IRAS22150+6190: A POORLY STUDIED YOUNG STAR

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ABSTRACT. Many young stellar objects have been discovered in the course of the InfraRed Astronomical Satellite (IRAS) mission, which observed almost the entire sky in four photometric bands between 12 and 100 microns in 1989. These discoveries led to constraining the evolution of stars of various masses and the material that was left from the proto-stellar clouds. Investigation of young stars are important because they allow us to learn more about star and planet formation modes as well as better understand processes of the proto-stellar debris dispersal. Nevertheless, not all optical counterparts of such objects have been revealed or studied in detail. We report our multicolor optical photometric observations of IRAS 22150+6109 obtained at the Tien-Shan Astronomical Observatory near Almaty, Kazakhstan, as well as preliminary results of our analysis of the spectral energy distribution. Fundamental parameters of the star are estimated under an assumption that it has a zero-age main-sequence luminosity and a spectral type of B3. Our plans on further observations and modeling of the object are outlined.

Key words: - Stars: emission-line, Be - Stars: evolution - Stars: pre-main sequence - (Stars:) circumstellar matter - (Stars:) individual: IRAS 22150+6109

1. Introduction

The subject of this study is the infrared source IRAS 22150+6109. We identified it with a $V = 11$ mag star found in the catalog of early-type emission-line objects by Wackerling (1970). The object is located in the direction of an active star-forming region L1188 in Cepheus at a distance of 910 pc from the Sun (Abraham et al., 1995). No emission from H_2O, OH, or CS molecules has been detected from the object (Wouterloot et al., 1993; Bronfman et al., 1996). Results on CO emission are controversial: negative detection by Wouterloot & Brand (1989) and positive detection by Kerton & Brunt (2003). Nevertheless, IRAS22150+6109 exhibits a strong infrared excess that is indicative of an intermediate-mass star in transition from the pre-main-sequence to main-sequence stage of evolution. The nearly main-sequence status is supported by a weak Hα emission detected by the Hamburg survey for emission-line stars (Kohoutek & Wehmeyer, 1999). It is included in a catalog of reflection nebulae Magakian (2003).

Our goal was to obtain an optical spectrum and optical multicolor photometry of the star to constrain its spectral energy distribution (SED), collect available infrared photometric data, and model the SED to derive the properties of the circumstellar dust.

2. Observations

The star was observed photometrically at the Tien-Shan Astronomical Observatory (near Almaty, Kazakhstan) in $UBVRI$–bands of the Johnson photometric system using the photometer FP3U (Bergner et al., 1988). Ten observations were obtained in 1997–1999. The photometry was published by Kuratov (2004). Additionally, a high-resolution spectrum ($R = 60000$) was obtained at the 2.7 m telescope of the McDonald Observatory (Texas, USA) in 2009 by one of us (A.M.).

Infrared photometric data were collected from different catalogs. Near-IR data in the JHK–bands were taken from the 2MASS catalog (Cutri et al., 2003), fluxes in four bands between 3.4 and 21 μm were taken

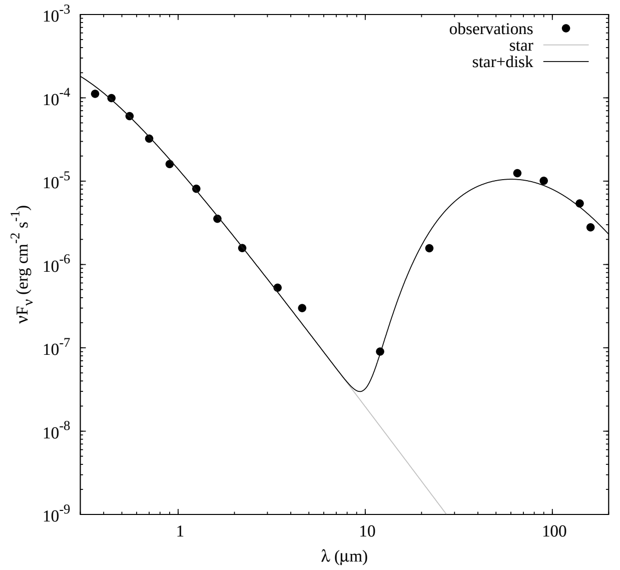

Figure 1: The observed photometric SED of IRAS 22150+6109 (black dots) is shown in comparison with the best-fit face-on disk model (black solid line). The model spectrum is shown with the gray solid line.

