Mira: A distance indicator

Kamal Jnawali

Rochester Institute of technology
Astronomical observation technique and instrumentation

12/10/2013

- Introduction

- Introduction
- Classification

outlines

- Introduction
- Classification
- Physics of pulsation

- Introduction
- Classification
- Physics of pulsation
- Why should we care to variable stars

- Introduction
- Classification
- Physics of pulsation
- Why should we care to variable stars
- Goal- Distance to Mira star

- Introduction
- Classification
- Physics of pulsation
- Why should we care to variable stars
- Goal- Distance to Mira star
- Data

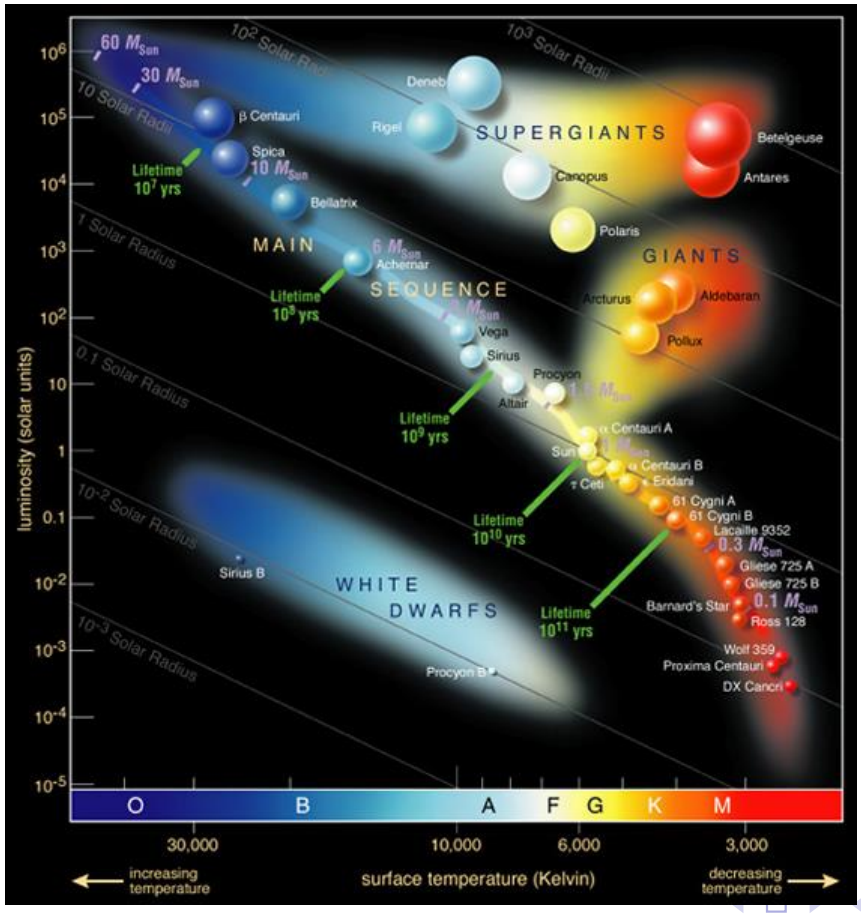
- Introduction
- Classification
- Physics of pulsation
- Why should we care to variable stars
- Goal- Distance to Mira star
- Data
- Calculation

- Introduction
- Classification
- Physics of pulsation
- Why should we care to variable stars
- Goal- Distance to Mira star
- Data
- Calculation
- Results

- Introduction
- Classification
- Physics of pulsation
- Why should we care to variable stars
- Goal- Distance to Mira star
- Data
- Calculation
- Results
- Future work

Omicron Ceti: How far is it?

