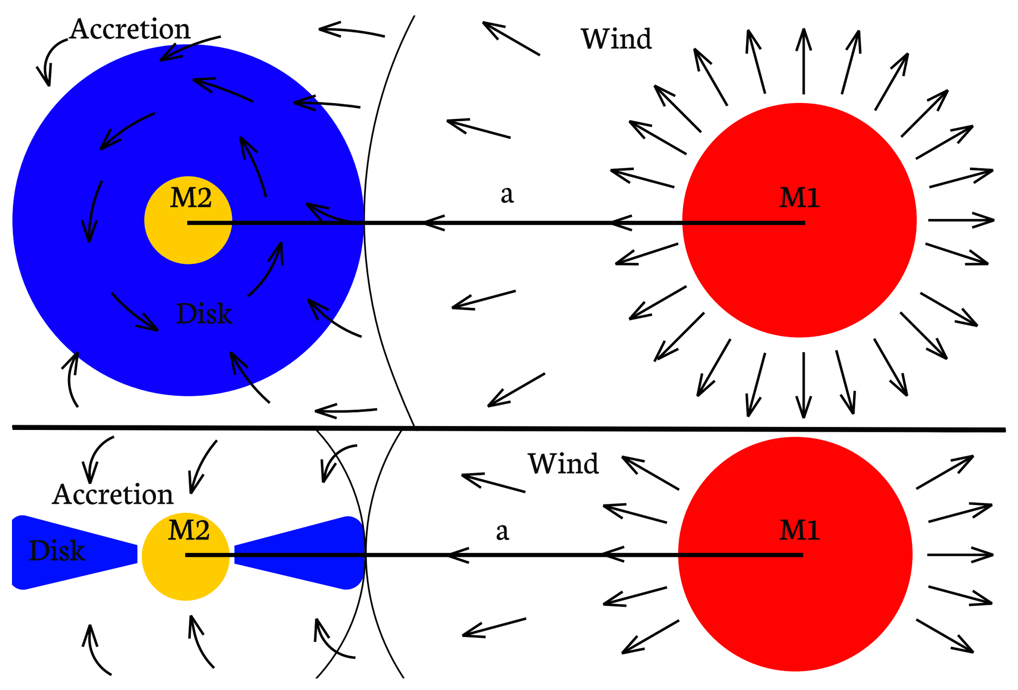
PLANET MIGRATION IN ACCRETION DISCS IN BINARY SYSTEMS

Alexey Nekrasov[1,2], **Sergei Popov**[1,2] and **Viacheslav Zhuravlev**[1]

[1]Sternberg Astronomical Institute, Lomonosov Moscow State University

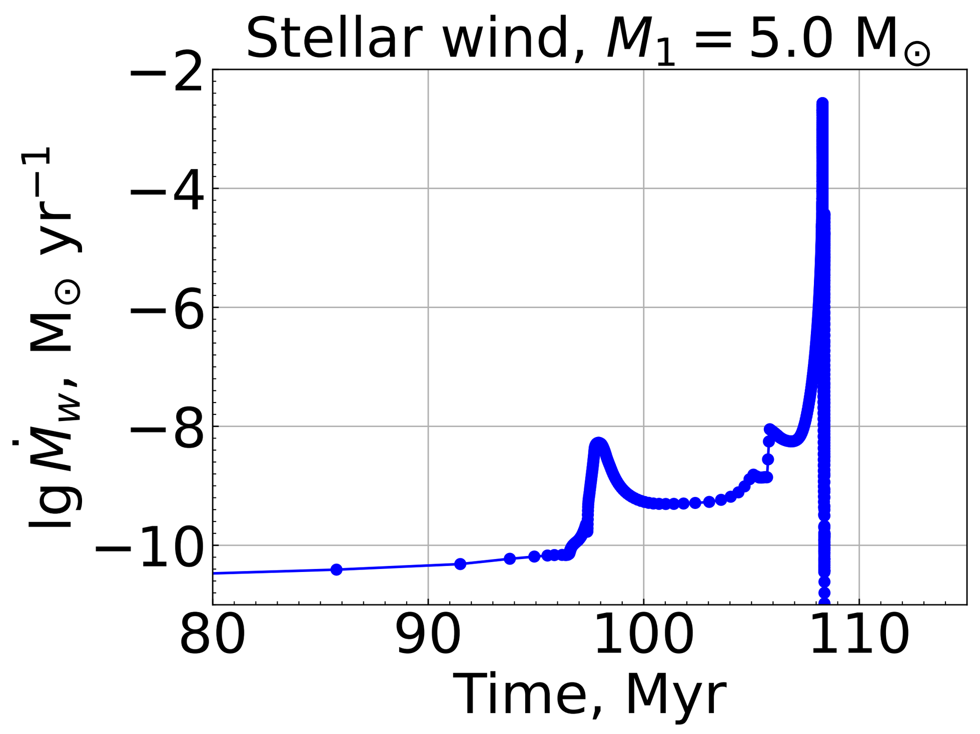
[2]Department of Physics, Lomonosov Moscow State University