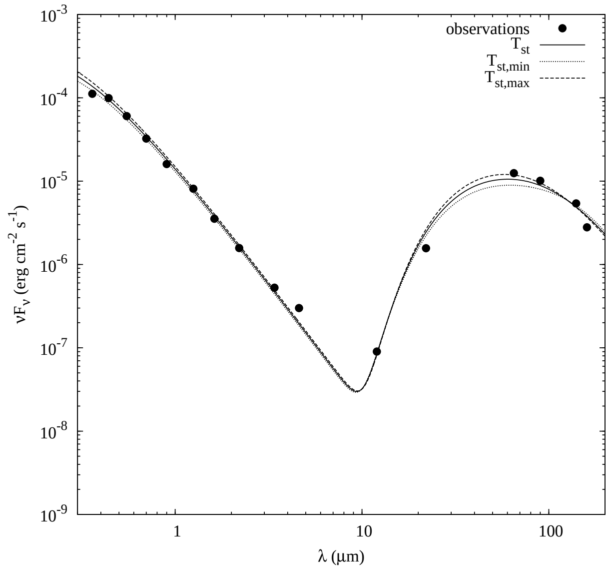

Figure 2: Best-fit SEDs for the star with T_* - solid line, $T_{*,min}$ - dotted line and $T_{*,max}$ - dashed line. The observed SED of IRAS 22150+6109 (black dots).

from the WISE catalog (Wright et al., 2010), and fluxes in five bands between 18 and 160 μm were taken from the AKARI catalog (Murakami et al., 2007).

Fluxes measured in magnitudes were converted into energy units using zero-magnitude fluxes adopted from the listed above sources of information. Optical magnitudes were converted into fluxes using the calibration from Straizhys (1977).

3. Data Analysis and Modeling

The spectrum we obtained has a low signal-to-noise ratio but is indicative of the stars properties. The absence of He I lines in emission implies a spectral type later than B2. The Hα line has a very weak single emission peak that points to a nearly face-on disk orientation.

The optical photometry obtained during nearly 2 years shows brightness variations of 0.2 magnitude with an average of $V = 10.82 \pm 0.07$ mag. The average color-indices suggest the stars spectral type of B3 and an extinction of $A_V = 2.0 \pm 0.1$ mag. The infrared photometry was obtained at different times from 2001 to 2010, but the fluxes seem to be consistent with each other (see Fig. 1). The observed SED was dereddened using a standard interstellar extinction law from Savage & Mathis (1979).

To model the SED of IRAS 22150+6109, we assumed that it consisted of a black-body emission from a dwarf star and a protoplanetary disk.

$$f_{\nu,*} = \varphi \pi R_*^2 B_\nu(T_*), \tag{1}$$

where φ is a flux normalization constant, $B_\nu(T)$ is the Plank function, R_* and T_* are the stellar radius and effective temperature. For the calculations we used $R_* = (5 \pm 0.3)\, R_\odot$ and $T_* = 20000 \pm 1000K$, which is typical for a B3 V star. To account for the excess radiation, which we assume to occur at wavelength $\lambda > 1\mu$m, we modeled a SED from a protoplanetary disk following the procedure described by Andrews & Williams (2005).

The flux density is given by

$$f_{\nu,disk} = \varphi \int_{R_{in}}^{R_{out}} B_\nu(T_r) Q_\nu 2\pi r dr, \tag{2}$$

where R_{in} and R_{out} are disk inner and outer radii, respectively. Dust grain emission efficiency $Q_\nu = 1 - exp(-\tau)$ and τ is an optical thickness of the disk material, $\tau = \Sigma_r\, \kappa_\nu$.