HR diagram


luminosity (solar units)
surface temperature (Kelvin)
increasing temperature
decreasing temperature
O
B
A
F
G
K
M
30,000
10,000
6,000
3,000
SUPERGIANTS
GIANTS
MAIN SEQUENCE
WHITE DWARFS
Deneb
Rigel
Betelgeuse
Antares
Canopus
Polaris
Arcturus
Aldebaran
Pollux
β Centauri
Spica
Bellatrix
Achernar
Vega
Sirius
Procyon
Altair
Sun
α Centauri A
α Centauri B
τ Ceti
ε Eridani
61 Cygni A
61 Cygni B
Lacaille 9352
Gliese 725 A
Gliese 725 B
Barnard's Star
Ross 128
Wolf 359
Proxima Centauri
DX Cancri
Sirius B
Procyon B
60 M_{Sun}
30 M_{Sun}
10 M_{Sun}
6 M_{Sun}
0.3 M_{Sun}
0.1 M_{Sun}
Lifetime 10^7 yrs
Lifetime 10^8 yrs
Lifetime 10^9 yrs
Lifetime 10^{10} yrs
Lifetime 10^{11} yrs
10 Solar Radii
1 Solar Radius
0.1 Solar Radius

Introduction

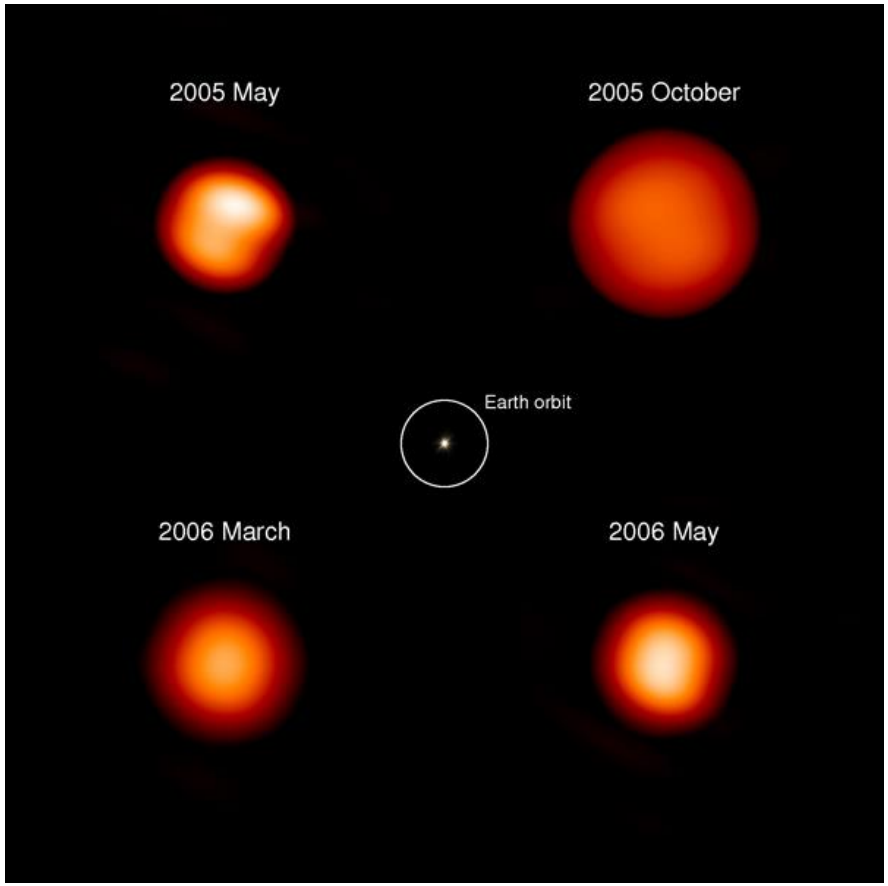
- Mira: Red giant
- Constellation = Cetus
- RA 02h19m20.8s / DEC -02d58m37s
- It is discovered by David Fabricius in 1596.
- Mira means wonderful star
- Radius=>400 $\times$ Radius of Sun
- Mass =0.6 to 4 $\times$ Mass of Sun
- Period= 80-1000 days
- Omicron Ceti -Oldest known Mira star

Variable stars

- Apparent magnitude(brightness) changes periodically

Classification

Pulsation in Mira (Fig-chandra.harvard.edu)



Pulsation: K mechanism/exchange between two state of He

- $\kappa \propto \frac{\rho}{T^{3.5}}$

Pulsation: K mechanism/exchange between two state of He

- $\kappa \propto \frac{\rho}{T^{3.5}}$
- If opacity blocks light then gas heats up.

