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# SEDs and Age Estimates of MYSOs: Study of Galactic Massive Star Forming Regions

Kamal Kumar Tanti, Jayashree Roy, Dr. Kalpana Duorah

**Abstract—** In this paper, we present the spectral energy distributions (SEDs) of six massive young stellar objects (MYSOs) detected from the NIR imaging survey carried out by Varricatt et al. (2010) and estimated their ages and masses. The SEDs of YSOs in six massive star forming regions has been reconstructed using 2MASS, MSX, IRAS, IRAC & MIPS, SCUBA, WISE, SPIRE and IRAM data partly available from previous works using the on-line SED Fitting tool (SED Fitter) developed by Robitaille et al. (2006, 2007). Apart from IRAS catalogue fluxes, the fluxes in the Mid-IR and sub-mm/mm were derived directly from the images. With the help of the analysis of spectral energy distributions, we have extracted important physical and structural parameters for each of the massive young stellar objects, along with the associated circumstellar disk and envelope. The cumulative distribution of stellar ages and masses of the massive YSOs indicates to a scenario for the formation history of massive stars in their respective star forming regions.

**Index Terms**— Spectral Energy Distribution (SED), Young Stellar Objects (YSO), Massive Star Forming Regions, Massive Star Formation, Age, Mass, On-line SED Fitting Tool, Circumstellar Disk, Envelope.

## 1 INTRODUCTION

MASSIVE stars (with mass M ≥ 8 M⊙, M⊙ = Solar Mass), formed in dense cores of molecular clouds, play a key role in the evolution of the Universe, by producing heavy elements, that injects energy within the interstellar medium and thereby regulate the rate of star formation. Though the luminosity of massive stars enables a complete census of their formation processes take place in the galaxy, still the formation and early evolution of massive stars are not at all well-understood. There are many reasons. During their early formation processes, it is generally very difficult to observe the massive stars due to their high dust extinction and shorter pre-main sequence time scale. In addition, massive stars seldom form in isolation; they formed in clusters and associations. Also, the radiation pressure generated by a massive proto-star, once the mass has reached ≈ 10 M⊙, would seem sufficient to be able to halt any further accretion. Thus it always remains a mystery how the massive stars are formed.


- ***Kamal Kumar Tanti*** *is currently pursuing PhD in Astronomy and Astrophysics in the Department of Physics, Gauhati University, Guwahati-781014, Assam, India. E-mail: research.kamal@gmail.com*
- ***Jayashree Roy*** *is a Post-doctoral Fellow at the Indian Institute of Astrophysics (IIA), Bangalore -560034, India. E-mail: jayashree.roy@gmail.com, jayashree@iiap.res.in*
- ***Dr. Kalpana Duorah****, Reader, Department of Physics, Gauhati University, Guwahati - 781014, Assam, India, E-mail: khowang56@yahoo.co.in*


The formation and the initial stages of the evolution of massive stars in our Galaxy take place inside dense regions within molecular clouds, from which they are born. This is the reason why the star formation studies have necessarily to deal with the protostars/young stellar objects (YSOs) in the environment of interstellar gas and dust from the parent cloud. In this environment, the young stellar objects and protostars are associated with circumstellar dust and molecular gas, which absorbs the stellar radiation and re-emits it to wavelengths long wards than 1 µm (Lada 1987). According to Lada, the protostars have a Spectral Energy Distribution (SED) with a positive slope in the 2-20 µm spectral range. By the shapes of the Spectral Energy Distributions (SEDs), Lada and his collaborators first classified pre-main sequence (PMS) stars into an evolutionary sequence, Classes I through III (later an earlier stage, Class 0 was also proposed to describe more deeply embedded sources). This has been proved for low mass YSOs, e.g. in Taurus Star Formation region (Hartmann et al. 2005). The case for young massive stars is topic of recent investigation (Zinnecker & York 2007).

The study of the circumstellar environment of Young Stellar Objects (YSOs) is very much important for understanding the pre-main sequence evolution processes of the stars. In order to study unresolved or close-to unresolved YSOs in distant regions, multi-wavelength photometry can be done and subsequently, the Spectral Energy Distributions (SEDs) can be constructed, from which various physical parameters of the source can be obtained.

The basic approach to analyze SEDs is to compute the radiation transfer models, first assuming a given circumstellar dust and gas geometry, as well as dust properties, predicting the emergent SED and finding a set of parameters that reproduce the observations. The main advantages of this technique are: one gets an insight into the actual physical properties of the source, rather than simply quantifying the shape of the SED; it can make use of any data available, while not being limited by the lack of a data point at a given wavelength. The more data are present, the better the parameters will be constrained.

The outline of this paper is as follows. Section 2 describes the radiation transfer modeling scheme including the treatments of radiative transfer in the dust and the gas components respectively. Section 3 presents the reason behind the selection of the six sources. The results of modelling in the form of structural and physical information extracted for these six sources are presented in Section 4. Conclusions are summarized in section 5.

## 2 Radiative Transfer Modeling and SED Fitting Tool

In order to characterize the physical properties and the evolutionary status of disks and envelopes around all the selected six YSO outflow sources, the SEDs of YSOs were modelled using on-line SED Fitting Tool of Robitaille et al. (2007), that uses a grid of 2D radiative transfer models presented in Robitaille et al. (2006), developed by Whitney et al. (2003, 2003b).