The dust opacity is described as a power law in frequency

$$\kappa_\nu = \kappa_0 \left(\frac{\nu}{\nu_0}\right)^\beta, \tag{3}$$

with index β and a normalization of $\kappa_0 = 0.1\, cm^2\, g^{-1}$ at $\nu_0 = 1000$ GHz (Beckwith et al., 1990). This value assumes a 100–to–1 mass gas–to–dust ratio.

The temperature T_r and surface density Σ_r distributions are assumed to be power law functions of the disk radius:

$$T_r = T_{sub} \left(\frac{r}{R_{sub}}\right)^q, \tag{4}$$

$$\Sigma_r = \Sigma_{sub} \left(\frac{r}{R_{sub}}\right)^p, \tag{5}$$

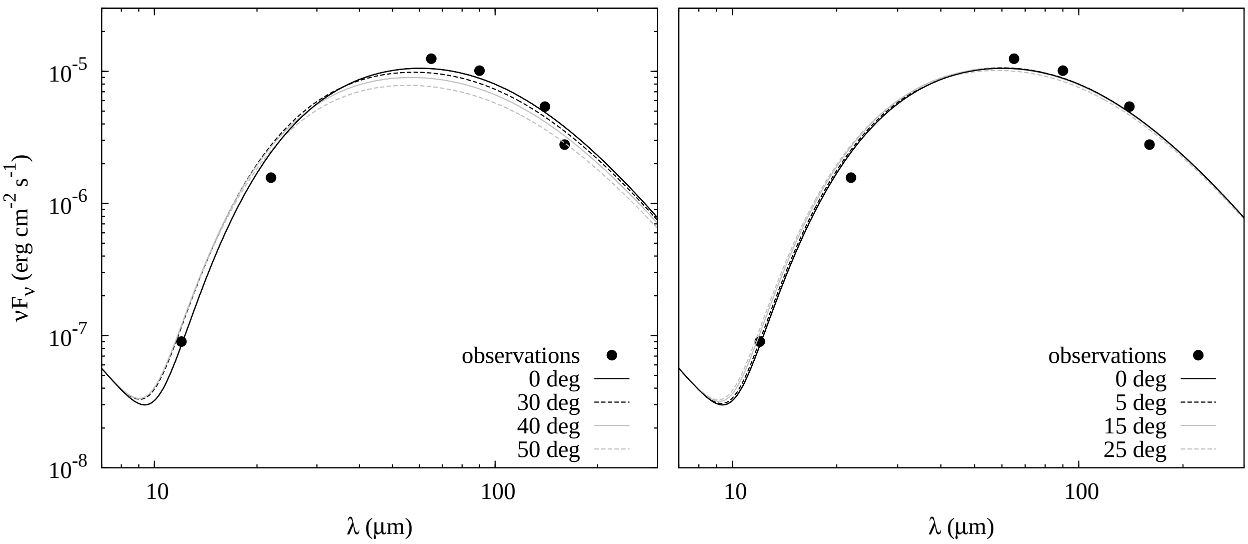

Figure 3: Model SEDs for the system (star+disk) inclined at i = 30–50 degrees (left panel) and for i = 5–25 degrees (right panel). The black solid line in each panel denotes the SED for the system with the disk oriented face-on ($i = 0$ degrees).

where R_{sub} is a disk radius at which it's temperature equals 1500 K - the sublimation temperature T_{sub} of the disk dust particles (Dullemond, Dominic & Natta, 2001). In our particular case $R_{sub} \approx 2$ AU. Σ_{sub} is a surface density at R_{sub}, that equals to 2000 $g\ cm^{-2}$ (Dullemond et al., 2001) and indices p and q are taken to be free parameters.

Based on the calculation algorithms described above, we simulated the SEDs of the disk with different sizes. We varied R_{in} between 2 and 200 AU with a step of 1 AU and R_{out} between 10 and 1500 AU with a step of 10 AU (excluding the cases when $R_{in} = R_{out}$). The surface density power law p we varied from -1.5 (as for the mass surface density of the current solar system, Carpenter et al., 2009) to 0 (constant surface density) with a step of 0.5. We varied β between 0 and 2 with a step of 1 (Beckwith et al., 1990) and q between -0.75 and -0.35 with a step of 0.05 Andrews & Williams (2005).