Pulsation: K mechanism/exchange between two state of He

- $\kappa \propto \frac{\rho}{T^{3.5}}$
- If opacity blocks light then gas heats up.
- Gas expands.Opacity decreases, photon passes through it.

Pulsation: K mechanism/exchange between two state of He

- $\kappa \propto \frac{\rho}{T^{3.5}}$
- If opacity blocks light then gas heats up.
- Gas expands.Opacity decreases, photon passes through it.
- Gas cools down to condensed state and the process continues to give periodic pulsation.

Pulsation: K mechanism/exchange between two state of He

- $\kappa \propto \frac{\rho}{T^{3.5}}$
- If opacity blocks light then gas heats up.
- Gas expands.Opacity decreases, photon passes through it.
- Gas cools down to condensed state and the process continues to give periodic pulsation.
- The κ relation is using for the ionized envelope proves the sustainability of the pulsation. Here the extra heat is being used to ionize the helium ion.So temperature dependence being less significant compared to ρ in the κ relation. κ is significantly determined by ρ.

Continue.

- There are two ionized state of Helium, $He^{+}$and He^{++}. There is also ionized state of hydrogen i.e. H^{+} . He^{++} is more opaque than He^{+}.

Continue.

- There are two ionized state of Helium, $He^{+}$and He^{++}. There is also ionized state of hydrogen i.e. H^{+} . He^{++} is more opaque than He^{+}.
- When He layer is heated He^{++} increases that traps the light and causing the further heating. Hence the gas near the surface gets expand results with cooling with increase in radius and luminosity.

Continue.

- There are two ionized state of Helium, $He^{+}$and He^{++}. There is also ionized state of hydrogen i.e. H^{+} . He^{++} is more opaque than He^{+}.
- When He layer is heated He^{++} increases that traps the light and causing the further heating. Hence the gas near the surface gets expand results with cooling with increase in radius and luminosity.
- When He layer is cooled, He^{+} increases which is less opaque(so do not absorb light) that makes decrease in radius and luminosity with compressing its size.

Pulsation: Acoustic mode

- Let us write a brief equation[Astro-dynamics Text-Book]
-
$$\frac{d^2(\delta r)}{dr_0^2} + (\frac{4}{r_0} - \frac{\rho_0 g_0}{P_0})\frac{d(\delta r)}{dr_0} + \frac{\rho_0}{\Gamma P_0}(\omega^2 + (4 - 3\Gamma))\frac{g_0}{r_0})\delta r = 0$$
-
$$P(m,t) = P_0(m)(1 + \delta P(m))exp(i\omega t)$$

Pulsation: Acoustic mode

- Let us write a brief equation[Astro-dynamics Text-Book]
- $$\frac{d^2(\delta r)}{dr_0^2} + (\frac{4}{r_0} - \frac{\rho_0 g_0}{P_0})\frac{d(\delta r)}{dr_0} + \frac{\rho_0}{\Gamma P_0}(\omega^2 + (4 - 3\Gamma))\frac{g_0}{r_0})\delta r = 0$$
- $$P(m,t) = P_0(m)(1 + \delta P(m))exp(i\omega t)$$
- Similar kind of the equations(like pressure) are also necessary to radius and density distribution

Pulsation: Acoustic mode

- Let us write a brief equation[Astro-dynamics Text-Book]
-
$$\frac{d^2(\delta r)}{dr_0^2} + (\frac{4}{r_0} - \frac{\rho_0 g_0}{P_0})\frac{d(\delta r)}{dr_0} + \frac{\rho_0}{\Gamma P_0}(\omega^2 + (4 - 3\Gamma))\frac{g_0}{r_0})\delta r = 0$$
-
$$P(m,t) = P_0(m)(1 + \delta P(m))exp(i\omega t)$$
- Similar kind of the equations(like pressure) are also necessary to radius and density distribution
- Two possible boundary condition give a case to fundamental mode and first overtone to the pulsation.