Robitaille et al. I & II (2006 & 2007) presented a grid of radiation transfer models of axisymmetric young stellar objects (YSOs), covering a wide range of stellar masses (from 0.1 to 50$M_\odot$) and evolutionary stages (from the early envelope infall stage to the late disk-only stage). The grid consists of 20,000 YSO models, with spectral energy distributions (SEDs) and polarization spectra computed at 10 viewing angles for each model, resulting in a total of 200,000 SEDs.

We have carried out the radiation transfer modeling of all the selected six sources, to extract the various physical parameters of the particular region, following Robitaille et al. I & II (2006 & 2007), and using the SED fitting tool, available online. Running the radiation transfer modelling with the tool, we have obtained a best-fit YSO SED plot for every source, where all the available data, for the given sources, in different wavelength bands, are fitted. We also extracted the top 10 YSO SED fits, at the same aperture, inclination angle, and different $\chi 2$ (Total) & Av values, that match the best-fit YSO SED, for the given source. The top 10 best-fit YSO SED models correspond to the SEDs at the correct viewing angle and at the same aperture (≈ 2762 AU). The first of the top 10 best-fit YSO SED models, with less $\chi 2$ (Total) value has been considered, as this model gives the best-matched YSO SED fit for the given source. We have tabulated all the physical parameters of the all the sources, as well as the circumstellar disk & envelope that correspond to the best-matched YSO SED fit, from which one can surely get insight of the respective YSO, as well as the disk and envelope.

To obtain better results, we compiled and used all the available NIR, MIR and FIR data, whichever available for the respective source. The 2MASS J-H-Ks band data, magnitudes in the Spitzer IRAC bands 1–4 & MIPS bands 1-2, IRAS 12, 25, 60, 100-µm data, MSX Bands A, C, D & E data, SCUBA 450 & 850-µm data, WISE 3.4, 4.6, 12, 22-µm data, SPIRE 250, 350, 500-µm data and the IRAM 1.2 mm data, were used to construct the SEDs of the all the sources, driving the outflow. All the six sources, SEDs are constructed using the above-said data, available from SIMBAD, VIZIER and other available literatures.

## 3 Selection of the Sources: YSOs in Galactic Massive Star Forming Regions

We selected six massive young stellar outflow candidates from the NIR imaging survey carried out by Varricatt et al. (2010). Bipolar molecular outflows have long indicated that accretion discs are present at the heart of massive star formation and this is why, we have selected these outflow sources to study and to better understand the processes of massive star formation. Varricatt et al (2010) had selected those candidates that are young, high-mass objects with evidence for outflows. Sources were selected that showed ammonia emission (Molinari et al. 1996) and also $H_2O$ and $CH_3OH$ maser emission (Sridharan et al. 2002), indicators of youth and high-mass. Those with high velocity CO, indicating outflows, from Shepherd & Churchwell (1996) and Beuther et al. (2002a) were included. The sources range in distance from ≈ 0.5 – 8 kpc and in measured bolometric luminosity from $\log (L/L_\odot) \approx 2.2 - 5.4$.

## 4 Results and Discussion

### 4.1 SEDs and Age Estimates of MYSOs: Study of Galactic Massive Star forming regions

As the massive ($M \geq 8$ $M_\odot$) and low & intermediate-mass ($M \leq 8$ $M_\odot$) stars form and evolve following an evolutionary sequence, the physical or structural properties of these young stellar objects also evolve. This indicates that there will be an evolution or variation of such properties. Fitting their Spectral Energy Distributions (SEDs) can provide us these properties, which can give us insights to understand the physical and structural evolution of pre-main sequence stars as well as the evolution of star clusters where these massive stars were born. In addition, it also provides evidence on the reliability of the particular SED fitting tool, which will contribute in improving the tool itself.

With the aim of extracting important geometrical and physical details of the galactic star forming regions— IRAS 18144-1723, IRAS 18345-0641, IRAS 19217+1651, IRAS 19410+2336, IRAS 21519+5613 & IRAS 22305+5803, we have calculated, examined and analyzed the physical and structural parameters of all the above six massive YSO outflow candidates (Varricatt et al. 2010), using the on-line SED fitting tool (SED fitter) of Robitaille et al. (2006, 2007). These sources have been selected to estimate the masses and ages and other parameters of every particular massive star forming regions, thereby providing a glimpse of the massive star formation processes. In addition, they have adequate observational data necessary to constrain the models. In what follows, the brief details of these sources along with the data available from different data sets and literatures and the results of radiative transfer models of the sources are described.

The physical properties of the central source, such as effective temperature and luminosity, are the most important parameters in understanding the evolutionary status of the central source, and play a crucial role in the physical properties of disks and envelopes, because dust in the disks and envelopes are heated by irradiation from the star and from accretion shocks at the stellar surface (Sung et el. 2010). Also, our one important aim is to calculate the stellar age and stellar mass that can be compared with the other available data and the evolutionary sequence.

The physical and structural parameters of all the six massive YSO outflow candidates, along with the associated circumstellar disk and envelope, obtained with the help of SED Fitting Tool, are shown in the Tables 1-6. Also, the best-fit model SEDs for all the six selected massive YSO outflow sources, viz. IRAS 18144-1723, IRAS 18345-0641, IRAS 19217+1651, IRAS 19410+2336, IRAS 21519+5613 & IRAS 22305+5803, are shown in the Figures 1-6, respectively.