The best fit we found by minimizing

$$\chi^2 = \sum_{i=1}^{n} \left(\frac{F_{obs} - F_{mod}}{F_{mod}}\right)^2, \quad (6)$$

where F_{obs} and F_{mod} are the observed and modeled fluxes (at the corresponding wavelength) respectively. We assume that disk emission excess only occurs at wavelengths > 1 μm, and hence we consider disk model fits only in this region.

We found that the best fit ($\chi^2 = 0.596$) has a system with R_{in} = 123 AU, R_{out} = 1030 AU, $p = -1, q = -0.65$ and $\beta = 1$. Figure 1 shows the SED for the system with the best fit parameters (black line), the observations (black filled circles), and SED from the star (gray line).

To investigate the modeling uncertainties due to those of the stellar parameters, we found a minimum of χ^2 assuming that T_* is $T_{*,min}$ = 19000 K and $T_{*,max}$ = 21000 K. Such a change of the stellar temperature causes mainly the differences in the disk inner and outer radii: R_{in} from 107 AU to 141 AU and R_{out} from 1180 AU to 770 AU, for $T_{*,min}$ and $T_{*,max}$, respectively. For the star with $T_{*,min}$, the best fit is found for the system with $\beta = 2$. All other parameters for $T_{*,min}$ and $T_{*,max}$ do not change comparing to the ones for T_*. Figure 2 illustrates the total SEDs for the best fit systems with different T_*.

We also analyzed the possibility that the dusty disk is tilted with respect to the line of sight. For this purpose we varied the disk parameters R_{in}, R_{out}, p and β in the same ranges and with the same steps as for the face-on disk. We did not vary q, because in all previous modeling (for different T_*) this parameter was always the same and equal to -0.65. Inclination i was an additional free parameter that we varied from 0 to 50 degrees with a step of 10 degrees. The geometry of an inclined disk was accounted for following the procedure described in Zakhozhay, del Burgo & Zakhozhay (2015), assuming that the inner and outer edges of the disk have a cut-off flat geometry and emit as black bodies with constant temperatures, equal to the temperatures at the inner and outer ages of the disk derived from the equation 4. We found that the minimum χ^2 has the system with the same parameters as those derived for $i = 0$. Figure 3 illustrates how the SED of the system (star+disk) changes with the