Pulsation: Acoustic mode

- Let us write a brief equation[Astro-dynamics Text-Book]
-
$$\frac{d^2(\delta r)}{dr_0^2} + (\frac{4}{r_0} - \frac{\rho_0 g_0}{P_0})\frac{d(\delta r)}{dr_0} + \frac{\rho_0}{\Gamma P_0}(\omega^2 + (4 - 3\Gamma))\frac{g_0}{r_0})\delta r = 0$$
-
$$P(m,t) = P_0(m)(1 + \delta P(m))exp(i\omega t)$$
- Similar kind of the equations(like pressure) are also necessary to radius and density distribution
- Two possible boundary condition give a case to fundamental mode and first overtone to the pulsation.
- We might imagine second overtone,third overtone which leads to more complex caluclation.

Pulsation: Acoustic mode

- Let us write a brief equation[Astro-dynamics Text-Book]
-
$$\frac{d^2(\delta r)}{dr_0^2} + (\frac{4}{r_0} - \frac{\rho_0 g_0}{P_0})\frac{d(\delta r)}{dr_0} + \frac{\rho_0}{\Gamma P_0}(\omega^2 + (4 - 3\Gamma))\frac{g_0}{r_0})\delta r = 0$$
-
$$P(m,t) = P_0(m)(1 + \delta P(m))exp(i\omega t)$$
- Similar kind of the equations(like pressure) are also necessary to radius and density distribution
- Two possible boundary condition give a case to fundamental mode and first overtone to the pulsation.
- We might imagine second overtone,third overtone which leads to more complex caluclation.
- Fundamental mode is expected to the Mira star.

Pulsation: Thermodynamics/Radiative theory

- For each layer of the star, net amount of work done during the pulsation cycle must equals to difference of the heat flowing into and out of the layer.

Pulsation: Thermodynamics/Radiative theory

- For each layer of the star, net amount of work done during the pulsation cycle must equals to difference of the heat flowing into and out of the layer.
- Work done$=\int \frac{\Delta T}{T_0}$ dQ

Pulsation: Thermodynamics/Radiative theory

- For each layer of the star, net amount of work done during the pulsation cycle must equals to difference of the heat flowing into and out of the layer.
- Work done$=\int \frac{\Delta T}{T_0}$ dQ
- For absorption of heat (dQ $>$0),we have $\Delta T > 0$ and for emission of heat (dQ$<$0), we have $\Delta T < 0$.

Pulsation: Thermodynamics/Radiative theory

- For each layer of the star, net amount of work done during the pulsation cycle must equals to difference of the heat flowing into and out of the layer.
- Work done$=\int \frac{\Delta T}{T_0}$ dQ
- For absorption of heat (dQ $>$0),we have $\Delta T > 0$ and for emission of heat (dQ$<$0), we have $\Delta T < 0$.
- The compression leads to increase in the temperature and thereby reduces the κ, heat is being escaped by setting dQ<0 and $\Delta T < 0$. The expansion state leads to decrease in temperature and thereby increase the κ, then heat is being absorbed by setting dQ>0 and $\Delta T > 0$. In such case the different layer should behave in same way to thermodynamical exchange of heat.

Pulsation: Thermodynamics/Radiative theory

- For each layer of the star, net amount of work done during the pulsation cycle must equals to difference of the heat flowing into and out of the layer.
- Work done$=\int \frac{\Delta T}{T_0}$ dQ
- For absorption of heat (dQ $>$0),we have $\Delta T > 0$ and for emission of heat (dQ$<$0), we have $\Delta T < 0$.
- The compression leads to increase in the temperature and thereby reduces the κ, heat is being escaped by setting dQ<0 and $\Delta T < 0$. The expansion state leads to decrease in temperature and thereby increase the κ, then heat is being absorbed by setting dQ>0 and $\Delta T > 0$. In such case the different layer should behave in same way to thermodynamical exchange of heat.
- Whole process continues to pulsate the star.

Why should we care to variable stars?

- It gives light curve equation which allows us to calculate the distance to the galaxy

Why should we care to variable stars?