Planets & wind-fed discs in binaries



In a close binary system an accretion disc can be formed around the secondary star when the primary leaves the Main sequence and starts to loose mass via a slow stellar wind. On the left we show the sketch (not to scale) of a binary system in two projections.

If the secondary component has a planetary system, then planets are embedded in the disc and start to migrate. We analyze evolution of such discs and model planetary migration in them. Properties of the disc depend on the mass loss rate by the donor and parameters of the binary. Evolution of the wind rate for $M = 5\,M_\odot$ donor is shown on the left (we vary masses of the primary).



We use a numerical model to study non-stationary and, in some cases, quasi-stationary α-discs with a variable mass inflow on the whole disc surface within the Bondi radius during late stages of evolution of the primary component. When the disc properties are calculated we model planetary migration in the disc.

Disc evolution & planet migration models

We calculate the accretion rate following the standard Bondi-Hoyle prescription (Bondi, Hoyle 1944):

$$\dot{M}_{\rm acc} = \dot{M}_{\rm w}\frac{r_{\rm a}^2}{4a^2},$$

where a is the binary separation, $\dot{M}_{\rm w}$ is the mass loss rate of the primary, and $r_{\rm a}$ is the Bondi radius. $\dot{M}_{\rm w}$ is changing in time according to MESA stellar evolution models.

The disc evolution is determined by the non-linear diffusion equation obtained by Shakura and Lyubarsky (1987) with an external source function from Peretz and Kenyon (2013), which directly depends on the Bondi-Hoyle accretion rate:

$$\frac{\partial \Sigma}{\partial t} = \frac{(GM_2)^2}{4\pi h^3}\frac{\partial^2 F}{\partial h^2} + \left(\frac{\partial \Sigma}{\partial t}\right)_{\rm ext},$$

where Σ is a surface density, F is a viscous torque, and h is a specific angular momentum value at a given radius.

Type 1 migration rate for a planet of a given mass $m_{\rm p}$ and a given orbital radius $r_{\rm p}$ is estimated according to Tanaka et al. (2002):

$$\frac{{\rm d}r_{\rm p}}{{\rm d}t} = -(2.72 + 1.08\beta)\delta^{-2} m_{\rm p} M_2^{-2}\frac{M_{\rm d}}{2\pi}v_{\rm p},$$