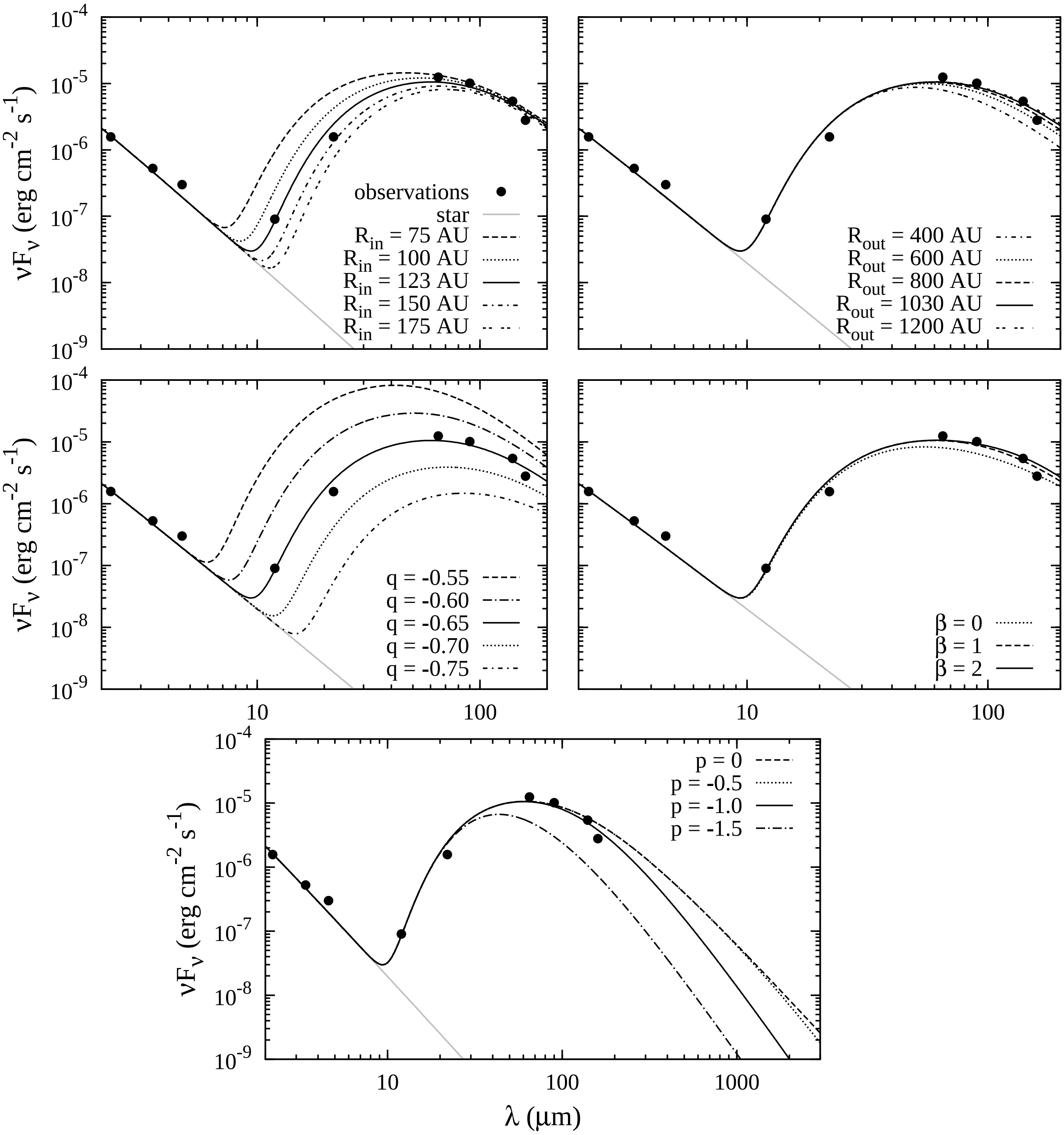

Figure 4: Effects of reasonable variations of the model parameters on the total system SED profile. The black solid line in each panel denotes the SED for the best fit system with $R_{in} = 123$ AU, $R_{out} = 1030$ AU, $p = -1, q = -0.65$ and $\beta = 1$. The parameter being varied from this fiducial set is indicated in each panel. The model spectra is shown with the gray solid line.

inclination increase for 30–50 degrees (left panel) and for 5–25 degrees (right panel). As one can see, the change of the SEDs shape is insignificant for the inclinations up to 10 degrees. In fact, the χ^2 increases only from 0.596 to 0.631. That is why we expect that disk should be oriented close to the face-on. Figure 4 illustrates how total system SEDs depend on the disk model free parameters.

4. Conclusions

From our modeling of the SED of IRAS 22150+6109, we found that the star is surrounded by a dusty disk that has been swept away to a distance of $\sim$60 sublimation radii and is viewed face-on. The disk has a shallower density distribution that a typical accretion disk. The stars brightness corrected for the reddening is consistent with a typical luminosity of a zero-age main-sequence star of the spectral type B3 located at a distance of $\sim$900 pc from the Sun. Our dusty disk modeling confirmed the nearly main-sequence status of the star. With the derived fundamental parameters (Teff, L), the star should have a mass of 6-7 $M_\odot$ and a very short pre-main-sequence lifetime (Palla & Stahler, 1993).

Higher signal-to-noise ratio optical spectra are needed to refine the fundamental parameters and check for binarity, because such stars are frequently born in pairs. We are also planning to model the SED with more realistic dust properties.

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