- It gives light curve equation which allows us to calculate the distance to the galaxy
- It gives important information on the internal and external composition of the stars and its surrounding

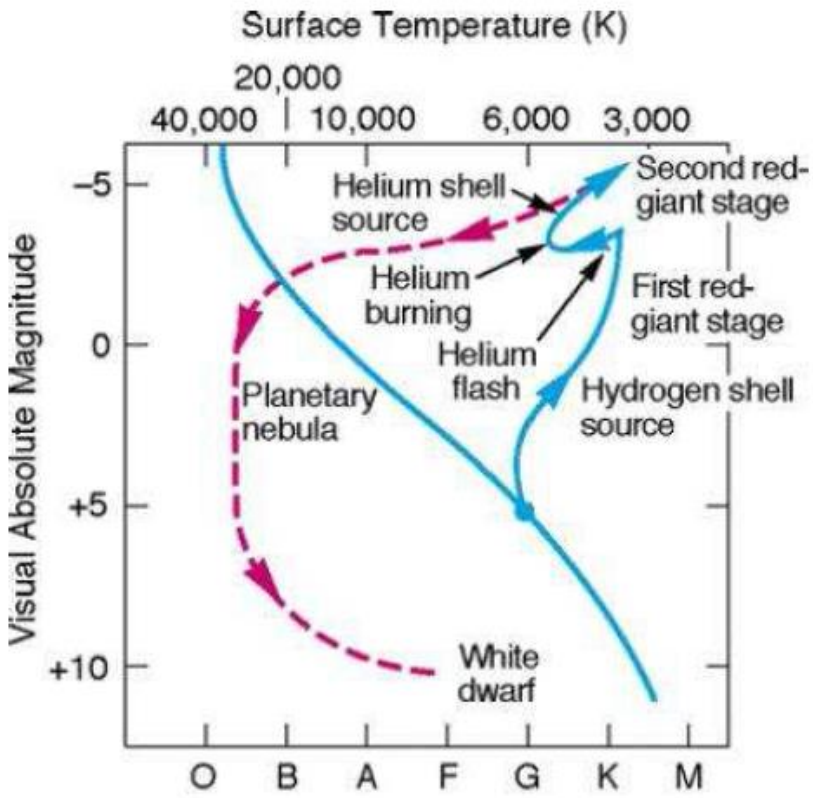
Why should we care to variable stars?

- It gives light curve equation which allows us to calculate the distance to the galaxy
- It gives important information on the internal and external composition of the stars and its surrounding
- It provides a path to study of evolution of the stars and universe

Why should we care to variable stars?

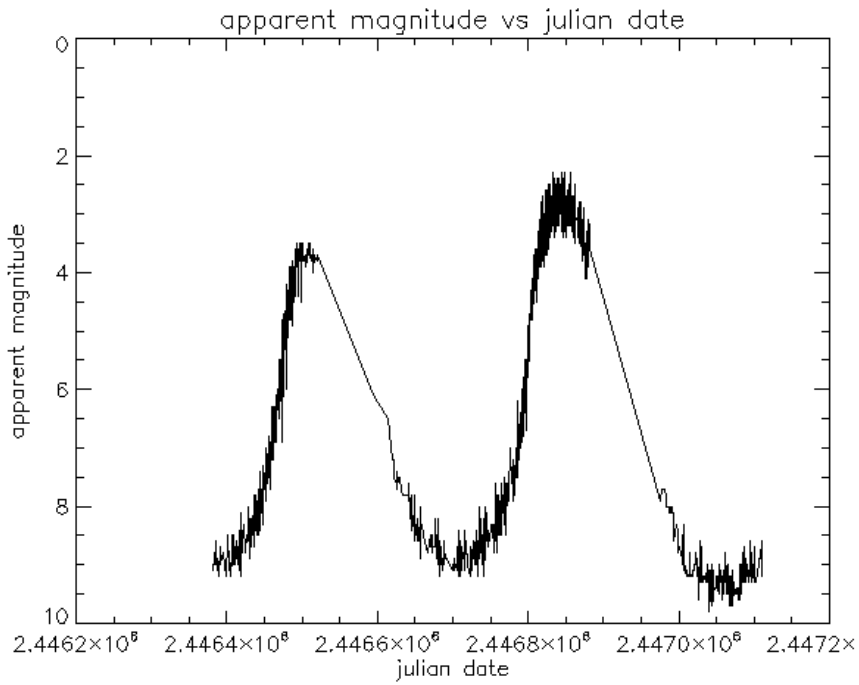
- It gives light curve equation which allows us to calculate the distance to the galaxy
- It gives important information on the internal and external composition of the stars and its surrounding
- It provides a path to study of evolution of the stars and universe
- Mass and Age are fundamental parameters to describe to stars,variable stars provide a way of calculation of these two parameters.

