A STUDY OF DUSTY ENVIRONMENT AT FAR INFRARED IRAS MAP AROUND THE MASS -LOSING CARBON-RICH AGB STAR AT LATITUDE -59.6^{o}

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Abstract
This paper discusses the physical properties of the dusty environment around the mass losing AGB star located at R.A. (J2000) =10h 25m 08s and Dec (J2000) =-59o 33’ 00”, in the far infrared (60 and 100μm) IRAS maps. A cavity like structure (major diameter ∼ 2.3 pc & minor diameter ∼0.21 pc) is found to lie at R.A. (J2000) = 10h 26m 54.73s and DEC (J2000) = -59o 18’ 22.5”, located at a distance ∼ 305 pc from the star. By using contour map diagram, we studied the distribution of flux density, dust color temperature, dust mass and outflow mass in the cavity. The dust color temperature is found to lie in the range 23.9 K to 25.1 K which shows the cavity is isolated and independently evolved. Such a low offset temperature variation shows that the star is in thermal equilibrium and its life is long. Dust particles are less interacting and mean free path is large. The cavity may be in thermally pulsating phase. A possible explanation of the results will be discussed.

Key Words: AGB Stars, Dust Color Temperature, Dust Mass and Excess Mass.

Introduction

The evolution of star that follows core helium burning depends strongly on the stellar mass. The mass determines how high the central temperature and the degree of degeneracy when heavier nuclear fuels are ignited. When the central helium supply is exhausted, helium will continue to burn in a shell, while the hydrogen burning shell is extinguished. In the HR diagram the star will move towards lower effective temperature and higher luminosity. This phase is quite similar to the red giant phase of low-mass stars, although the temperatures are slightly hotter. For this reason it is known as the asymptotic giant branch, AGB. Asymptotic giant branch (AGB) stars are the final nuclear burning stage of low- and intermediate-mass stars driven by nuclear burning. This phase of evolution is characterized by two nuclear burning shells of hydrogen and helium where hydrogen burns shell lies below the convective envelope and helium burning shell lies above the electron-degenerate core of carbon and oxygen, or for the most massive AGB stars a core of oxygen, neon, and magnesium [1: 435]. This AGB stage is characterized by low surface effective temperatures (below 3000K) and intense mass loss (from10^{-7} to 10^{-4} M yr^{-1}) [2: 822]. When the gas temperature drops to the sublimation temperature range, heavy elements in the mass outflow from a central star will condense to form dust. Dusty circumstellar envelopes will format the distance of several stellar radii .Dust grains in the envelopes absorb stellar radiation and re-emit infrared radiation so AGB stars are important infrared sources. The mass loss process plays an important role in the evolution of AGB stars. It affects the lifetime of the AGB phase and the core-mass of the subsequent post-AGB stars. Statistics of a large sample of AGB stars would help to constrain the evolution of dust envelope. There are two main types of AGB stars: the O-rich with C/O < 1 and mainly silicate-type grains in the outflow, and C-rich with C/O > 1 and mainly carbonaceous grains in the envelopes [1:435]. Due to different dust compositions of these two types of AGB stars, different infrared spectral features are obtained which can be used to distinguish the two groups of the stellar objects. Most of the carbon compounds such as aromatic hydrocarbon, benzene, methane, etc. are responsible for biological life so carbon- rich AGB stars are preferred in our research work.

