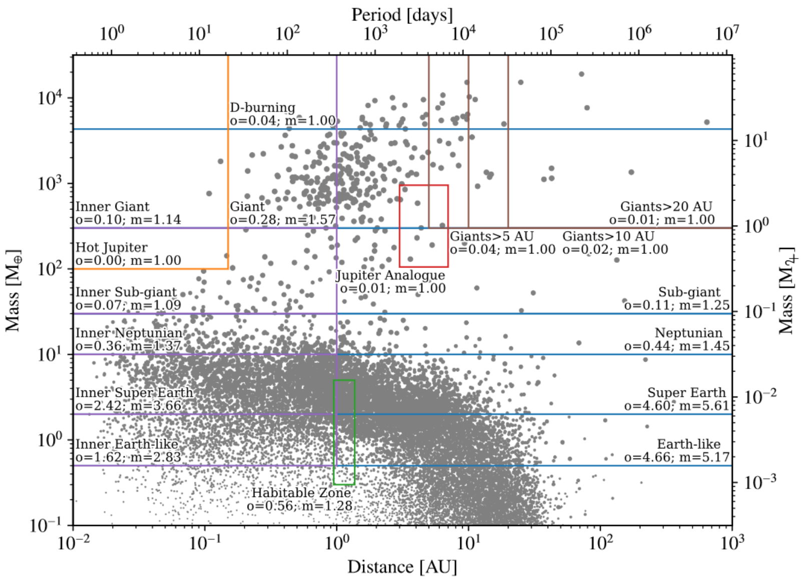
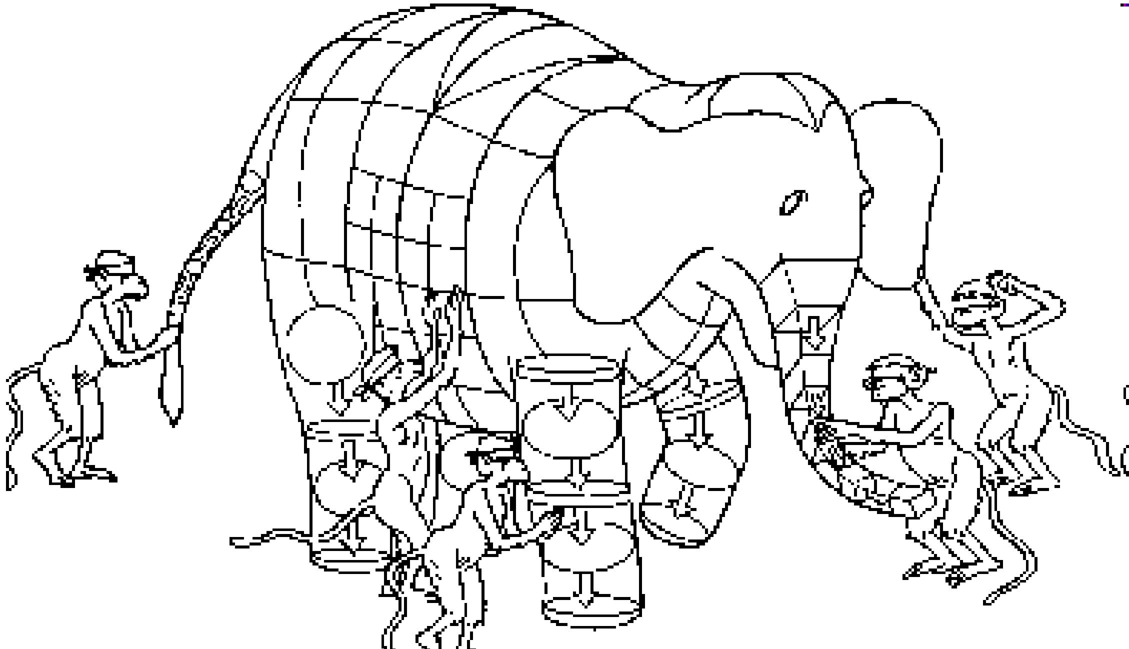


Семинар по популяционному синтезу

08.12.2020

arXiv. 1402.7086



Протопланетный диск

I). $\Sigma_{gas} \sim e^{-t/\tau}$

АВМ. диск Ш-С (α), резкая эвол.