Process of steller evolution



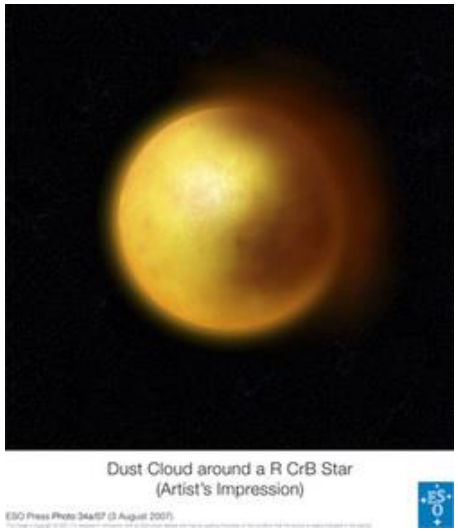
Mira-pulsating variable star (My Target Star)

- For distance indicator

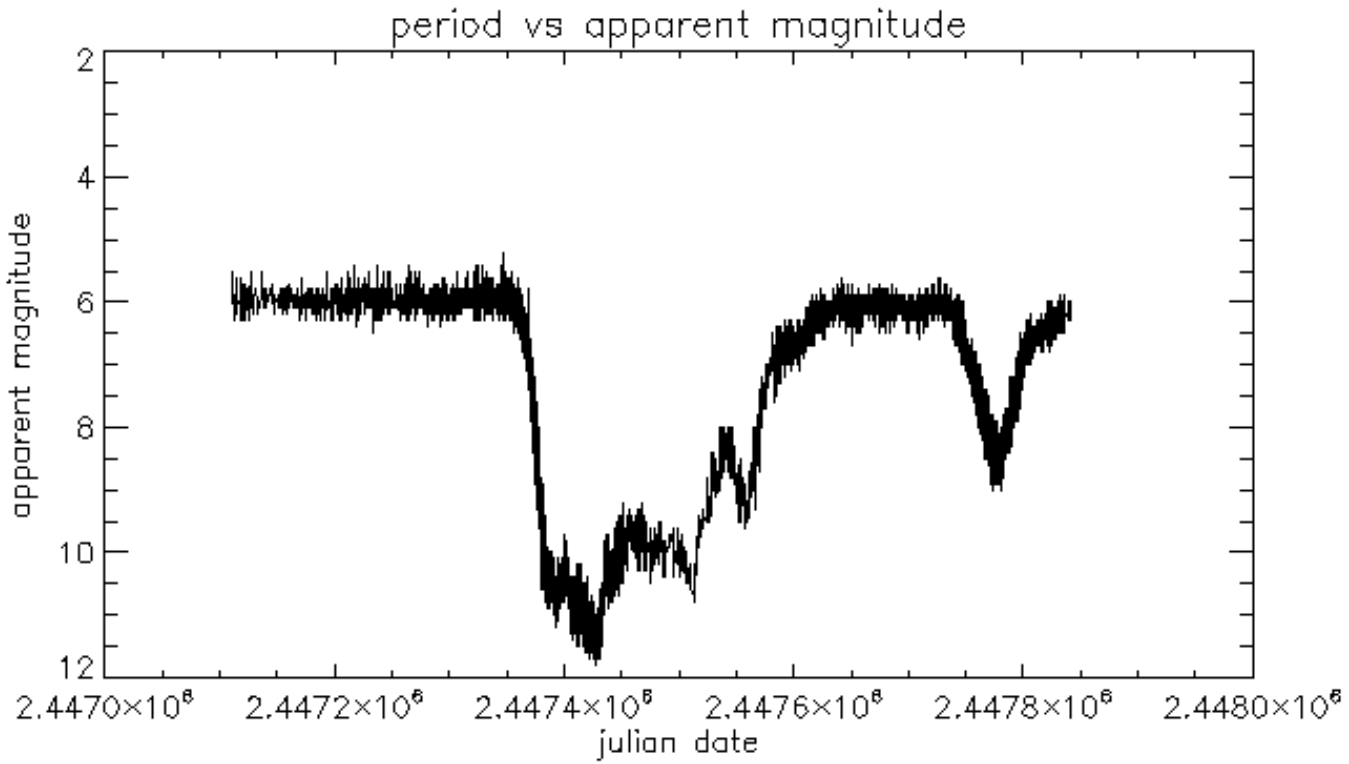


R Coronae Borealis(RCB)-eruptive variable star

- Very good source for study of the dust formation
- Carbon rich red super giant
- Fig :Mike Goldsmith



R Coronae Borealis(RCB)



Goal

- The distance to star based on period luminosity relation

Goal

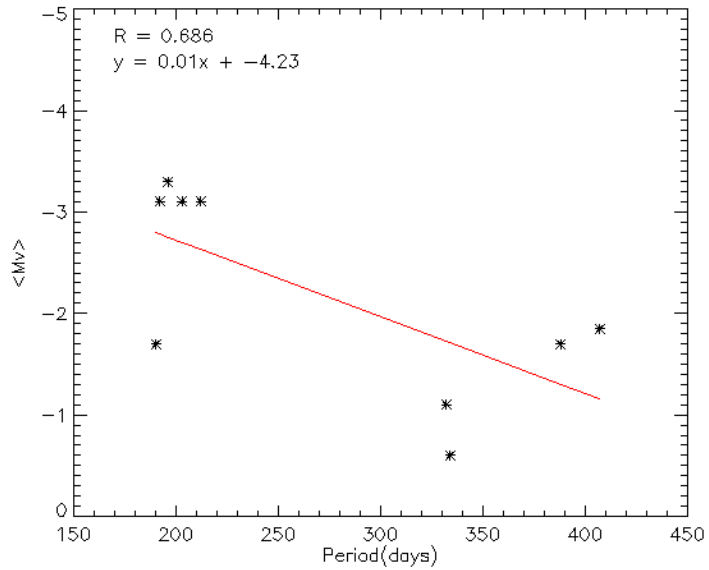
- The distance to star based on period luminosity relation
- The relation was first observed by Henrietta Swan Leavitt for Cepheid star.

Goal

- The distance to star based on period luminosity relation
- The relation was first observed by Henrietta Swan Leavitt for Cepheid star.
- Then,what will be the distance to Mira(Omicron Ceti)?

Plot: Period vs absolute magnitude

- $< M_v >$=0.01×T(days) - 4.32
- This equation could not give best fit line for period-absolute magnitude.



Calculation

- More precise relationship between absolute magnitude and period (Bergh) in V-band