He-core burning phase is about 10 times shorter than the H-core burning shell so that the He-core burning leaves a C/O core behind that is surrounded by both a hydrogen and helium burning shell. For low and intermediate mass stars, carbon doesn't ignite and C/O core contracts and becomes electron degenerate. During the early AGB phase, the abundance of He in the centre goes to zero where He-burning continues in a shell around a degenerate C-O core. In the meantime, the H- layer around the helium shell expands and cools sufficiently so that hydrogen burning shell is extinguished. Convective envelope sets in and moves inwards and second dredge-up takes place. He shell is the main source for nuclear production so that it burns outward and reaches the hydrogen shell. In case of thermally pulsating AGB phase, helium shell becomes thin and remains thermally unstable as a result thermal pulses are produced. In each thermal pulse, luminosity of helium shell nearly approaches 108L [3: 515].The production of such high luminosity in helium shell is called He shell flash or thermal pulse which is used to expand the outer layers. Such strong expansion drives the H shell cooler and less dense as a result H shell is extinguished. The inner edge of deep convective envelope can then move inward and mix to the surface products of internal nucleosynthesis. This mixing process which occurs periodically after each TP is known as third dredge-up which is the mechanism for producing carbon stars. During TP-AGB phase, main dominant source of nuclear energy is the hydrogen shell. Thermally pulsating AGB phase is the phase after the first thermal pulse to the time when the star ejects its envelope.

In this paper, we study the physical properties of far infrared cavity, that we investigated during a systematic search on IRAS maps, located close to a carbon-rich AGB star (AGB 09-52) at -52.8o latitude. In section 2, we describe methods of calculation. A brief description of the result and discussion will be given in the section 3. Finally, we conclude our results in the section 4.

Methods

We investigated a cavity-like structure in both 60 and 100 micron IRAS maps around a AGB star. We briefly describe a method for calculation of dust color temperature and dust mass of the dusty environment around carbon-rich Asymptotic Giant Branch named AGB10-59.

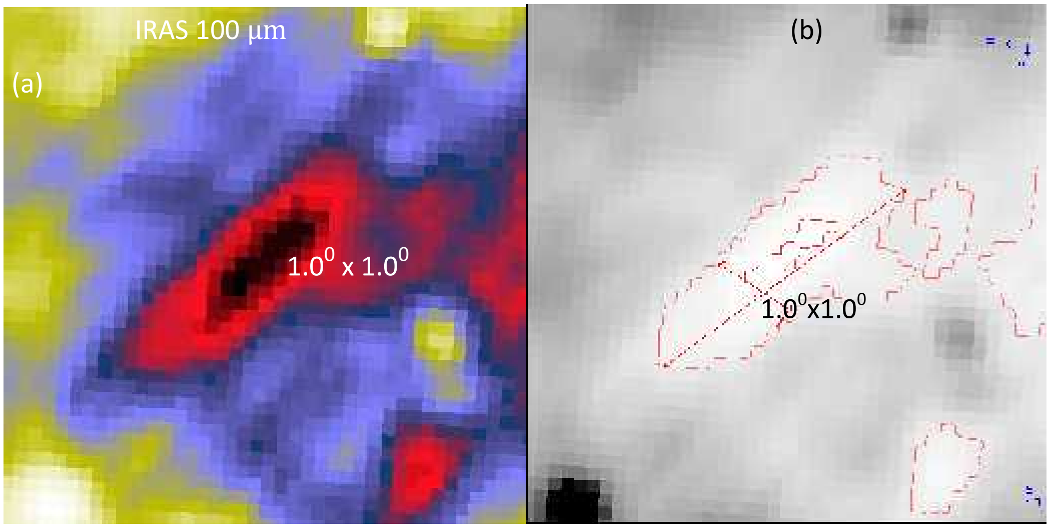

Fig. 1. (a) IRAS 100 µm and 60 µm far infrared image of the core region of AGB 10-59 centered at R.A. (J2000) = 10h 26m 54.73s, Dec. (J2000) = -590 18’ 22.5” and (b) Contour map of the cavity where major diameter (AB), minor diameter (CD) and diameter between minimum flux &minimum temperature.