## 4.2 Physical and Structural Parameters of Massive Young Stellar Objects (MYSOs)

In this section, we compile the results of SED modeling and computed the physical and structural parameters of all the six selected massive young stellar objects. We also present the best-fit model SEDs for all the six sources. In addition, we tabulated the physical and structural parameters of the sources in form of tables.

### (a) IRAS 18144-1723

IRAS 18144-1723 is an infra-red (IR) source and candidate massive star forming region, with inferred distance of 4.33 kpc and luminosity of $21.2\times10^3 L_\odot$. This region is associated with an ammonia core (Molinari et al. 1996) and water and methanol masers (Palla et al. 1991; Szymczak et al. 2000; Kurtz et al. 2004). From the (sub-)mm continuum emission study, Fontani et al. (2006) derived the following parameters of the IR source: deconvolved angular diameter ($\theta_{cont}$) ≈ 14.8 arcsec, integrated 850 µm continuum flux ($F_\nu$) ≈ 7.76 Jy, linear size (D) ≈ 0.31 pc, gas+dust mass ($M_{cont}$) ≈ 1118 $M_\odot$ and Visual extinction ($A_v$) ≈ 496 mag. The integrated 450 µm continuum flux ($F_\nu$) is estimated 28.3 Jy. From the SED model fits, Molinari et al. (2008) classified the source as an IR-P (Infrared-Primary) source and of spectral type O5 and derived parameters for the source: bolometric luminosity $176\times10^3 L_\odot$, envelope mass 2145 $M_\odot$, envelope radius $30\times10^4$ AU.

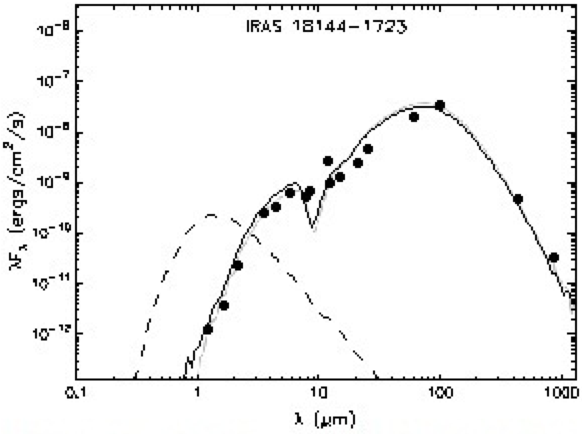


**Fig. 1. The Best-fit model SED for IRAS 18144-1723**

Fig. 1 shows the best-fit YSO SED model for IRAS 18144-1723. The physical and structural parameters of the source, as well as the circumstellar disk & envelope are estimated and tabulated in the Table 1 which corresponds to the best-matched YSO SED fit.

With the help of the SED Fitting tool developed by Robitaille et al. (2007) and subsequent analysis of spectral energy distributions of the massive young stellar object, we have extracted different physical and geometrical parameters for the young stellar source IRAS 18144-1723, along with the associated circumstellar disk and envelope. These parameters are tabulated in Table 1. The best-fit YSO SED model of the source is shown in Figure 1. IRAS 18144-1723 is a young Class I model that has stellar mass 15.44 $M_\odot$, stellar temperature of 14,321 K, stellar age $2.10\times10^4$ yr and stellar radius 24.22 $R_\odot$. The central YSO source is surrounded by a $1.29 \times 10^{-2}$ $M_\odot$, 75.6 AU disk and a $3.0\times10^3$ $M_\odot$, $1.0 \times 10^5$ AU envelope with an accretion rate of $5.76 \times 10^{-3}$ $M_\odot$/yr, viewed at an inclination

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angle of i = 31.8º. The interstellar extinction necessary for this model to fit the data is $A_v$ = 102 mag.

**Table 1: Physical and structural parameters of IRAS 18144-1723.**

| Parameters | Values |
|---|---|
| Stellar Age (yr) | 2.10e+4 |
| Stellar Mass ($M_\odot$) | 15.44 |
| Stellar Radius ($R_\odot$) | 24.22 |
| Stellar Temperature (K) | 14321 |
| Envelope Accretion Rate ($M_\odot$/yr) | 5.76e-3 |
| Envelope Outer Radius (AU) | 1.00e+5 |
| Envelope Cavity Angle (degrees) | 23.5 |
| Envelope Inner Radius ($R_{sub}$) | 2.32e+0 |
| Disk Mass ($M_\odot$) | 1.29e-2 |
| Disk Outer Radius (AU) | 7.56e+1 |
| Disk Inner Radius ($R_{sub}$) | 2.32e+0 |
| Disk Inner Radius (AU) | 2.61e+1 |
| Disk Scaleheight factor | 0.742 |
| Disk Flaring Power | 1.132 |
| Disk Accretion Alpha | 6.97e-2 |
| Envelope Cavity density (cgs) | 1.30e-20 |
| Ambient density (cgs) | 9.60e-21 |
| Disk accretion rate ($M_\odot$/yr) | 1.63e-6 |
| $A_v$ [circumstellar] (mag) | 1.02e+2 |
| Total Luminosity | 2.22e+4 |
| Disk Scaleheight at 100AU | 6.79 |
| Envelope Mass | 3.00e+3 |

### (b) IRAS 18345-0641

IRAS 18345-0641 is one of the high mass YSOs surveyed by Sridharan et al. (2002) and Beuther et al. (2002b,c,d), with distance measured as 9.5 kpc and luminosity of 39.8×$10^3$ $L_\odot$. The source has a single, moderately collimated outflow, extending over 1.84 pc and of estimated mass 143 $M_\odot$, centred close to the location of the peak mm-emission (Beuther et al. 2002c). Water and methanol masers had been detected by Sridharan et al. (2002) and Beuther et al. (2002d). Szymczak et al. (2000) reported that the maser emission from the source is highly variable and dominated by two main components. Sridharan et al. (2002) reported that the source IRAS 18345-0641 is associated with both maser and centimeter continuum emission. Schnee et al. (2009) considered IRAS 18345-0641 to be a maser-only high-mass protostellar object (HMPO), as the masers and 1.2 mm continuum peak are coincident to within 1 arcsec, but the centimeter continuum emission is offset from the maser position by 44 arcsec, or 2 pc.