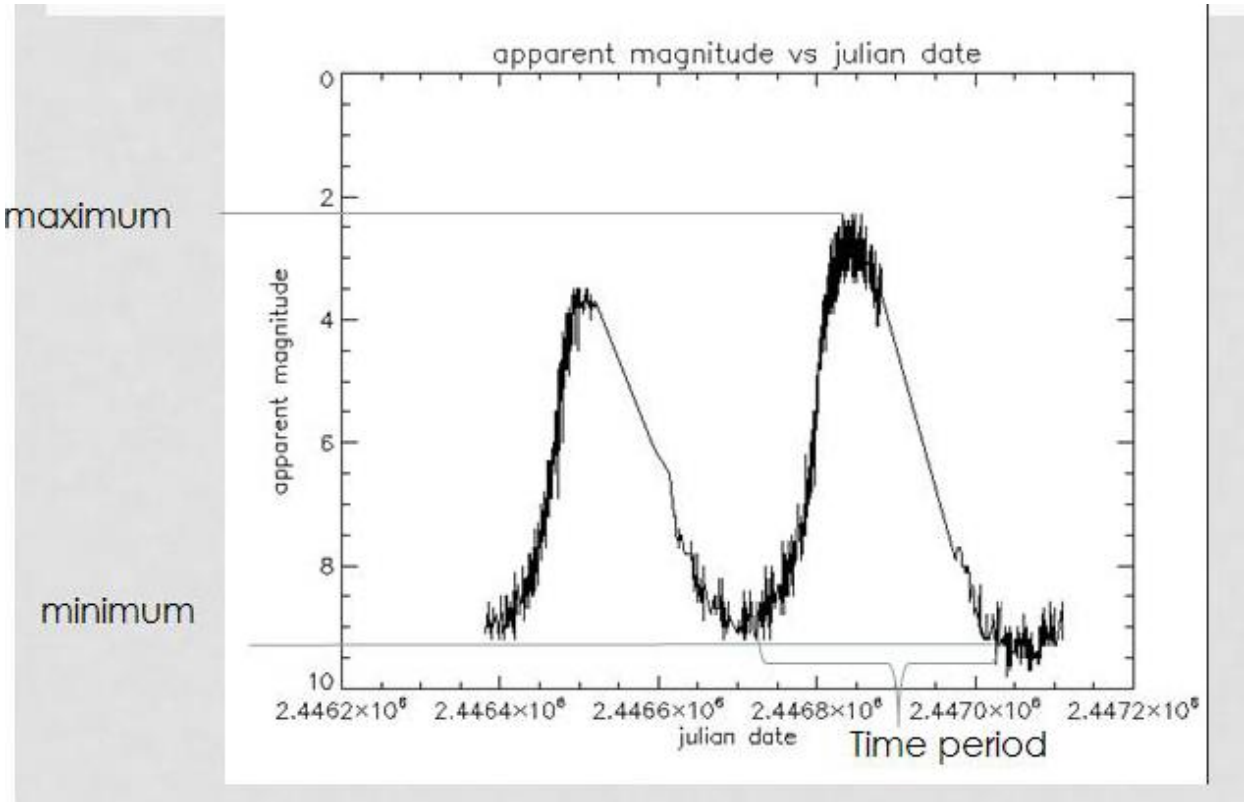
$$< M_v >= -14.39 + 5.9 \times log(T(days))$$

where,
M_v is absolute magnitude
T is time-period

Observation

- Data: American Association of Variable Stars Observation(AAVSO)
- Band: Visual

Plot: Period vs apparent magnitude



Calculation: apparent magnitude,absolute magnitude, time period

- Apparent magnitude: m=5.85
- Absolute magnitude:M_v= 0.47
- Time Period: T=330

Calculation: distance

- $d = 10^{(\frac{m-M_V+5}{5})}$
- $d = 10^{2.1} = 126$ parsec =411 light years
- This is the distance to the Omicron Ceti.

Results

- d=(126 ± 6) pc
- Distance to Omicron Ceti is 128 pc (Ryde et al)

Future work

1. More precise Period-Luminosity relation in infrared band.
2. Attenuation in the visual band occurs strongly compared to infrared band in Mira star type variable stars .
3. Developing the Period-Luminosity relation based on the infrared observation
4. Calculating the distance to Omicron ceti based on the infrared band observation.
5. Working in the infrared band, we can get tremendous amount of information like mass loss rate,description of dust around the star.

References

1. AAVSO: Observational Data
2. AAVSO:Mira Star
3. Bergh Van Den,S:1984Ap and SS.102..295V
4. Evans, N. R.:1970AJ.....75..636E.
5. Patricia Whitelock :Variables and the Magellanic clouds
6. N. Ryde and F. L. Schier : 2001ApJ...547..384R
7. Feast, M. W. 1984MNRAS.211P..51F

Mira: Shooting star
Fig- Nasa/JPL Caltech/C Martin/M. Seibert

Mira is Mira

Thank You