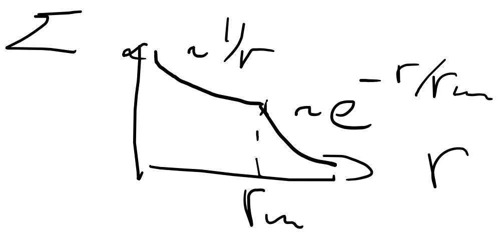
II). $\Sigma = \Sigma_{10} \cdot f_g \cdot \left(\frac{r}{10\,ae}\right)^{-q}$ $\qquad \Sigma_{10} = 75\ g/cm^2$

$f_g = f_{g,0}\, e^{-t/\tau}$ $\qquad q = 1 \qquad \tau \in [10^6, 10^7\ yrs]$

$\Sigma = 0$ на 0.04 ае.

III). $T = 280K \cdot \left(\frac{r}{1\,ae}\right)^{-1/2} \left(\frac{L_*}{L_\odot}\right)^{1/4}$

ice line $T = 170K \Rightarrow a_{ice} = 2{,}7 \left(\frac{L_*}{L_\odot}\right)^{1/2}$ ае



АВМ. $\frac{1}{\rho}\frac{\partial P}{\partial z} = -\Omega^2 z$ $\qquad \Omega^2 = \frac{GM_*}{r^3}$ $\qquad T_{ice} = 160K$

$$\frac{\partial F}{\partial z} = \frac{9}{4}\rho\nu\Omega^2$$

F - поток

$$F = -\frac{16\pi\sigma T^3}{3k\rho}\frac{\partial T}{\partial z}$$

k - opacity

$$\nu = \alpha\frac{c_s}{\Omega}$$

$$\begin{cases} P_s = \frac{\Omega^2 H \tau_{ab}}{k_s} \\ F_s = \frac{3}{8\pi}\dot{M}_*\Omega^2 \\ 2\sigma(T_s^4 - T_b^4) - \frac{\alpha k T_s \Omega}{8\mu m_H k_s} - \frac{3}{8\pi}\dot{M}_*\Omega^2 = 0 \end{cases}$$

τ_{ab} - толщина от $z=H$ до ∞

$$\dot{M}_* = 3\pi\tilde{\nu}\Sigma \qquad \Sigma = \int_{-H}^{H}\rho\,dz \qquad \tilde{\nu} = \int_{-H}^{H}\nu\rho\,dz$$

$$T_s^4 = \frac{T_{s,no\,irr}^4}{f_{ezk}} + T_{s,irr}^4$$

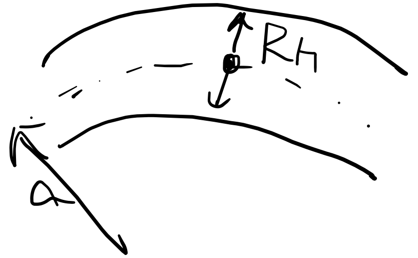
$$T_{s,irr} = T_* \left[\frac{2}{3\pi}\left(\frac{R_*}{r}\right)^3 + \frac{1}{2}\left(\frac{R_*}{r}\right)^2\left(\frac{H_p}{r}\right)\left(\frac{d\ln H_p}{d\ln r} - 1\right)\right]^{1/4}$$

$$\frac{\partial \Sigma}{\partial t} = \frac{3}{r}\frac{\partial}{\partial r}\left[r^{1/2}\frac{\partial}{\partial r}\left(\tilde{\nu}\Sigma r^{1/2}\right)\right] + \underbrace{\dot{\Sigma}_w(r)}_{<0\ \text{фотоисп.}} + \underbrace{\dot{Q}_{planet}}_{<0}$$