Fig. 2 shows the first of the top 10 best-fit YSO SED models for IRAS 18345-0641, as this model gives the best-matched YSO SED model fit for the given source. We have tabulated all the physical parameters of the source, as well as the circumstellar disk & envelope, as shown in the Table 2 that corresponds to the best-matched YSO SED fit, from which one can surely get some insight of the YSO, as well as the disk and envelope.

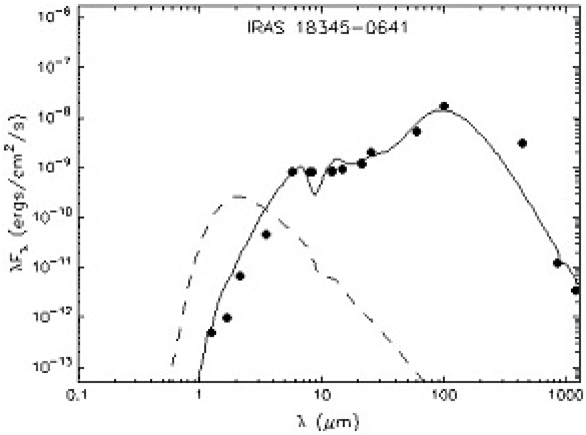


**Fig. 2. The Best-fit model SED for IRAS 18345-0641**

The foreground visual extinction AV is estimated to be 969 mag. The fitting gives a stellar mass of 12.99 $M_\odot$, stellar age of 1.36×$10^4$ yr, stellar temperature of 6733 K and a total luminosity of 7.21×$10^3$ $L_\odot$. The mass of the YSO and the systemic luminosity are reasonably well determined, so are the envelope parameters. The radius of the YSO, the disk accretion rate and the disk mass and radii are estimated as 62.39 $R_\odot$, 5.63×$10^{-6}$ $M_\odot$/yr, 3.47×$10^{-2}$ $M_\odot$ and 10.3 AU respectively. The parameters related to envelope that surround the central source are estimated as: envelope mass ≈ 2680 $M_\odot$, envelope radius ≈ 8.02×$10^4$ AU and envelope accretion rate ≈ 5.72×$10^{-3}$ $M_\odot$/yr.

**Table 2: Physical and structural parameters of IRAS 18345-0641.**

| Parameters | Values |
|---|---|
| Stellar Age (yr) | 1.36e+4 |
| Stellar Mass ($M_\odot$) | 12.99 |
| Stellar Radius ($R_\odot$) | 62.39 |
| Stellar Temperature (K) | 6733 |
| Envelope Accretion Rate ($M_\odot$/yr) | 5.72e-3 |
| Envelope Outer Radius (AU) | 8.02e+4 |
| Envelope Cavity Angle (degrees) | 5.9 |
| Envelope Inner Radius ($R_{sub}$) | 1.25e+0 |
| Disk Mass ($M_\odot$) | 3.47e-2 |
| Disk Outer Radius (AU) | 1.03e+1 |
| Disk Inner Radius ($R_{sub}$) | 1.25e+0 |
| Disk Inner Radius (AU) | 7.42e+0 |
| Disk Scaleheight factor | 0.986 |
| Disk Flaring Power | 1.046 |
| Disk Accretion Alpha | 2.80e-3 |
| Envelope Cavity density (cgs) | 4.32e-20 |
| Ambient density (cgs) | 3.37e-21 |
| Disk accretion rate ($M_\odot$/yr) | 5.63e-6 |
| $A_v$ [circumstellar] (mag) | 9.69e+2 |
| Total Luminosity | 7.21e+3 |
| Disk Scaleheight at 100AU | 6.10 |
| Envelope Mass | 2.68e+3 |

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### (c) IRAS 19217+1651

IRAS 19217+1651 is a massive star forming region, associated with a massive dust core detected at 850 and 450 µm by Williams et al. (2004) and at 1200 µm by Beuther et al. (2002a). This high-mass region IRAS 19217+1651, at an inferred distance of 10.5 kpc and with luminosity of $79.4\times10^3$ $L_\odot$, exhibits a bipolar outflow, whereas the region is dominated by the central driving source (Beuther et al. 2004). The core has major and minor axes of 18 arcsec and 15 arcsec respectively, at 1.2 mm. This implies an estimated core radius of 0.42 pc (assuming a distance of 10.5 kpc). The mass of the core determined from the 850 µm observations is 2 × 103 $M_\odot$. Class II methanol and water masers was detected by Beuther et al. (2002b) near the peak position of the dust core and so, they suggested that this is a massive-star-forming region in an early stage of evolution. From the radio-continuum observations at 7 mm, done by Very Large Array (VLA), Garay et al. (2007) detected two components of this high-mass source: the emission arises from a bright compact component (labelled A), with an angular size of ≈ 0.16 arcsec, and a more extended, weaker component (labelled B) located 1 arcsec northeast of component A, with an angular size of 0.8 arcsec. The component A is a hypercompact H II region, that is optically thick below 15 GHz, while component B is optically thin in the 8.4–22.5 GHz range, where each component has its own ionizing star. The regions of ionized gas associated with IRAS 19217+1651 is hypercompact, with diameters of 0.009 pc and emission measures of $7.0\times10^8$ pc $cm^{-6}$.