Dust Color Temperature Estimation

Schnee et al. [4: 442] derived an expression to calculate dust color temperature. The flux density of emission at a wavelength λi is given by

$$Fi = \left[\frac{2hc}{a_i^3 \left(e^{\frac{hc}{a_i k T_d}} \right) - 1} \right] Nd\ \alpha\ \lambda i\text{-}\beta\ \Omega i \qquad \text{... (1)}$$

where β is the spectral emissivity index, Nd is the column density of dust grains, α is a constant i.e. free parameter which relates the flux with the optical depth of the dust, and Ωi is the solid angle subtended at λi by the detector. In Dupac et al. [5: L11], there is an inverse relationship between temperature and emissivity spectral index. we have

With the assumptions that the dust emission is optically thin at 60 µm and 100 µm and that Ωω ≈ Ω100 (true for IRAS image), we can write the ratio, R, of the flux densities at 60 µm and 100 µm as

$$R = 0.6{-}(3+\beta)\ \frac{e^{144/T_d} - 1}{e^{240/T_d} - 1} \qquad \text{... (3)}$$

The spectral emissivity index (β) depends on dust grain properties like composition, size, and compactness. For a pure blackbody would have β = 0, the amorphous layer-lattice matter has β ∼ 1, and the metals and crystalline dielectrics have β ∼ 2 which is used in our calculations.

For a smaller value of Td, 1 can be dropped from both numerator and denominator of Eq. (3) and it takes the form

$$R == 0.6^{-(3+\beta)} \frac{e^{144/T_d}}{e^{240/T_d}} \qquad \ldots (4)$$

$$\text{Where } R = \frac{F(60\mu m)}{F(100\mu m)}$$

Taking natural logarithm on both sides of Eq. (4) and solving it, we find the expression for the temperature as

ln(R)=ln 0.6−(3+β) [144/Td-240/Td]

= ln 0.6−(3+β)[-96/Td]

$$Td = \frac{-96}{\ln\{R \times 0.6(3+\beta)\}} \qquad \ldots (5)$$

F(60 µm) and F(100 µm) are the flux densities in 60 µm and 100 µm respectively and Eq. (5) can be used for calculation of the dust grain temperature.

Dust Mass Estimation

Dust mass is another important physical quantity which is useful to analysis the cavity structure. We need the known distance of the loops to calculate its dust mass which was provided in catalog of far infrared loops in the galaxy [6: 1227].

For the calculation of dust mass, we first obtained the value of flux density (Sv) at 100 µm maps.

The dust mass is estimated using [7: 267],

$$M = \frac{4ar}{3Qn} \left| \frac{SnD2}{B(n, T)} \right| \qquad \ldots(7)$$

where, weighted grain size (a) = 0.1 µm, grain density (ρ) = 3000 kg m-3, grain emissivity (Qv) = 0.0010 (for 100 µm) [8: 725].

The Planck's function B(ν, T), which is the function of temperature and frequency and is given by the expression:

$$B(\quad T) = \frac{2hc}{l3} \left(\frac{1}{\frac{hc}{elkT} - 1} \right) \ldots (8)$$

Where, h = Planck's constant, c = velocity of light, ν = frequency at which the emission is observed, T = the average temperature of the region.

For 100 µm wavelength, the expression for the dust mass (8) reduces to,

$$Mdust = 0.4 \left[\frac{SnD2}{B(n, T)} \right] \qquad \ldots (9)$$

We use equation (9) to calculate dust mass of the cavity

Result and Discussion

Structure: Contour Maps

While going through the systematic search on IRAS maps, we discovered an isolated cavity in the 100 µm and 60 µm at R.A. (J2000) = 10h 26m 54.73s and Dec. (J2000) = -59o 18' 22.5". With the help of the software ALADIN2.5, we have studied physical properties (size, dust color temperature, dust mass, etc) of the cavity. We selected contour level in such a way that it circles the cavity. The major axis, minor axis and line passing through minimum temperature and minimum flux are shown in the fig.1(b).

Distribution of Flux Density

By using ALADIN 2.5 software, the values of flux densities at 60µm and 100µm have measured. The flux density distribution within the contour of the region of interest has studied. We plotted a graph between flux at 100µm and 60µm with the help of ORIGIN 5.0 which is shown in fig.2(a). From the linear fit, slope of the line was 0.21. The linear equation of the fitted line is, y=-7.5+0.21x. Using the slope of best fitted plot, dust color temperature is found as 23.3 K which is nearly similar with our calculated value.

