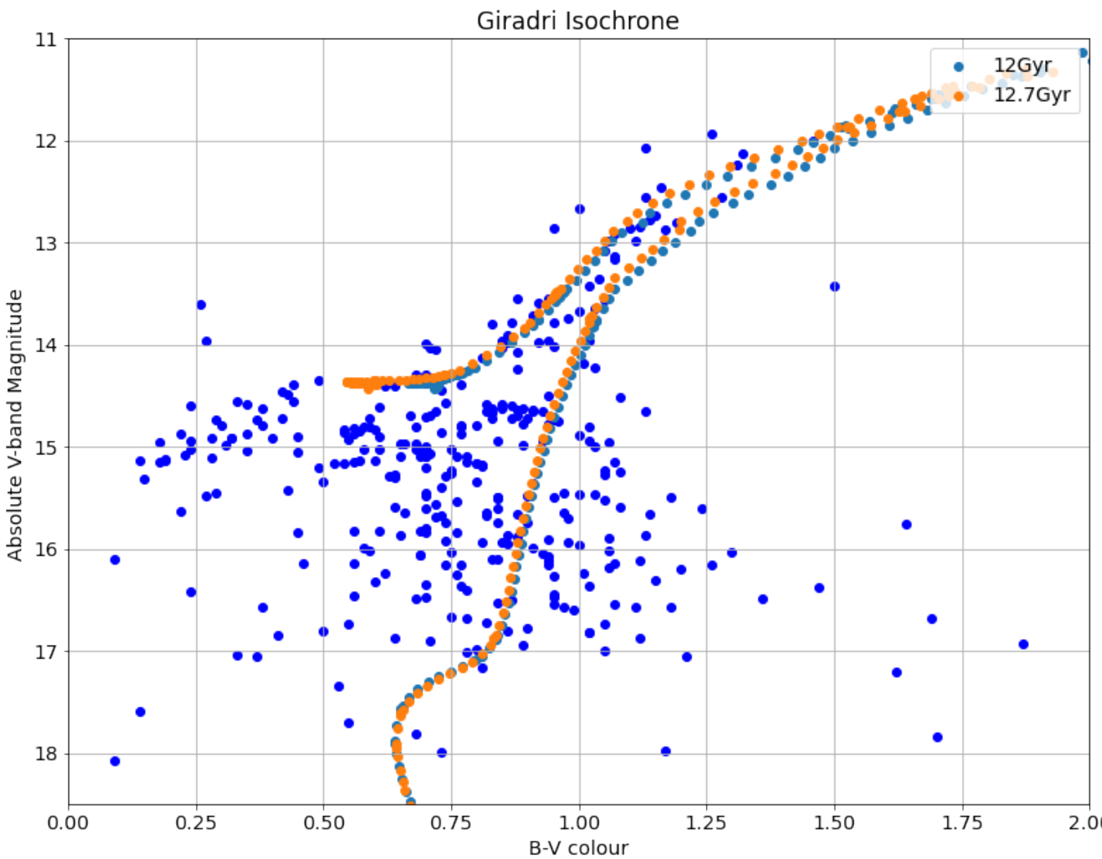


Figure 9: Reddened Giradi Isochrones of ages 12 and 12.7Gyr. Reddening value used: $E(B-V) = 0.25$ giving a new $(m-M)_V = 13.1$

Judging from this fitting, we can see that the shape of the red giant and horizontal branch don't line up very well. Looks like the magnitude colour needs to be shifted to the right to fit well… However, the new distance calculated is ~4.2 kpc, this is at least near the literature values given in **Table 1** of the fact sheet.