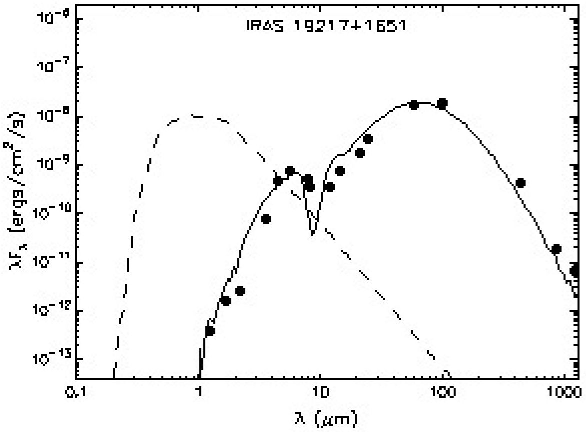


**Fig. 3. The Best-fit model SED for IRAS 19217-1651**

Fig. 3 shows the best-fit YSO SED model for IRAS 19217+1651. The physical and structural parameters of the source, as well as the circumstellar disk & envelope are tabulated in the Table 3 that corresponds to the best-matched YSO SED fit.

With the help of the analysis of spectral energy distributions, we have extracted some physical parameters for the young stellar source IRAS 19217+1651, along with the associated circumstellar disk and envelope. These parameters are tabulated in Table 3. The best fit model to source shown in Figure 3 is a young Class I model with stellar age of $8.11\times10^3$ yr, stellar temperature of 5066 K, stellar mass of 13.67 $M_\odot$, stellar radius of 117.78 $R_\odot$ central source surrounded by a $1.04\times10^{-2}$ $M_\odot$, 58.3 AU disk and a $1.15\times10^3$ $M_\odot$, $1.0\times10^5$ AU envelope with disk accretion rate of $4.62\times10^{-8}$ $M_\odot$/yr and envelope accretion rate of $1.92\times10^{-3}$ $M_\odot$/yr, viewed at an inclination of i = 31.8º. The interstellar extinction necessary for this model to fit the data is Av = 103 mag.

**Table 3: Physical and structural parameters of IRAS 19217+1651**

| Parameters | Values |
|---|---|
| Stellar Age (yr) | 8.11e+3 |
| Stellar Mass ($M_\odot$) | 13.67 |
| Stellar Radius ($R_\odot$) | 117.78 |
| Stellar Temperature (K) | 5066 |
| Envelope Accretion Rate ($M_\odot$/yr) | 1.92e-3 |
| Envelope Outer Radius (AU) | 1.00e+5 |
| Envelope Cavity Angle (degrees) | 17.1 |
| Envelope Inner Radius ($R_{sub}$) | 3.88e+0 |
| Disk Mass ($M_\odot$) | 1.04e-2 |
| Disk Outer Radius (AU) | 5.83e+1 |
| Disk Inner Radius ($R_{sub}$) | 3.88e+0 |
| Disk Inner Radius (AU) | 2.38e+1 |
| Disk Scaleheight factor | 0.774 |
| Disk Flaring Power | 1.069 |
| Disk Accretion Alpha | 2.30e-3 |
| Envelope Cavity density (cgs) | 1.36e-20 |
| Ambient density (cgs) | 5.61e-21 |
| Disk accretion rate ($M_\odot$/yr) | 4.62e-8 |
| $A_v$ [circumstellar] (mag) | 1.03e+2 |
| Total Luminosity | 8.20e+3 |
| Disk Scaleheight at 100AU | 5.07 |
| Envelope Mass | 1.15e+3 |

### (d) IRAS 19410+2336

IRAS 19410+2336 is a young massive star forming region which is considered as a prime example of the complexity of high-mass star formation due to the intense outflow activity ongoing there. The distance and luminosity of the source are estimated as 2.1, 6.4 kpc and (10, 100) $\times10^3$ $L_\odot$, respectively. From 1.2 mm dust continuum map of IRAS 19410+2336 obtained with the IRAM 30m telescope at low spatial resolution, Beuther et al. (2002b) reveals that there are two massive adjacent star forming clumps that roughly aligned in a north-south direction and