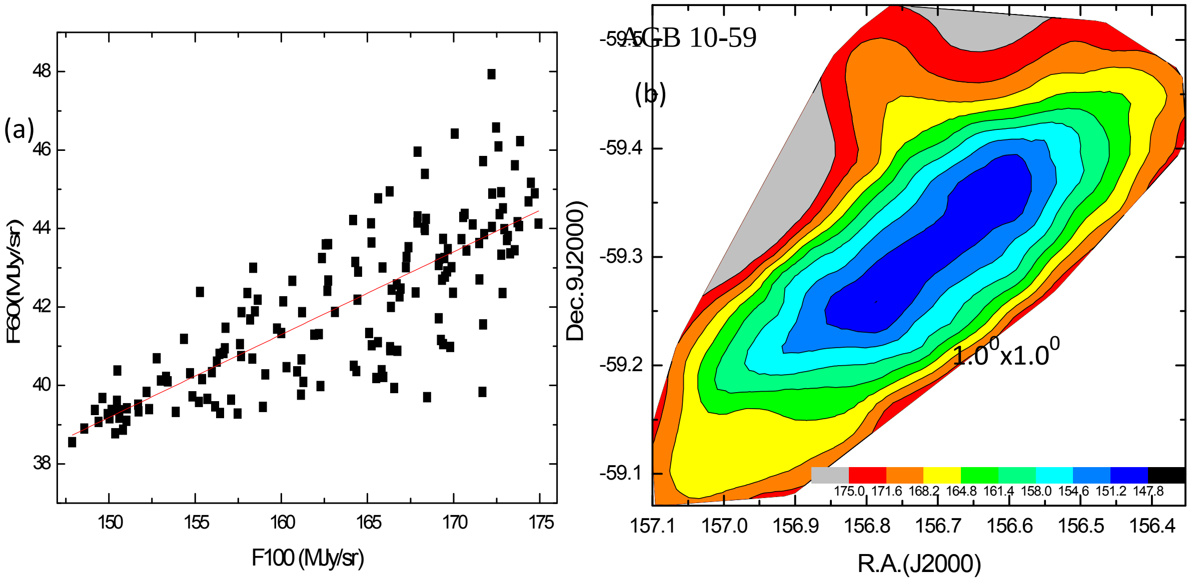

Fig.2(a) The 100µm verses 60µm flux density in the region of interest and 2(b) Contour map at 100µm flux density where the AGB star is located at the center R.A. (J2000) = 10h 26m 54.73s, Dec. (J2000) = -590 18' 22.5".

Again distribution of flux at 100µm of the pixels within the contour level with right ascension (R.A.) and declination (Dec.) are plotted by using ORIGIN 8.0 and the graph is shown in fig.2 (b). Graph shows that all the fluxes from minimum to maximum lie within the contour level. Most of the maximum flux regions lie at the boundary.

Dust Color Temperature and Its Variation

Using the method of [4: 442], we calculated dust color temperature of each pixel inner the outer isocontour in the region of interest. We use the IRAS 100 µm and 60 µm FITS images downloaded from the IRAS. For the calculation of temperature we choose the value of β = 2 following the explanation given by [5: L11]. Variation of temperature with corresponding R.A.(J2000) and Dec.(J2000) are plotted by using ORIGIN 8.0 and the graph is shown in figure 3(a). Graph shows that temperature distributions are in separate cluster but minimum temperature region is little bit shifted from minimum flux density which is unusual behaviour. Such type of nature is obtained due to external factors.

