

Circumsubstellar disk SEDs in dependence on system parameters

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Formulae for critical angles and areas that permit to imagine configurations of observed systems and to calculate their spectral energy distributions (SEDs) as dependencies on their geometrical parameters and inclination angles toward observer are obtained. Using these formulae an atlas of SEDs was created. The SEDs were calculated for 1120 systems with different central object masses, ages, inner disk radii, flaring geometries and inclination angles. The dependencies of SED shapes on systems ages, inclinations and substellar masses are analysed.

Key words: protoplanetary disks, brown dwarfs, spectral energy distribution

INTRODUCTION

At the beginning of this century a physical model for substellar objects (Brown Dwarfs) evolution was created by a research group from the Astronomical Institute of V. N. Karazin Kharkiv National University [5]. This model represents the evolution of substellar objects with masses from 0.01 to 0.08 M_{\odot} and with ages within the range from 1 Myr to 10 Gyr.

On the other hand, with the discovery of circumstellar disk around Vega by Aumann and co-authors [1] the active investigation of protoplanetary disks has begun. During the last decade the observations of protoplanetary disks around substars were actively carried out as well (e. g. [3, 4, 6]). So the aim of this research is to create a new algorithm for calculation of the spectral energy distribution (SED) of protoplanetary disks that may surround such substellar objects, inclined on a given angle, and to study how the changing of different parameters would affect the SEDs shape.

Here we present the results for the following cases:

- substellar masses within the range of 0.01-0.08 M_{\odot} ;
- protoplanetary disks with different inclination (0° - 80°);
- systems ages are 1-30 Myr;
- substars and protoplanetary disks irradiate as a black body;
- distance from the Sun to substar equals to 10 pc;
- inner disk radii equal to central object radius and sublimation radius at the age of 1 Myr.

METHOD OF CALCULATIONS

SEDs for substars and surrounded disks were calculated in a black body approximation. Disks' SEDs were calculated using the model from [2] for a flat passive circumstellar disk. Passive disk is a disk that passively (without accretion) reradiates the energy

it absorbs from the central object. Its temperature T_{disk} changes with distance as:

$$T_{\text{disk}} = \left(\frac{2}{3\pi}\right)^{0.25} \left(\frac{R}{r}\right)^{0.75} T_{\text{eff}}, \quad (1)$$

where R is the central object radius, r is the distance within a disk, T_{eff} is the effective temperature of the central object. The outer disk radius R_{out} was calculated with the formula that was obtained based on the analysis of 107 protoplanetary disks around single main sequence and T Tauri stars [11]:

$$R_{\text{out}}[\text{AU}] = 150 \left(\frac{M}{M_{\odot}}\right)^{0.75}, \quad (2)$$

where M is the mass of the central object.

To take into account the disk inclination the special algorithm for emitting areas projection on the sky plane was created. The formula that permits to calculate limiting angles for systems inclination at first and then the areas of emitting surfaces projections for systems that contain spherical central source and surrounded disk was obtained. This method was previously described in [7, 8, 12].

Using these formulae 1120 SEDs for substars with disks with different geometry and inclination angle were calculated. Calculated arrays for irradiated fluxes that were obtained with the new algorithm are analysed.

The developed calculations algorithm was verified on fluxes received with ground-based and space observations [6]. Simulated SEDs and determined system characteristics for 10 substars from the Upper Scorpius open cluster were presented in [9, 12]. As a result of SED simulations new parameters for inner disk radii, inclination angles and system ages were obtained. New physical parameters (masses,

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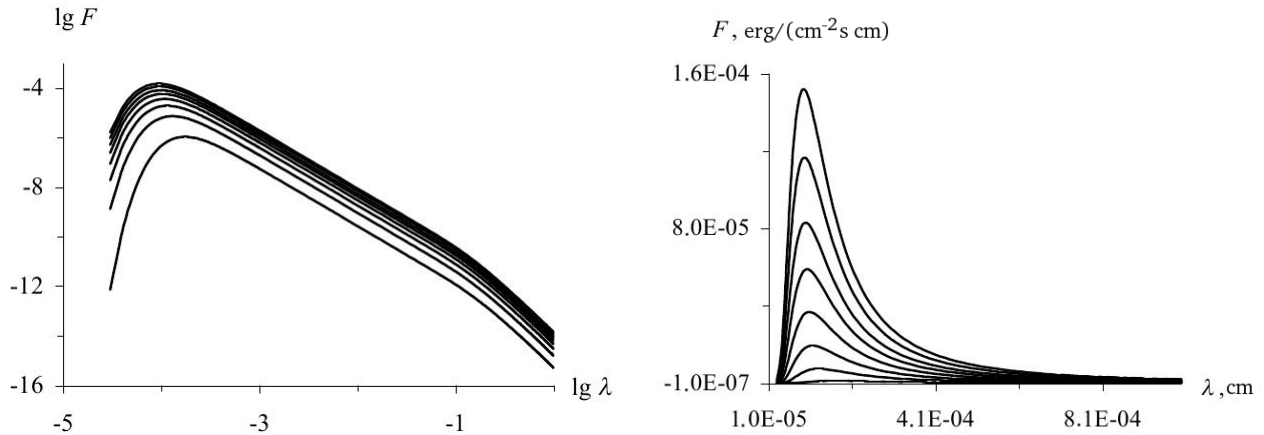


Fig. 1: SEDs for substars with disks located face on without inner holes with age 1 Myr in logarithmic (left) and absolute (right) scales. Different lines correspond to different masses (from top to bottom): $0.08-0.01 M_{\odot}$ with a step $0.01 M_{\odot}$.

radii and effective temperatures) for central substars were estimated as well. Substellar parameters do not differ essentially from that found in [6] (the comparison for 6 systems is shown in a table in [12]) but these data should be improved in future by taking into account atmospheric features of every particular Brown Dwarf.

RESULTS

Mass, chemical composition and age determine the radius of substar, its effective temperature and luminosity. Geometrical parameters of the adopted model are fixed, except the disk inclination, on which the integral flux depends essentially. Therefore, the dependence of flux on substellar mass and age, and the disk inclination toward observer, is analysed. The maximum flux (in systems with defined parameters) belongs to a system with substellar mass $0.08 M_{\odot}$, age 1 Myr, and disk located face on.

Figs. 1-5 show the SED shape of systems without and with an inner hole as a dependence on central Brown Dwarf mass (Fig. 1), age (Fig. 2-3) and inclination (Fig. 4-5) in logarithmic and absolute scale. The SED shape dependence on the inclination angle was studied in detail in [10]. It was noticed that at small inclination angles the flux from the gapless system will be always stronger because the emitting area of such disk is larger. But at large inclination angles the flux from system with inner hole is more intensive. This fact can be interpreted as follows: when disk has no inner hole its inner edge starts to cover a part of the central object at the moment when inclination is $j > 0^{\circ}$. And when the disk inner hole exists, the inner edge of the disk starts to cover a part of the central object at quite large angles (its exact value depends on system geometrical parameters, for the systems that are presented here its value is $\sim 75^{\circ}$). And as a flux from the central object always give the largest contribution to the to-

tal flux, SED of a system with inner hole will have a maximum at largest values.

CONCLUSIONS

The SED shape of Brown Dwarf with protoplanetary disk strongly depends on the age and inclination of the system. The mass of the central object affects mostly its intensity. So exploration makes it possible to determine: firstly, the mass of the central object, and then the presence of inner hole of the system, the approximate age of the system (that permits to exclude an idea of simultaneous star formation in a cluster) and the system inclination.

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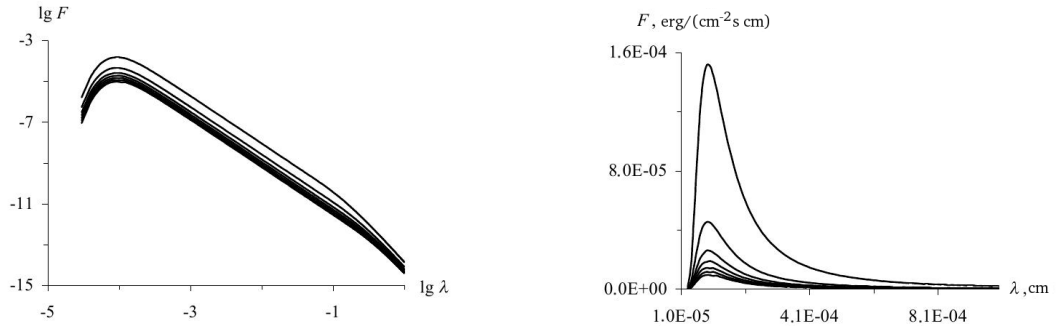


Fig. 2: SEDs for substars with disks located face on without inner holes with substellar mass $0.08 M_{\odot}$ in logarithmic (left) and absolute (right) scales. Systems ages (form top to bottom): 1-30 Myr with step 5 Myr.

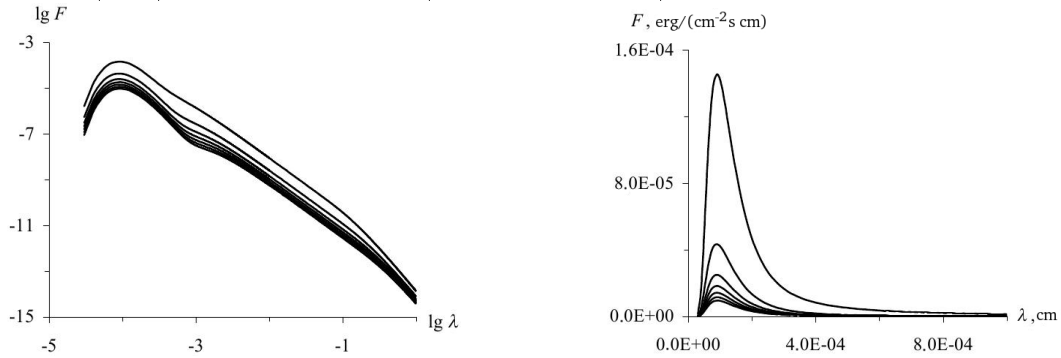


Fig. 3: The same as in Fig. 2, but with inner holes.

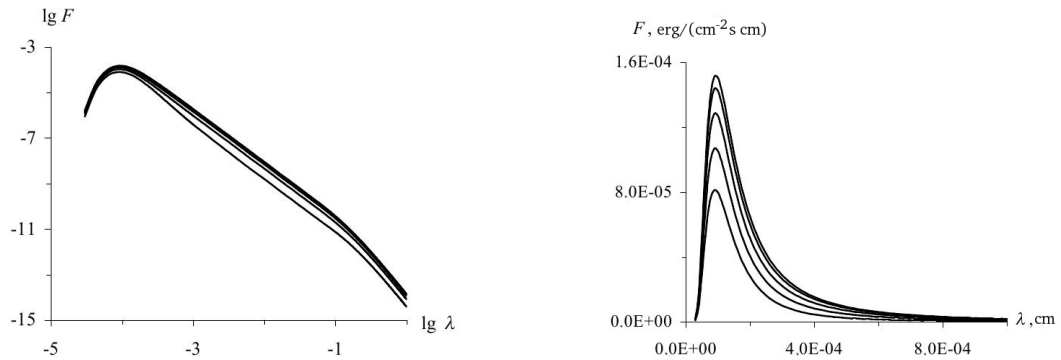


Fig. 4: SEDs for substars with disks without inner holes, with substellar mass $0.08 M_{\odot}$ and age 1 Myr in logarithmic (left) and absolute (right) scales. System inclinations (form top to bottom): 0° - 80° with step 20° .

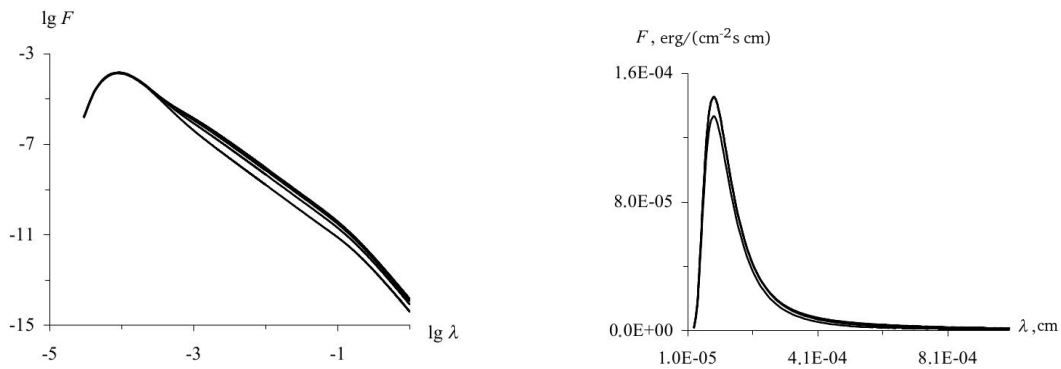


Fig. 5: The same as in Fig. 4, but with inner holes.