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separated by ≈ 53 arcsec. They also implied that the southern clump, with a mass of about 840 $M_{\odot}$, is more massive than the northern clump, with a mass of 190 $M_{\odot}$. Using the observations in CO (2-1) with 11 arcsec angular resolution, Beuther et al. (2002c) showed that each of the northern and southern clumps is associated with a bipolar molecular outflow in the east-west direction. The southern clump is resolved into at least four cores in the 2.6 mm continuum using the Plateau de Bure Interferometer, whereas the northern clump is resolved into two cores (Beuther et al. 2003). They found at least seven (possibly even nine) bipolar outflows in this region with accretion rates of the order of $10^{-4}$ $M_{\odot}yr^{-1}$, sufficiently high to overcome the radiation pressure and form massive stars via continuous disk accretion processes. The higher spatial resolution observations at 1.3mm, and also with the Plateau de Bure Interferometer, show that these two clumps split up into a even larger number of substructures, with at least 12 cores in each one (Beuther & Schilke 2004). These cores have masses ranging between 1.7 and 25 $M_{\odot}$, and visual extinctions of up to 1000 mag. At the very centre of the southern clump and coinciding with the most prominent of the mm sources, Beuther et al. (2002d) detected $H_2O$ and Class II $CH_3OH$ masers, which are considered to be closely associated with the earliest stages of massive star formation. Only at this position is there evidence for a weak 1 mJy unresolved (at angular resolution of 0.7 arcsec) cm continuum source (Sridharan et al. 2002). Beuther et al. (2002a) reported the detection of hard X-ray emission from a number of point sources in the vicinity of IRAS 19410+2336. They conclude that this X-ray emission is due to intermediate-mass pre-main-sequence Herbig Ae/Be stars or their precursors. So far, only the kinematic distance to this object is known and there exists a distance ambiguity, with a near distance of 2.1 kpc and a far distance of 6.4 kpc (Sridharan et al. 2002).

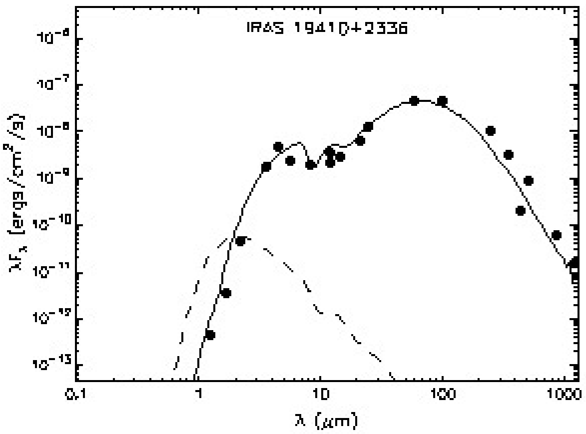


**Fig. 4. The Best-fit model SED for IRAS 19410+2336.**

In 2004, Beuther & Schilke derived the first Core Mass Function (CMF) for a massive star forming (MSF) region and this region is IRAS 19410+2336. They found that this CMF also resembled the Salpeter IMF (Initial Mass Function) and the CMF and the IMF are related in a one-to-one or nearly one-to-one relationship. This suggests that the fragmentation processes within a molecular cloud would set the shape of the IMF at an early evolutionary stage.

Fig. 4 shows the best-fit YSO SED model for IRAS 19410+2336. With the study of spectral energy distributions, the physical and structural parameters of the source, as well as the circumstellar disk & envelope are estimated and tabulated in the Table 4 which corresponds to the best-matched YSO SED fit.

**Table 4: Physical and structural parameters of IRAS 19410+2336**

| Parameters | Value |
|---|---|
| Stellar Age (yr) | 7.77e+4 |
| Stellar Mass ($M_{\odot}$) | 10.10 |
| Stellar Radius ($R_{\odot}$) | 9.64 |
| Stellar Temperature (K) | 17996 |
| Envelope Accretion Rate ($M_{\odot}$/yr) | 2.08e-3 |
| Envelope Outer Radius (AU) | 1.00e+5 |
| Envelope Cavity Angle (degrees) | 33.2 |
| Envelope Inner Radius ($R_{sub}$) | 1.17e+1 |
| Disk Mass ($M_{\odot}$) | 9.77e-3 |
| Disk Outer Radius (AU) | 8.62e+1 |
| Disk Inner Radius ($R_{sub}$) | 1.17e+1 |
| Disk Inner Radius (AU) | 8.56e+1 |
| Disk Scaleheight factor | 0.957 |
| Disk Flaring Power | 1.158 |
| Disk Accretion Alpha | 1.97e-2 |
| Envelope Cavity density (cgs) | 2.68e-21 |
| Ambient density (cgs) | 1.93e-21 |
| Disk accretion rate ($M_{\odot}$/yr) | 1.19e-5 |
| $A_v$ [circumstellar] (mag) | 2.84e+1 |
| Total Luminosity | 9.06e+3 |
| Disk Scaleheight at 100AU | 9.89 |
| Envelope Mass | 1.14e+3 |

Given an input distance range of 2 - 6 kpc, the SED fitting tool finds that the first best-fit model to the SED of IRAS 19410+2336 have central star mass of 10.1 $M_{\odot}$, stellar temperature of 17,996 K and stellar radius of 9.64 $R_{\odot}$. The stellar age and total luminosity of the YSO are estimated as $7.77\times10^4$ yr and $9.06\times10^3$ $L_{\odot}$. The parameters of envelope and disk that surround the central source are calculated as: envelope mass ≈ $1.14\times10^3$ $M_{\odot}$, envelope radius ≈ $1.0\times10^5$ AU and envelope accretion rate ≈ $2.08\times10^{-3}$ $M_{\odot}$/yr; and disk mass ≈ $9.77\times10^{-3}$ $M_{\odot}$, disk radius ≈ 86.2 AU & disk accretion rate ≈ $1.19\times10^{-5}$ $M_{\odot}$/yr. The interstellar extinction for fitting this model is Av = 28.4 mag.