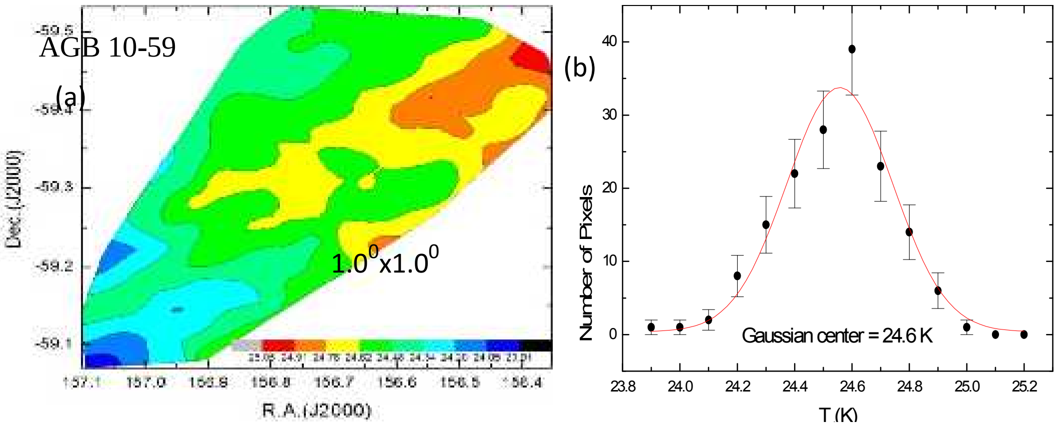

Fig. 3: (a) Contour map of dust color temperature and (b) Gaussian fit between dust color temperature and number of pixels. The field is centered at R.A.(J2000)= 10h 26m 54.73s and Dec. (J2000) = -59o 18’ 22.5”.

The region in which minimum and maximum temperature is found in the range of 23.9 K to 25.1 K with an offset temperature of dust 1.2 K. Such a low offset temperature variation shows that there is symmetric outflow or symmetric distribution of density and temperature. When this result is compared with the result obtained in [9: 5] where temperature variation is 20K to 22K so our result is also comparable with that result. In the contour map, minimum flux and minimum temperature region are shifted which is due to some external factors possibly due to AGB wind. There is good agreement in case of temperature in the Gaussian fit with offset 0.4 K.

Size of the Structure

Major and minor diameter of the structure can be easily calculated by using a simple expression i.e., L = R × θ, where R = 305 pc is the distance of the structure and θ = pixel size (in radian). After calculation the major and minor diameter of the cavity region are found to be 2.3 pc and 0.21 pc respectively. Thus, the size of the structure is 2.3 pc × 0.21 pc .

Dust Mass Estimation and its variation

For the calculation of dust mass, we need the distance to the region of interest. The distance of the structure is 305 pc [6: 1227]. By using the temperature of each pixel and corresponding distance of the structure, we calculated mass of each pixel. Average mass of each pixel is 2.7x1026 kg and total mass of the structure is 4.4 x 1028 kg i.e 0.02M . But mass of dust obtained around white dwarf WD 1003-44 in [9: 5] is 0.08M . It means mass of dust around AGB Star is less than White Dwarf.