$\dot{\Sigma}_{w,int}$; $\dot{\Sigma}_{w,ext}$

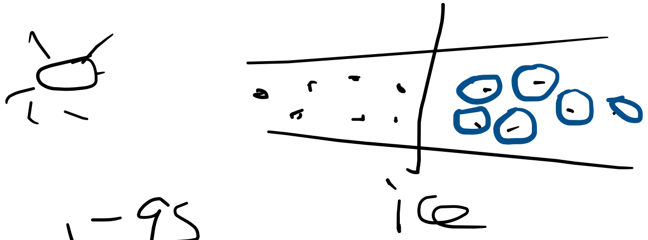
$$\Sigma_g(t=0,r) = \Sigma_0\left(\frac{r}{1\,au}\right)^{p_g}\cdot e^{-(r/R_{cut})^{2+p_g}}\cdot\left(1-\sqrt{\frac{r}{R_{in}}}\right) \qquad p_g = -1$$

R_H



$$R_H = a\left(\frac{M}{3M_*}\right)^{1/3}$$

диск планетезималей
лёд и камень.



IL: $\Sigma_s = \Sigma_{s,10} \cdot \eta_{ice} \cdot f_d \left(\frac{r}{10\,ае}\right)^{-q_s}$

$\Sigma_{s,10} = 0{,}32$ г/см^2

$q_s = 1{,}5$

$f_{d,0} = f_{g,0} \cdot 10^{[Fe/H]}$

$\eta_{ice} \begin{cases} 1, & r < a_{ice} \\ 4{,}2, & r > a_{ice} \end{cases}$

АВМ: $\Sigma_s(t=0, r) = f_{D/G} \cdot f_{R/I} \; \Sigma(t=0, r)$

$f_{D/G} = f_{d,0} / f_{g,0}$

$f_{R/I}$

1. Тормож. в газе

2. "перемешивание" экзопланет

3. взаим. между планетезим.

Seeds. IL. $10^{-8} M_\oplus$

ABM $10^{-2} M_\oplus$

IL. $\tau_{c,acc} = 3{,}5 \cdot 10^5 \text{yrs}\ \eta_{ice}^{-1} f_d^{-1} f_g^{-2,5} \left(\frac{a}{1ae}\right)^{5/2} \left(\frac{M_c}{M_\oplus}\right)^{1/3} \left(\frac{M_*}{M_\odot}\right)^{-1/6}$

ABM. $\frac{dM_{core}}{dt} = \frac{2\pi \Sigma_s R_H^2}{P_{orb}} P_{coll}$

I2. $M_{c,hydro}$

$$M_{c,hydro} = 10 M_\oplus \left(\frac{\dot{M}_c}{10^{-6} M_\oplus / \mathrm{yr}} \right)^{1/4}$$

$$\frac{dM_{planet}}{dt} \simeq \frac{M_{planet}}{\tau_{KH}}$$

$$\tau_{KH} = \tau_{KH1} \left(\frac{M_{planet}}{M_\oplus} \right)^{-k_2}$$

$k_2 = 3 \div 4$

$\tau_{KH1} = 10^8 \div 10^{10}$ yrs

АВМ.

$$\frac{dr}{dM_r} = \frac{1}{4\pi \rho r^2}$$

$$\frac{dP}{dM_r} = -\frac{G M_r}{4\pi r^4}$$

$P(\rho)$, opacity

$$\frac{dT}{dP} = \begin{cases} \nabla_{ad}, & \text{с конв} \\ \nabla_{rad}, & \text{без конв} \end{cases}$$

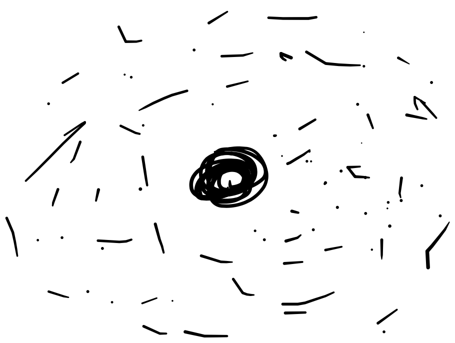
$$L = L_{cont} + L_{acc}$$

L_{cont} — сжатие оболочки

L_{acc} — аккр. планетез. на ядро

$$L_{acc} = G \frac{\dot{M}_{core} \cdot M_{core}}{R_{core}}$$

$< 10\, M_\oplus$



$$R_H = GM \Big/ \left[\frac{c_s^2}{K_1} + \frac{GM}{K_2 \cdot R_H} \right]$$

$$K_1 = 1$$

$$K_2 = 1/4$$

$$P_{surf} = P_{disk}(a)$$

$$T_{surf} = \left(T_{disk}^4 + \frac{3\tau L}{16\pi\sigma R_H^2} \right)^{1/4}$$

$> 10\, M_\oplus$

$$F(r) = 3\pi\nu(r)\Sigma(r) + 6\pi r \frac{\partial(\nu\Sigma)}{\partial r}$$

$$\dot{M}_{gas,max} = \max\left[F(a_p + R_H), 0\right] + \min\left[F(a_p - R_H), 0\right]$$

$$P_{surf} = P_{disc}(a_p) + \frac{\dot{M}_{gas}}{4\pi R_p^2} U_{ff} + \frac{2g}{3k}$$

k-opacity

$g = g(R_p)$

$$T_{surf}^4 = (1-A)\,T_{neb}^4 + T_{int}^4, \quad T_{int}^4 = \frac{3\tau L_{int}}{8\pi\sigma R_p^2}$$

альбедо

диск расс.

$$P_{surf} = 2g/3k$$

$$T_{surf}^4 = (1-A)\,T_{eq}^4 + T_{int}^4$$

обычн
звезд.

Type I

II. Tanaka et al. (2002)

ABM. Paardekooper et al. (2011)

Type II. IL. $M_{g,\,vis} = \dfrac{40 M_*}{Re}$ $\quad Re = \dfrac{a^2 \Omega}{\nu}$

ABM. $M_{g,\,th} = 3 \left(\dfrac{\beta\, M_{disc}}{r} \right)^3 M_*$ $\quad \beta \simeq 1$

M_{planet} vs. $M_{disc} \simeq \pi \Sigma r^2 = R_M$

$$\frac{da}{dt} = -\frac{3\nu}{2a} \cdot \min\left\{ 1, \boxed{\frac{M_{disc}(a)}{M_{planet}}} \right\}$$

disc доминирует

planeta доминирует

$$R_{es} = \begin{cases} 2c_2 \left(\frac{30ae}{a}\right)^{1/2} \frac{M_{disc}(a)}{M_{planet}} & : \text{IL} \qquad c_2 = 0{,}1 \\ \frac{2\Sigma a^2}{M_{planet}} & : \text{ABM} \end{cases}$$

Lin, Papaloizou (1995)

IL: $M > 8 M_{g,th}$ $\dot{M} = 0$

ABM: $\dot{M} \downarrow \neq 0$

Нач. усл.

1. Σ

IL. Gauss $\lg f_{g,0}$ $\langle\rangle = 0,\ \sigma = 1$

ABM. Gauss $\lg\left(\frac{M_{disc}}{M_b}\right)$ $\langle\rangle = -1.66$ $\sigma = 0,57$

2. Время шкалы газов. диска $\Sigma \sim e^{-t/\tau}$

IL. Gauss $\lg \tau$ $\langle\rangle = 6,5$ $\sigma = 0.5$

ABM.

3. Solids.

IL. $f_{d,0} = f_{g,0} \cdot 10^{[Fe/H]}$ Gauss $[Fe/H]$

$\langle\,\rangle = 0 \quad \sigma = 0.2$

ABM. $f_{D/G} = f_{D/G,0} \cdot 10^{[Fe/H]}$ Gauss $[Fe/H]$

$\langle\,\rangle = -0.02 \quad \sigma = 0.22$

4. Профиль диска

IL $\Sigma \sim \sigma_{1/r}$

ABM. $\Sigma \sim r^{-1/5} \Rightarrow \Sigma(r) = \ldots\ldots$

5. Seeds. ABM. Рандом. в log.

IL.