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### (e) IRAS 21519+5613

IRAS 21519+5613 is luminous far-Infrared (FIR) source which has been have been proposed to be precursors of UC HII regions by Molinari et al. (1996, 1998). Su et al. (2004) estimated the far-IR luminosity of this source as 1.91 × $10^4$ L$_\odot$ at their inferred distance of 7.3 kpc. Despite its high luminosity, no radio emission at 6 cm was detected toward this source at a 3σ upper limit of ≈ 0.3 mJy beam$^{-1}$ in 3 arcsec beam (Molinari et al. 1998). This places an upper limit on the diameter of any UC-HII region (assuming that it is optically thick at 6 cm and has an electron temperature of ≈ 10,000 K) of ≈ 0.001 pc, 2 orders of magnitude smaller than the typical size of UC-HII regions. This luminous IRAS source exhibit water maser activity and is associated with dense molecular gas traced by ammonia and CS (J = 2-1) (Wouterloot, Brand, & Fiegle 1993; Molinari et al. 1996; Bronfman, Nyman, & May 1996; Migenes et al. 1999). This implies that this source is a credible candidate high-mass protostar (Su et al. 2004).

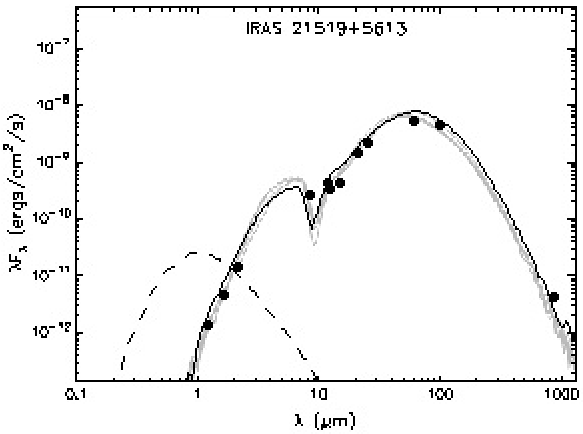


**Fig 5. The Best-fit model SED for IRAS 21519+5613.**

Fig. 5 shows the best-fit YSO SED model for IRAS 21519+5613. The physical and structural parameters of the source, as well as the circumstellar disk & envelope are estimated and tabulated in the Table 5 which corresponds to the best-matched YSO SED fit.

The SED fitting tool gives a stellar mass of 11.69 M$_\odot$, stellar radius of 6.79 R$_\odot$, stellar temperature of 24,558 K and a total luminosity of 1.51×$10^4$ L$_\odot$ for the YSO central source, IRAS 21519+5613. The stellar age is estimated as 6.74×$10^4$ yr and the interstellar extinction for fitting this model is $A_v$ = 72.4 mag. The disk parameters, viz., disk mass, disk radius and disk accretion rate are measured as 2.11×$10^{-3}$ M$_\odot$, 146 AU, and 4.48×$10^{-8}$ M$_\odot$/yr respectively. The parameters of envelope that surround the central source are calculated as: envelope mass ≈ 1.45×$10^3$ M$_\odot$, envelope radius ≈ 1.0×$10^5$ AU and envelope accretion rate ≈ 2.34×$10^{-3}$ M$_\odot$/yr.

**Table 5: Physical and structural parameters of IRAS 21519+5613.**

| Parameters | Value |
|---|---|
| Stellar Age (yr) | 6.74e+4 |
| Stellar Mass (M$_\odot$) | 11.69 |
| Stellar Radius (R$_\odot$) | 6.79 |
| Stellar Temperature (K) | 24558 |
| Envelope Accretion Rate (M$_\odot$/yr) | 2.34e-3 |
| Envelope Outer Radius (AU) | 1.00e+5 |
| Envelope Cavity Angle (degrees) | 21.3 |
| Envelope Inner Radius (R$_{sub}$) | 1.00e+0 |
| Disk Mass (M$_\odot$) | 2.11e-3 |
| Disk Outer Radius (AU) | 1.46e+2 |
| Disk Inner Radius (R$_{sub}$) | 1.00e+0 |
| Disk Inner Radius (AU) | 9.75e+0 |
| Disk Scaleheight factor | 0.948 |
| Disk Flaring Power | 1.122 |
| Disk Accretion Alpha | 1.29e-2 |
| Envelope Cavity density (cgs) | 2.00e-20 |
| Ambient density (cgs) | 5.41e-21 |
| Disk accretion rate (M$_\odot$/yr) | 4.48e-8 |
| $A_v$ [circumstellar] (mag) | 7.24e+1 |
| Total Luminosity | 1.51e+4 |
| Disk Scaleheight at 100 AU | 9.27 |
| Envelope Mass | 1.45e+3 |

### (f) IRAS 22305+5803

Bronfman et al. (1996) and Molinari et al. (1996) had detected a dense core towards the massive star forming region IRAS 22305+5803, which is at a distance of 5.4 kpc and of luminosity 14.1×$10^3$ L$_\odot$ (Varricatt et al. 2010). The source is associated with water maser emission (Palla et al. 1991). Using high spatial resolution in $HCO^+$ (1-0), Molinari et al. (2002) resolved a remarkable, clumpy ring of line emission with the IRAS position located in the south-west part of the ring. Using VLA 3.6-cm radio continuum observations, they detected a faint radio source (0.12-0.03 mJy) within the western part of the $HCO^+$ ring. With the help of IRAM observations at 1.3mm, they revealed a compact core which is associated with the source detected at 3.6 cm. From the radio flux detected at 3.6-cm, they derive that the source is a B2 ZAMS star. Wouterloot & Brand (1989) detected CO (1-0) emission (with a blue shoulder) in this region. In 2005, Zhang et al. mapped a bipolar outflow in CO line, close to the IRAS source, which implies that there is an ongoing outflow activity in this massive star forming region.