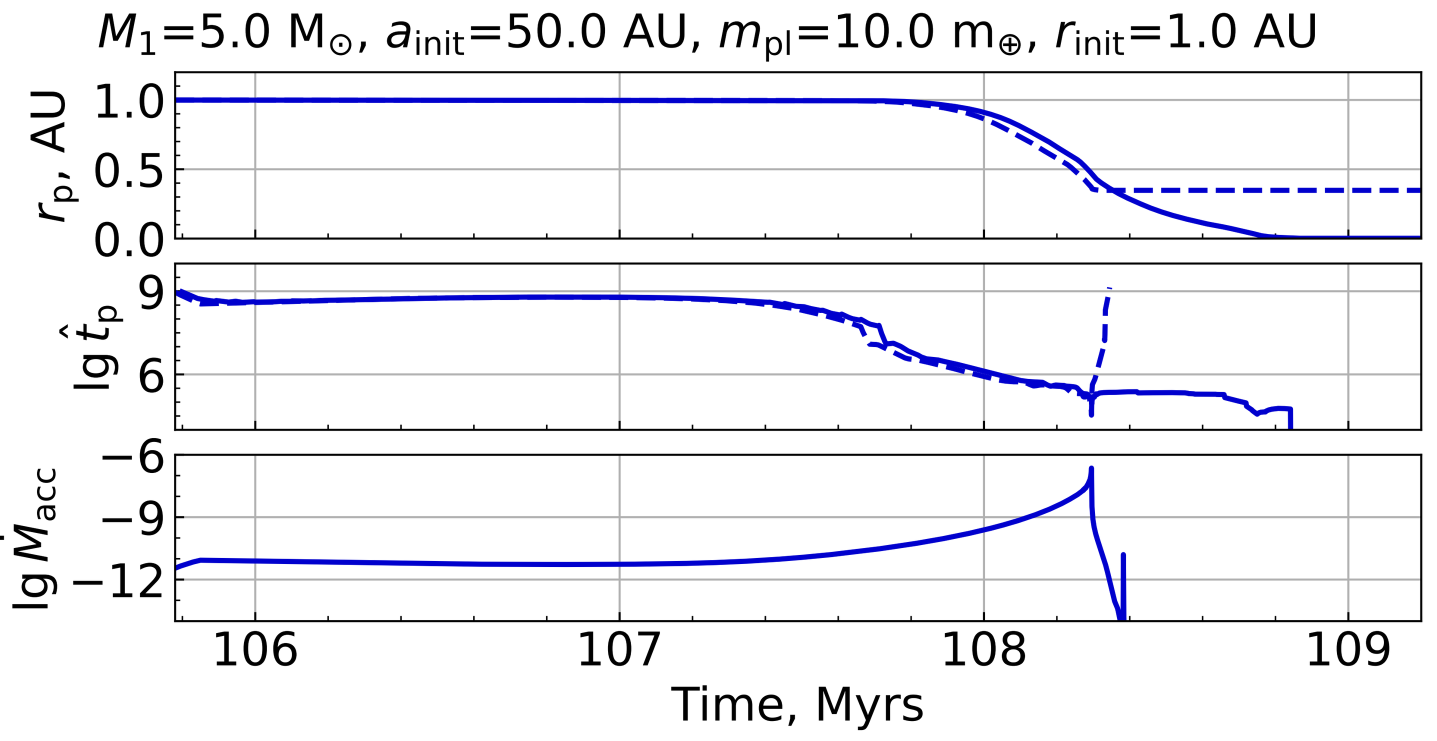
where $\delta = H/r$ is the aspect ratio of the disc at the planetary orbit distance, β is the power law index of the surface density profile $\Sigma \propto r^{-\beta}$, $v_{\rm p}$ is the Keplerian velocity of the planet, and finally $M_{\rm d} = 2\pi r_{\rm p}^2\Sigma$.

If a planet has a sufficient mass for a gap opening, then the type 2 migration rate is estimated according to Ivanov et al. (1999):

$$\frac{{\rm d}r_{\rm p}}{{\rm d}t} = v_{\rm r}\frac{M_{\rm d}}{M_{\rm d} + m_{\rm p}} = \frac{3}{2}\alpha\delta^2\frac{2r_{\rm p}}{F}\frac{{\rm d}F}{{\rm d}r}\frac{M_{\rm d}}{M_{\rm d} + m_{\rm p}}v_{\rm p}.$$

Results & summary

In this study we modeled planetary migration in a wind-fed accretion disc around a secondary component of a binary system. We calculated a detailed model of a non-stationary disc irradiated by the host star (and the donor, in some runs). Relatively massive discs are formed when the primary component enters the RGB (or AGB) stage of evolution. Then a planet can experience significant migration in such disc.



In the plot we show evolution of the orbital distance, $r_{\rm p}$ (AU) and $\dot{M}_{\rm acc}$ (M$_\odot$/yr). Also we show evolution of $\hat{t}_{\rm p} = \frac{r_{\rm p}}{|{\rm d}r_{\rm p}/{\rm d}t|}$ which is a characteristic migration timescale (given in years) of the planet. Solid lines for $r_{\rm p}$ and $\hat{t}_{\rm p}$ correspond to non-stationary discs and dashed – to quasi-stationary.

We demonstrate that in binaries with an initial separation $a \lesssim 80$ – 100 AU giant planets can approach distances $\lesssim 0.05$ AU from the host star where tidal forces become non-negligible. Neptune-like planets can reach such small distances in cases when the donor is a relatively massive star (5-8 M$_\odot$), or in binaries with $a \lesssim 20$ AU. Thus, migration in discs followed by tidal migration might result in intensive planet-star interaction, including mergers.