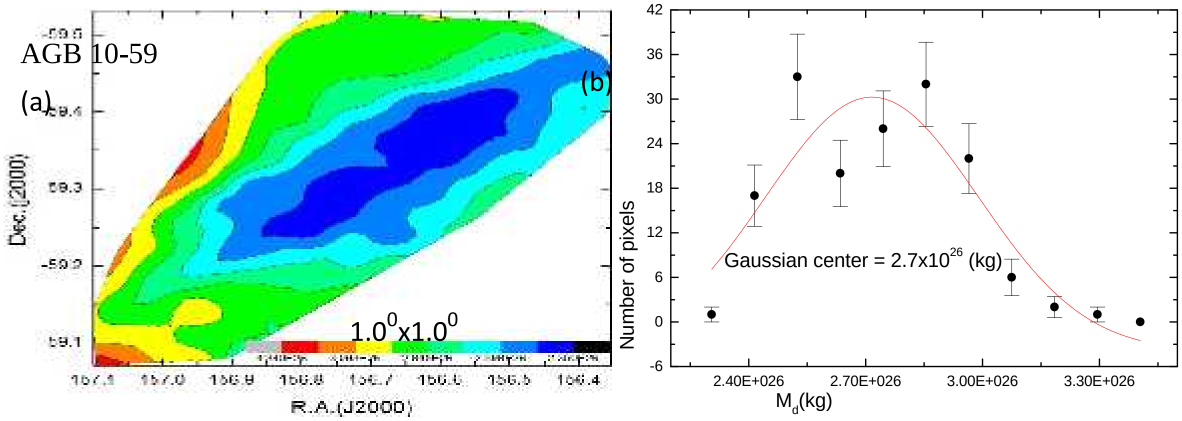

Fig.4: (a) contour map of dust mass and (b) Gaussian fit between mass and number of pixels. The field is centered at R.A.(J2000)= 10h 26m 54.73s and Dec. (J2000) = -59o 18’ 22.5”.

Distribution of dust mass of the pixels within the selected contour level with R.A. (J2000) and Dec.(J2000) are plotted in contour map by using ORIGIN 8.0. Graph obtained is shown in fig.4 (a) which shows that minimum mass region didn't lie at the maximum temperature region in the selected contour which is unusual trend and is possibly due to AGB wind. There is no good agreement in case of dust mass where offset mass is -3.9 kg.

Calculation of Excess Mass

For the calculation of excess mass, we have drawn two circles i.e. inner and outer circle with the help of software Aladin V8.0. Circle through major diameter is supposed as outer circle and the circle through minor diameter is supposed as inner diameter of the interested region. With the help of those circles we have calculated excess mass.

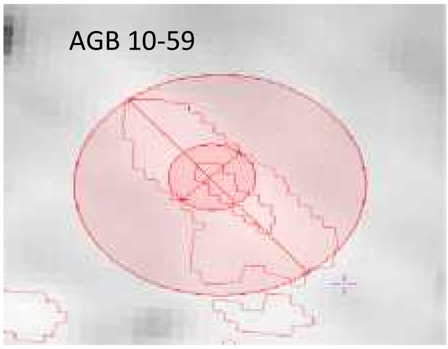

Figure 5: The inner and outer circle drawn in the structure at the center R..A.(J2000)= 10h 26m 54.73s and Dec. (J2000)= -59o 18’ 22.5” for calculation of excess mass.

From the calculation total mass of the inner circle was found to be 9.7 x 1027 kg and the total mass of outer circle including inner circle was 1.2 x 1029 kg . So the mass deficit in the inner pixel which was blown away by the AGB star is 1.1 x 1029 kg i.e. 0.06 M .

Conclusion

The physical properties of the cavity-like structure that we investigated while searching around carbon-rich AGB stars. A study of flux density and dust color temperature maps mass of dust; mass deficit of the cavity was calculated. Our conclusions are as follows:

1. The major and minor diameter of the cavity like structure was found to be 1.55 pc and 0.61 pc respectively.
2. The maximum temperature 23.9 K was found at R.A.(J2000) = 145.120 & Dec.(J2000) = -59.070 and minimum temperature 25.1 K was found at R.A.(J2000) = 145.360 & Dec.(J2000) = -59.470 with offset of 1.2 K.. Low offset in the temperature hints that there is symmetric outflow or symmetric distribution of density and temperature.
3. In general, minimum flux and minimum temperature lie at same point in the pixel but in this case minimum temperature is shifted which may be due to external factors, possibly wind emitted from the AGB star. Similarly maximum temperature and minimum mass region didn't lie at same region which isn't normal behavior.
4. Average mass of dust in each pixel is 2.7x1026 kg.
5. Total mass of inner circled cavity was 9.7 x 1027 kg and that of the outer circle including inner circle was 1.2 × 1029 kg . The mass deficit of the structure was 1.1 × 1029 kg i.e. 0.06 M.

We intend to study the role of cabon-rich AGB star to form the far-infrared cavity in the future.

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