Fig. 6 shows the best-fit YSO SED model for IRAS 22305+5803. The physical and structural parameters of the source, as well as the circumstellar disk & envelope are estimated and tabulated in the Table 6 which corresponds to the best-matched YSO SED fit.

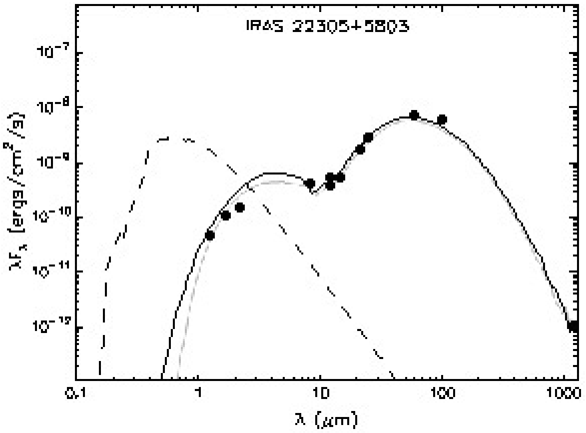


**Fig 6. The Best-fit model SED for IRAS 22305+5803.**

The analysis of SEDs of the massive YSOs for the source gives us different physical and geometrical parameters for the young stellar source IRAS 22305+5803 as well as for the surrounded circumstellar disk and envelope to the central source. These parameters are tabulated in Table 6 and the best-fit YSO SED model of the source shown in Figure 6. IRAS 22305+5803 is a young Class I model that have stellar mass 10.55 $M_\odot$, stellar temperature of 7216 K, and stellar age of $2.80\times10^4$ yr and stellar radius of 38.11 $R_\odot$. The central YSO source is surrounded by a disk of disk mass $9.93 \times 10^{-3}$ $M_\odot$ & disk radius 17.3 AU and an envelope of envelope mass 661 $M_\odot$ and envelope radius of $1.0 \times 10^5$ AU, with an envelope accretion rate of $1.04 \times 10^{-3}$ $M_\odot$/yr, viewed at an inclination of i = 31.8°. The interstellar extinction necessary for this model to fit the data is Av = 20.2 mag.

## 5 SUMMARY AND CONCLUSION

In this paper, we presented all the physical and structural/geometrical parameters of all the six massive YSO outflow candidates, along with the associated circumstellar disk and envelope, obtained with the help of SED Fitting Tool. Also, the best-fit model SEDs for all the six selected massive YSO outflow sources are being presented in this paper which will help us in understanding the physical and structural evolution of pre-main sequence (PMS) stars. Also, it explains self-consistently the embedded Young Stellar Objects (YSO) in dense interstellar clouds as well as the evolution of star clusters in the above massive star forming regions. This leads to a scenario for the formation history of massive stars in their respective star forming regions and subsequently, to a better understanding of the massive star formation processes in dense molecular clouds in our galaxy.

The stellar mass of the target massive YSOs are ranging from 10.1 $M_\odot$ to 15.44 $M_\odot$. The stellar temperatures of the sources are ranging between 5,066 K and 24,558 K. The stellar ages of all the sources are calculated, that ranges between $8.11\times10^3$ yr and $7.7\times10^4$ yr. The stellar radius of the selected YSOs ranges between 6.79 $R_\odot$ to 117.78 $R_\odot$.

The near- and mid-IR fluxes have a significant influence on the reliable determination of the physical and structural parameters of the central source and of their surrounding envelope and disk. Contamination of the source magnitudes at these wavelengths due to the contribution from the associated outflow activities may be the cause for the poor estimate of these parameters. Hence, photometry at high sensitivity and spatial resolution in the 2–20-μm wavelength range is warranted for a more accurate determination of the stellar and disk parameters. Photometry at sub-mm wavelengths also is required for this source to better constrain the model fit.

**Table 6: Physical and structural parameters of IRAS 22305+5803.**

| Parameters | Value |
|---|---|
| Stellar Age (yr) | 2.80e+4 |
| Stellar Mass ($M_\odot$) | 10.55 |
| Stellar Radius ($R_\odot$) | 38.11 |
| Stellar Temperature (K) | 7216 |
| Envelope Accretion Rate ($M_\odot$/yr) | 1.04e-3 |
| Envelope Outer Radius (AU) | 1.00e+5 |
| Envelope Cavity Angle (degrees) | 25.3 |
| Envelope Inner Radius ($R_{sub}$) | 2.52e+0 |
| Disk Mass ($M_\odot$) | 9.93e-3 |
| Disk Outer Radius (AU) | 1.73e+1 |
| Disk Inner Radius ($R_{sub}$) | 2.52e+0 |
| Disk Inner Radius (AU) | 1.06e+1 |
| Disk Scaleheight factor | 0.695 |
| Disk Flaring Power | 1.206 |
| Disk Accretion Alpha | 1.13e-2 |
| Envelope Cavity density (cgs) | 2.84e-20 |
| Ambient density (cgs) | 2.37e-21 |
| Disk accretion rate ($M_\odot$/yr) | 4.64e-7 |
| $A_v$ [circumstellar] (mag) | 2.02e+1 |
| Total Luminosity | 3.54e+3 |
| Disk Scaleheight at 100AU | 6.79 |
| Envelope Mass | 6.61e+2 |

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