⋆ Using other reddening values

[20]:
```
# using Alcaino 1976 value of reddening: 0.14
EBV = 0.14
RV = 3.1*EBV
plot(B,V,"B","V",0 , 2, 18.5, 11)
true_mod('12Gyr.txt', 13.65, '12Gyr')
true_mod('12.7Gyr.txt', 13.65, '12.7Gyr')
#true_mod('12.5Gyr.txt', 13.65, '13Gyr')
```

```
Distance: 5.370317963702527 kpc
Distance: 5.370317963702527 kpc
```

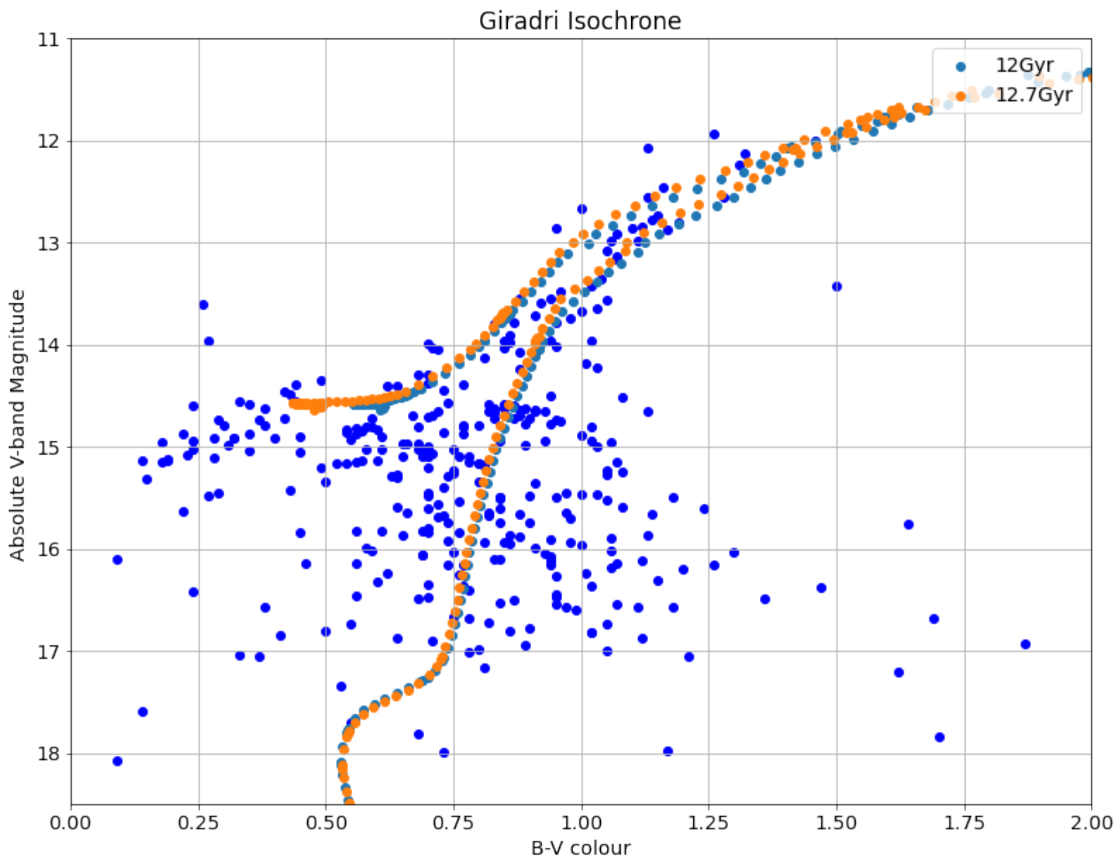


Figure 10: Reddened Giradi Isochrones of ages 12 and 12.7Gyr. Reddening value used: $E(B-V) = 0.14$ giving a new $(m-M)_V = 13.65$

The value for $E(B-V)$ given by Alcaino 1976 found in **Table 1** makes a better fit for the giant branch, thus giving a distance value of ~5.4 kpc.

- Note that the value is the same to Alcaino 1976 value of ~5.4 kpc

1.5 NOTES

- Found that using a reddening value of 0.14 gives a more accurate shape to our isochrones when fitting on to our NGC3201 data
- Age of NGC3201 is ~ 12 to 12.7Gyr
- Distance ~4.2 to 5.4kpc

–> Unfinsihed: Need to calculate age and distance using other method

[ ]: