Spectral energy distributions of fragmenting protostellar disks

Olga Zakhozhay

Main Astronomical Observatory National Academy of Sciences of Ukraine

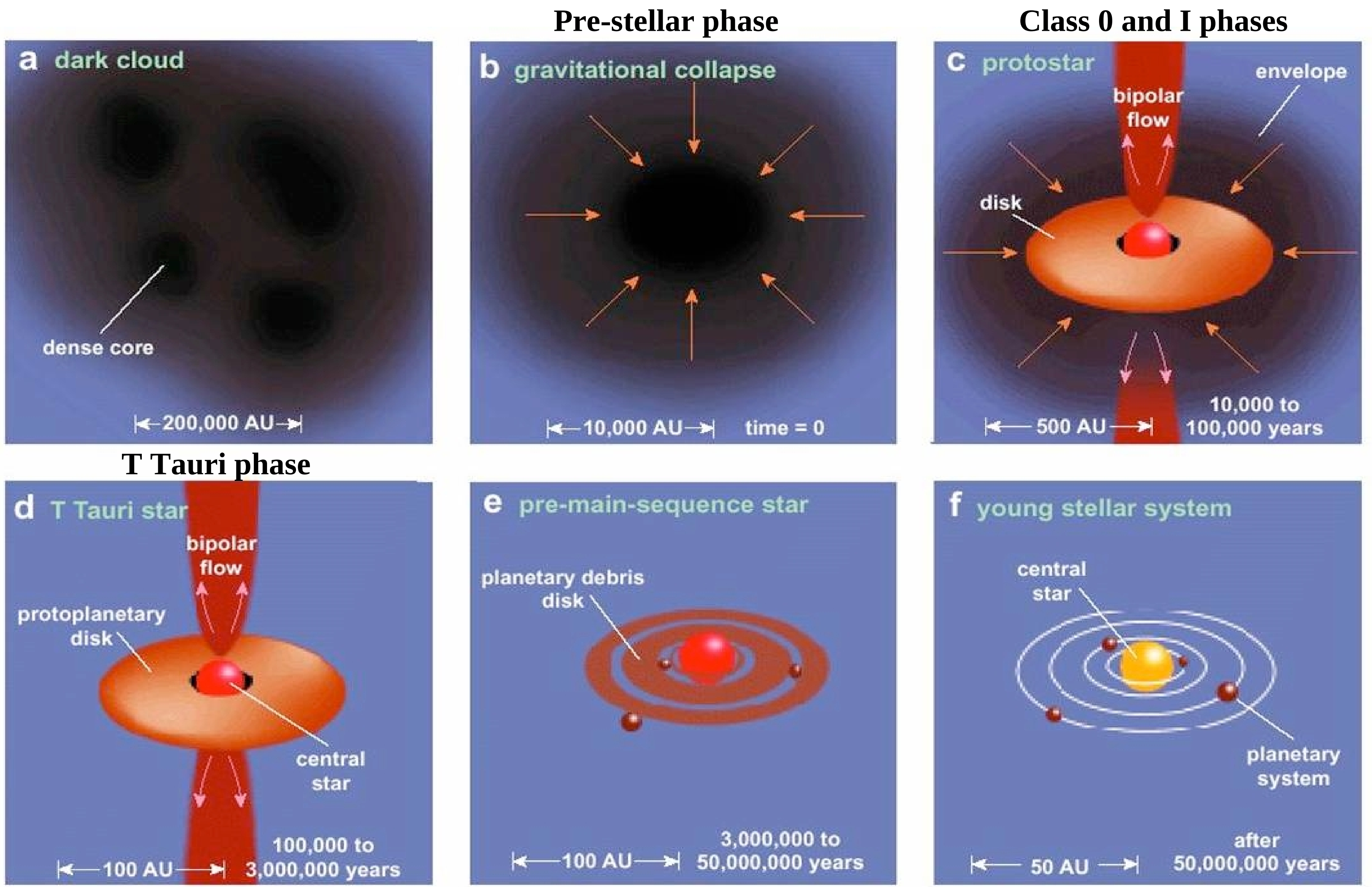
zkholga@mail.ru

in collaboration with **Eduard Vorobyov**

Institute for Astrophysics, University Vienna

Motivation

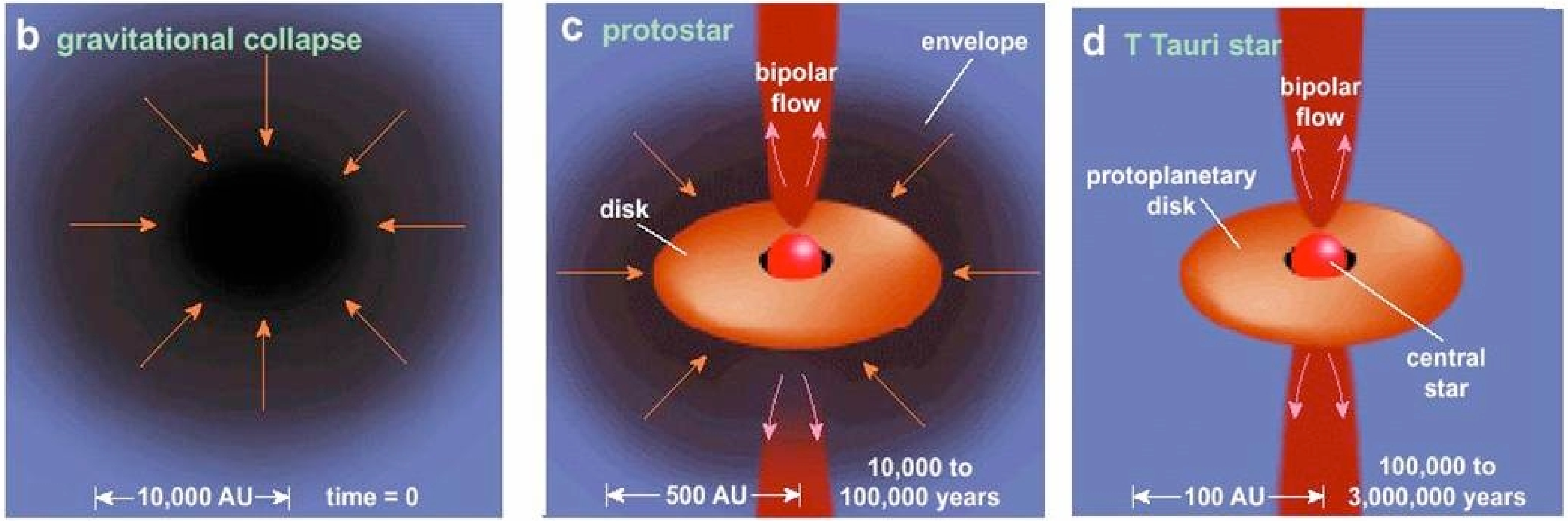
Main stages of protostellar disk evolution



Motivation

Global models that self-consistently follow Cloud => Disk transition

Pre-stellar phase　　Class 0 and I phases　　T Tauri phase



Disk formation and evolution, and planet formation, are integral parts of the star formation process

- § 1+1D models (Hueso & Guillot 2005; Visser et al. 2009; Rice at al. 2010),
- § 2D models (Yorke & Bodenheimer 1999; Boss & Hartmann 2001; Vorobyov & Basu 2006, 2010, Zhu et al. 2009),
- § 3D models (Krumholz et al. 2007; Kratter et al. 2010; Machida et al. 2009, 2010).

Motivation

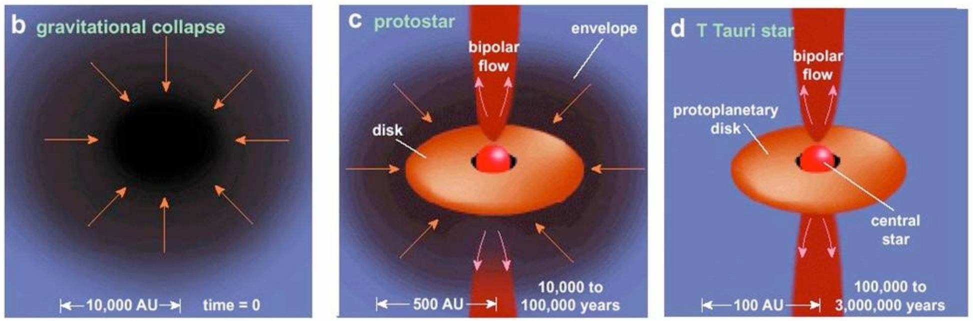
Numerical scheme of Vorobyov & Basu model

Hydro code

Accretion rates onto the star →

← Photospheric & accretion luminosities

Stellar evolution code



- Collapse of pre-stellar cloud,
- Formation of the central star (approximated by a point object inside a central sink cell),
- Disk formation and long-term evolution (up to 1 Myr),
- Finite-difference Eulerian code on polar coordinates,
- Third-order accurate advection (PPA),
- Log-spaced grid in radial direction (Vorobyov & Basu 2006, 2010).

- Stellar mass, radius, temperature, etc.,
- Stellar chemical abundances,

Baraffe et al. 1998, 2002, 2003;
Chabrier et al. 2000;
Chabrier & Baraffe 2000.

The aims:

- Comparative study of spectral energy distributions (SEDs) of fragmenting versus non-fragmenting protostellar disks;
- Search for observational signatures that can unambiguously point to the presence of massive fragments in protostellar disks, which can be precursors of giant planets and brown dwarfs.

Research tasks:

- To develop a method for SED calculations of young stellar objects (YSOs) using the physical parameters of YSOs from numerical hydrodynamics models (Vorobyov & Basu 2006, 2010);
- To perform numerical simulations for a number of protostellar disk realizations, paying specific attention to systems that show disk fragmentation;
- To determine if massive fragments can leave unambiguous signatures in the SEDs and if these signatures can be seen at different viewing angles;
- To establish the possibility to detect massive fragments in protoplanetary disks with biggest modern telescopes.

Calculation algorithm

Integral SED from systems

$$F = F_{disk} + F_*$$

Disk

$$F_{disk} = F_d + F_{sc}$$

F_d – flux from disk,
F_{sc} – flux from sink cell.

Protostar

$$F_n^* = \frac{\pi R_*^{\,2}}{d^2} B_\nu (T_{eff}^*),$$

R_* – protostellar radius,
T_{eff} – effective temperature of the protostar:

$$T_{eff}^* = \sqrt[4]{\frac{L_{acr} + L_{ph}}{4p R_*^2 s}},$$

L_{acr} – accretion luminosity,
L_{ph} – photospheric luminosity.

Calculation algorithm

Flux from every specific grid cell of the disk

$$F_d = \frac{S\cos w}{d^2} B_\nu(T_{eff})(1 - e^{-\Sigma k_n \sec g}),$$

S – physical area of a grid cell (i,j),

ω – normal angle between a grid cell (i,j) of the disk surface and the line of sight,

γ – inclination angle of the disk with respect to the observer,

d – distance to YSO, set to 100 pc,

Σ – surface density of each grid cell (i,j),

κ_ν – opacity (Ossenkopf & Henning 1994, case for the thin ice mantles after 10^5 yr of coagulation (OH5 dust)).

Effective temperature

$$T_{eff} = \max\{T_{irr}, T_{surf}\},$$

T_{irr} – stellar/background irradiation of the disk surface,

T_{surf} – temperature of active viscous/shock heating of the disk interiors.

Calculation algorithm

Flux from the sink cell

$$F_{sc} = \frac{4p \cdot \cos g \cdot hn^{3}}{d^{2}c^{2}} \int_{R_{in}}^{R_{out}} \frac{1 - e^{-\Sigma(r) k_n \sec g}}{e^{\frac{hn}{kT(r)}} - 1} r dr,$$

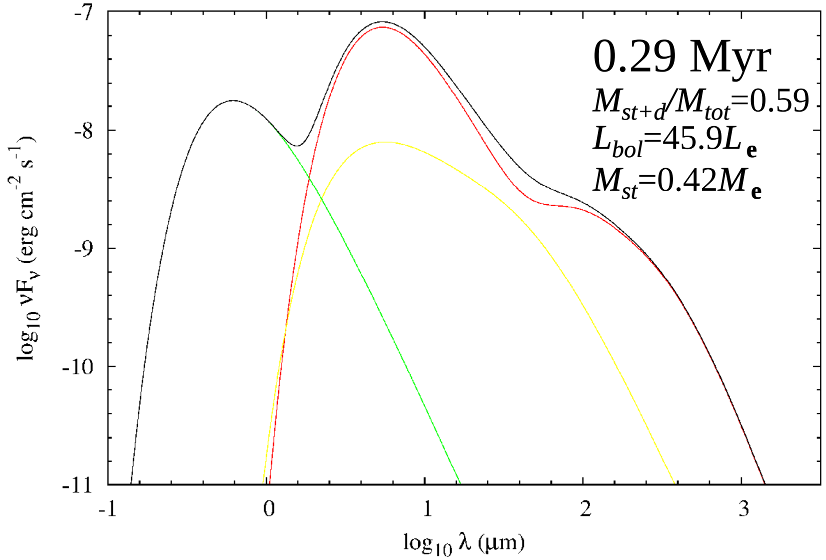
R_{in} – inner edge of the disk,
R_{out} – the boundary between disk and sink cell,
$T(r)$ – effective temperature distribution,
$\Sigma(r)$ – surface density distribution:

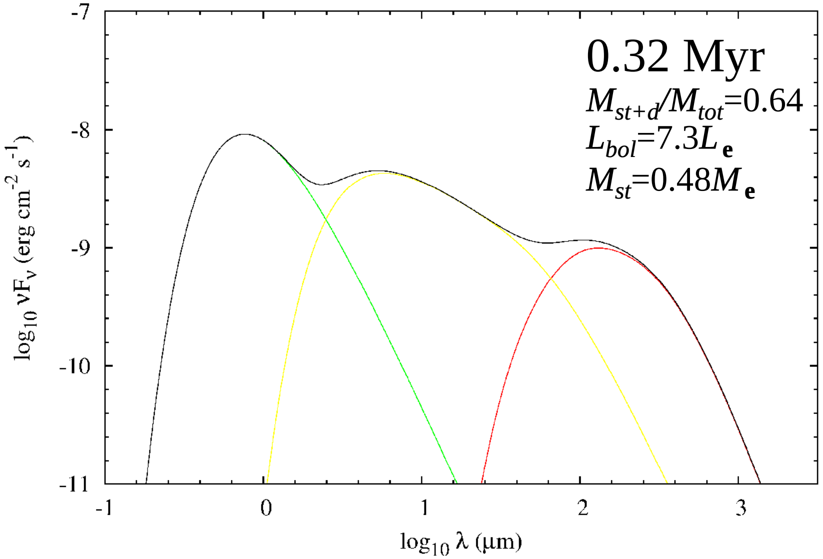
$$\Sigma(r) = \Sigma_0 \left(\frac{r}{r_0} \right)^{-p},$$

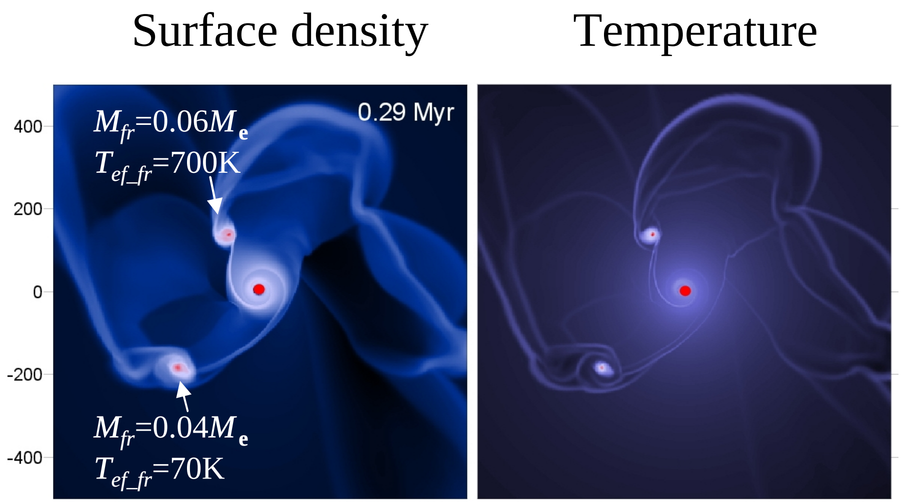
p = 1.0–1.5, as typical value for irradiated and viscous disks (Beckwith et al. 1990).

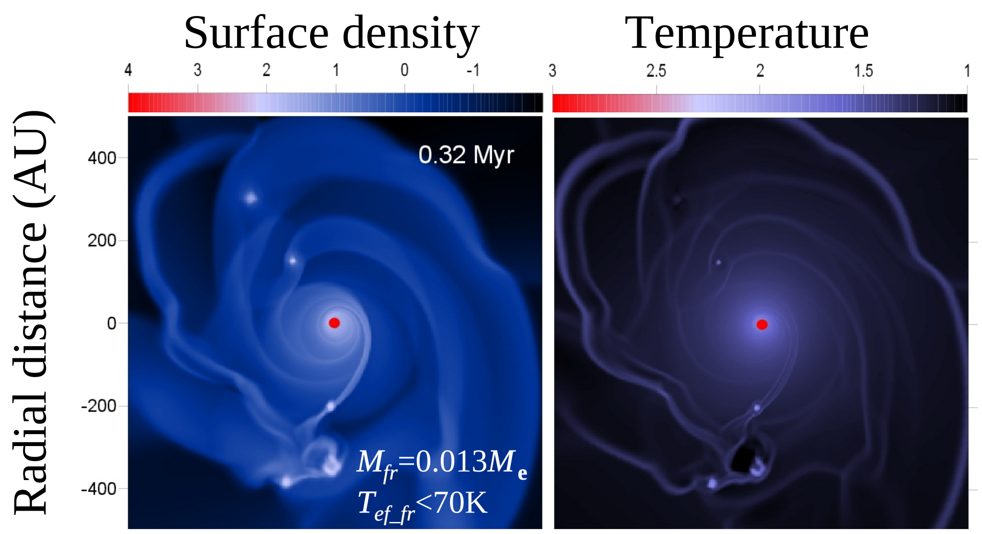
Spectral energy distribution

For systems with initial core mass $1.23M_{\mathbf{e}}$, located face on (0.29 Myr and 0.32 Myr)



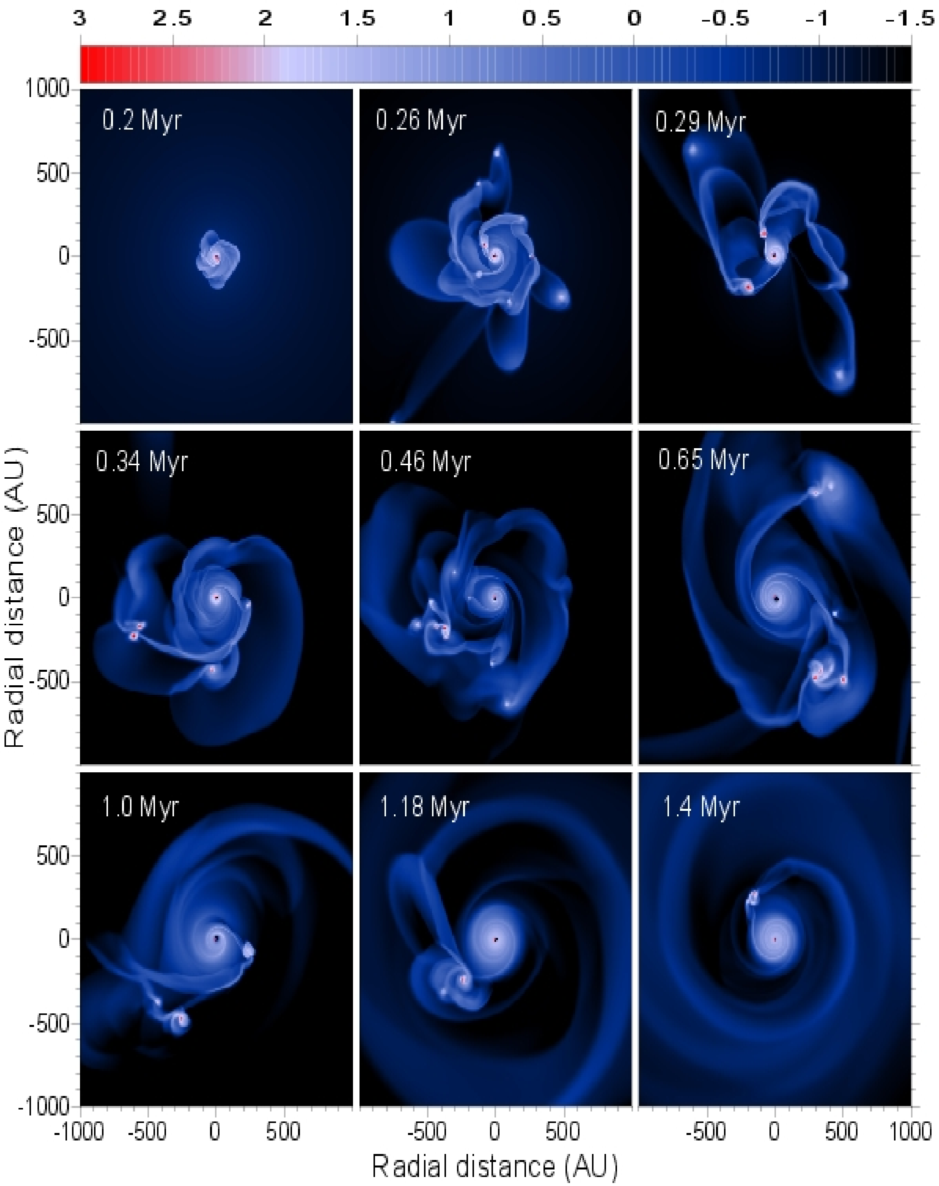


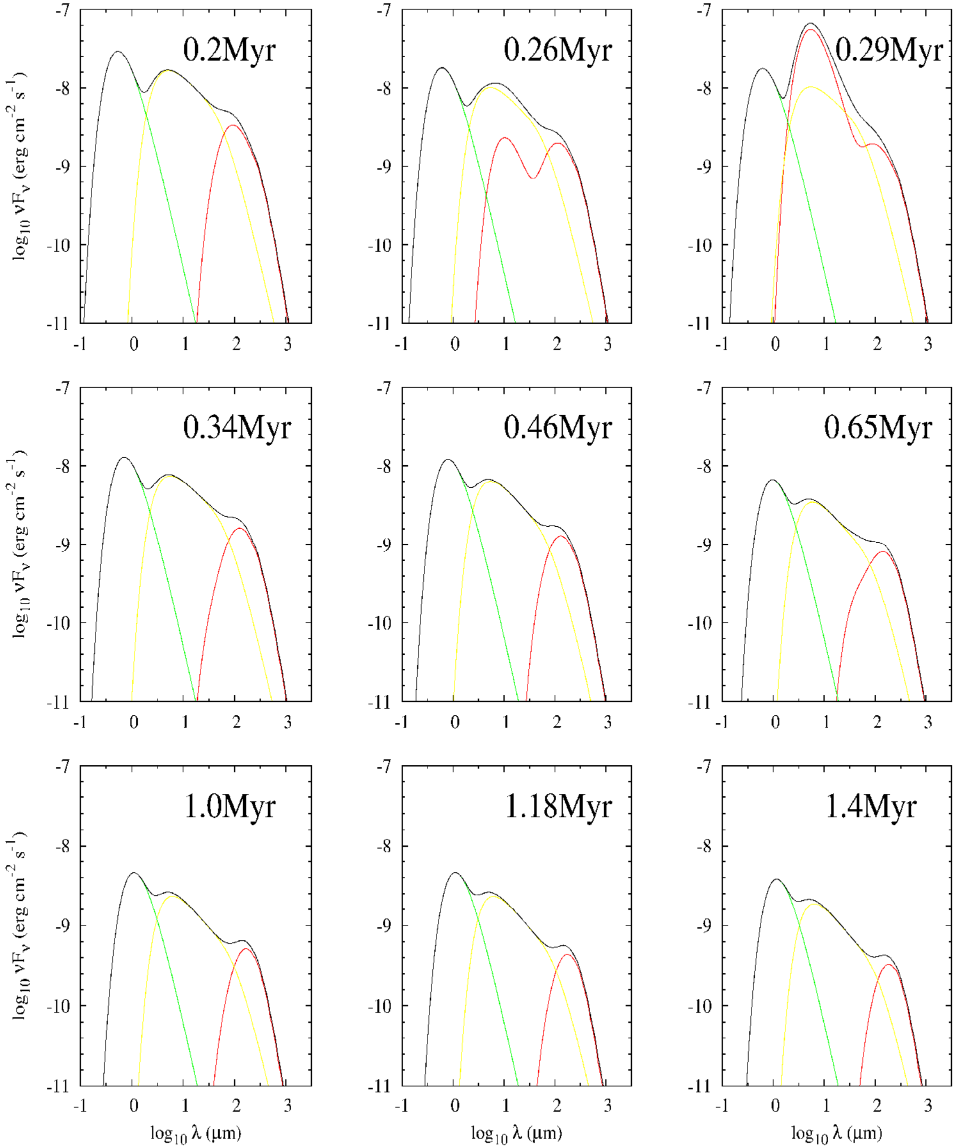




Surface densities and SEDs

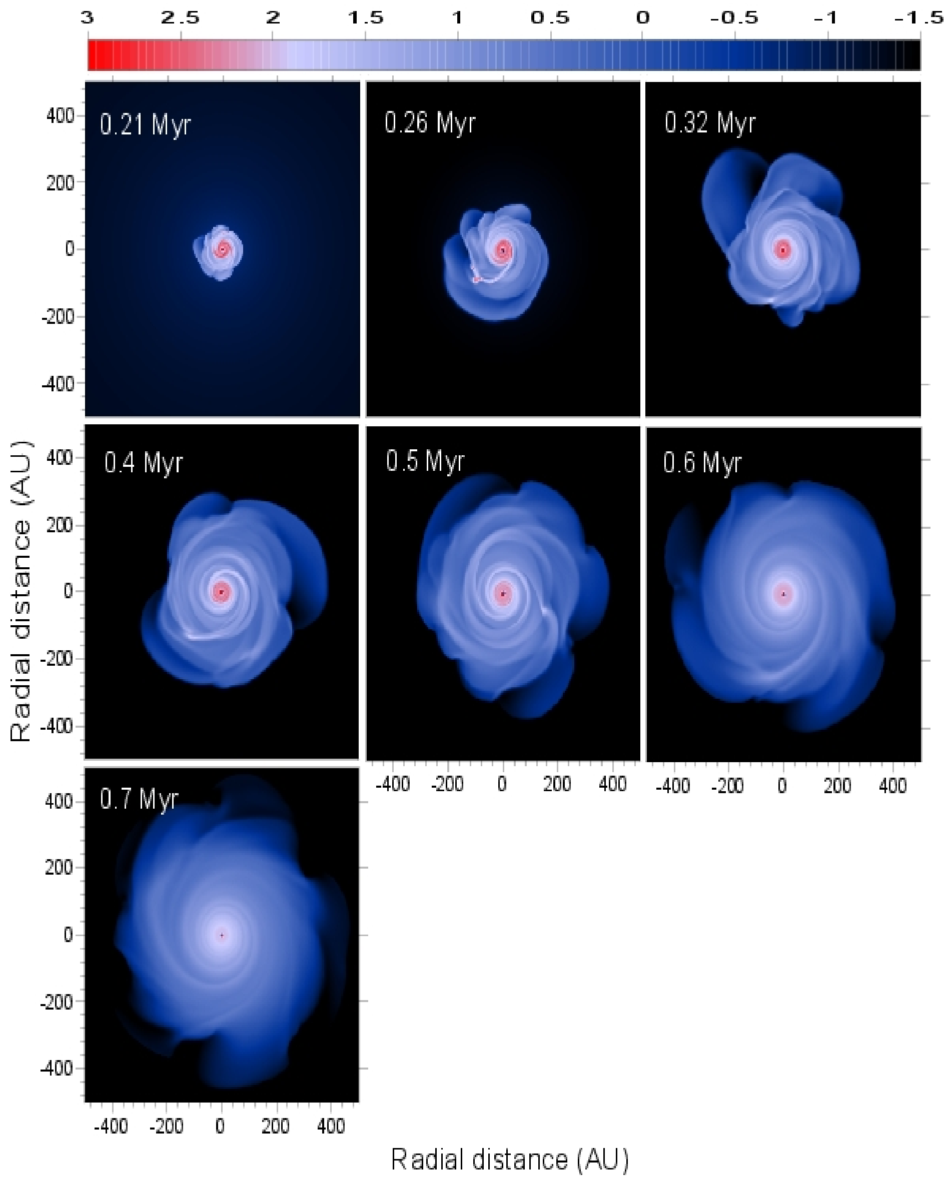
For systems with initial core mass $1.23M_{\mathbf{e}}$, located face on (0.2-1.4 Myr)

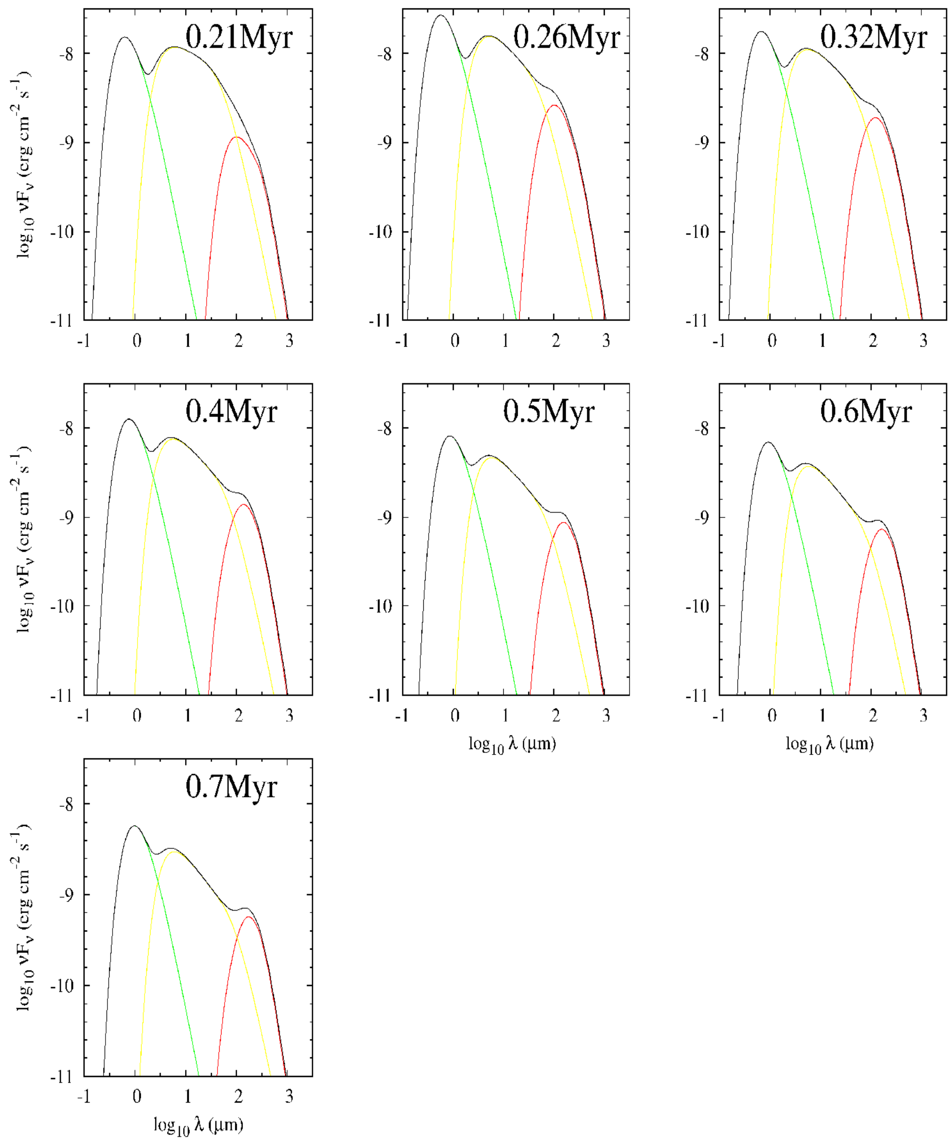




Surface densities and SEDs

For systems with initial core mass 1M_{e}, located face on (0.21-0.7 Myr)





Summary

– a method for SEDs construction for fragmenting protostellar disks is developed;
– calculations for systems located face on have been performed;
– preliminary results show that SED shape is sensitive to the presence of hot fragments in protostellar disk.

Future work

– Improvement of existing algorithm for SEDs simulations by taking into account non-zero inclination angles of systems;
– constructing of ALMA synthetic images for prototype models that would show unambiguous signatures of disk fragmentation in the SEDs.