Close-in Giant Planets via In-situ Gas Accretion & Their Natal Disk Properties

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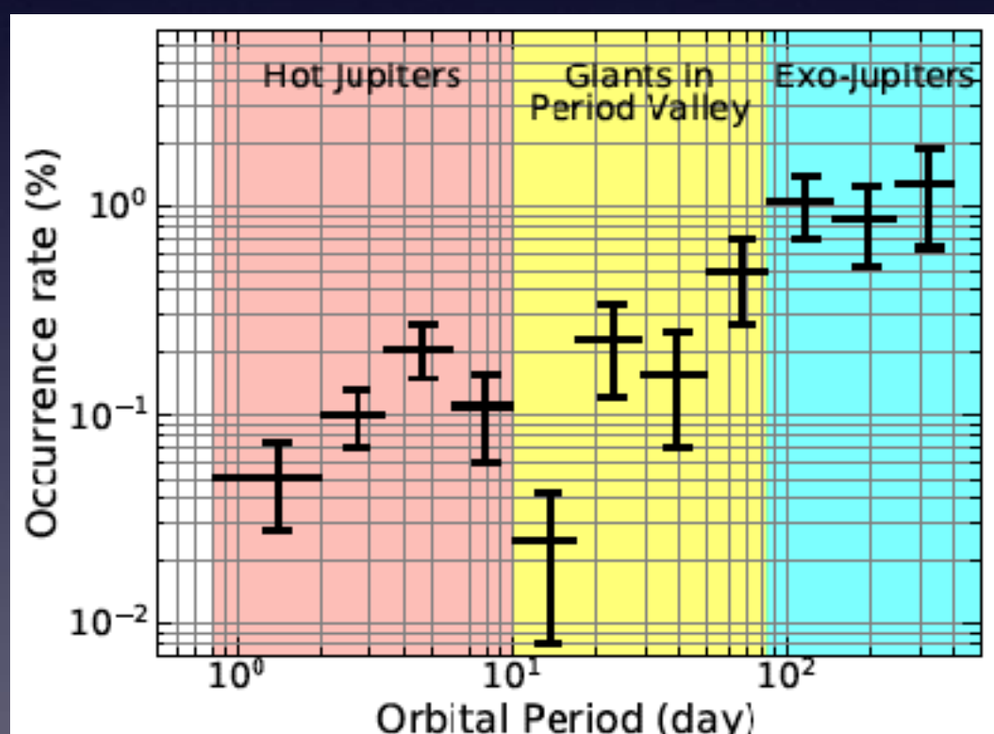
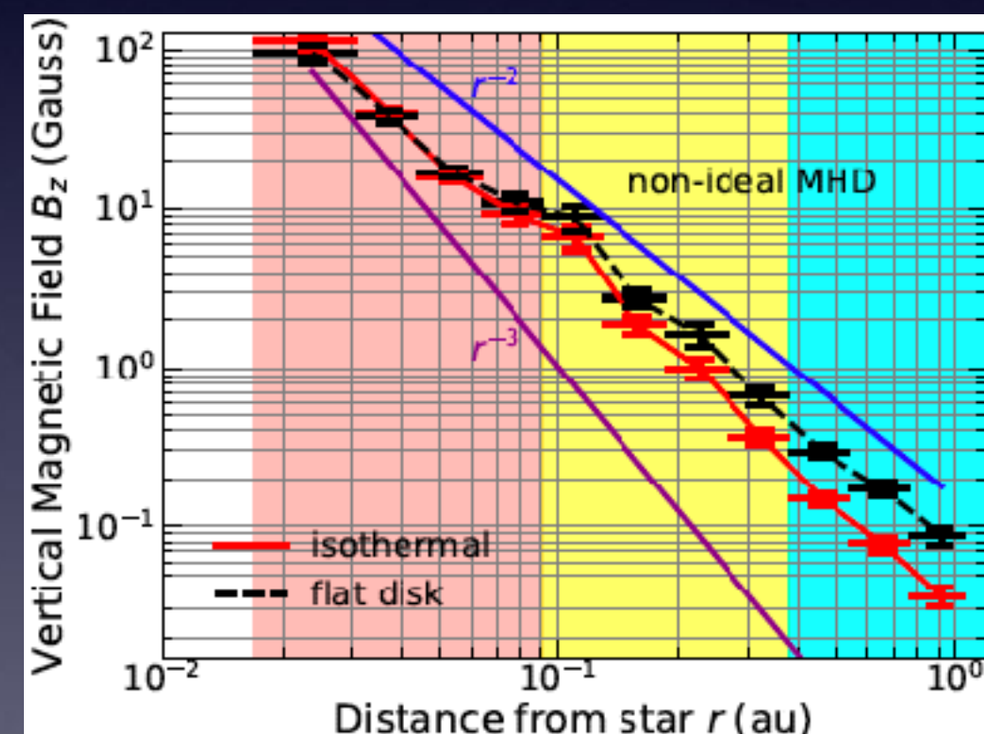


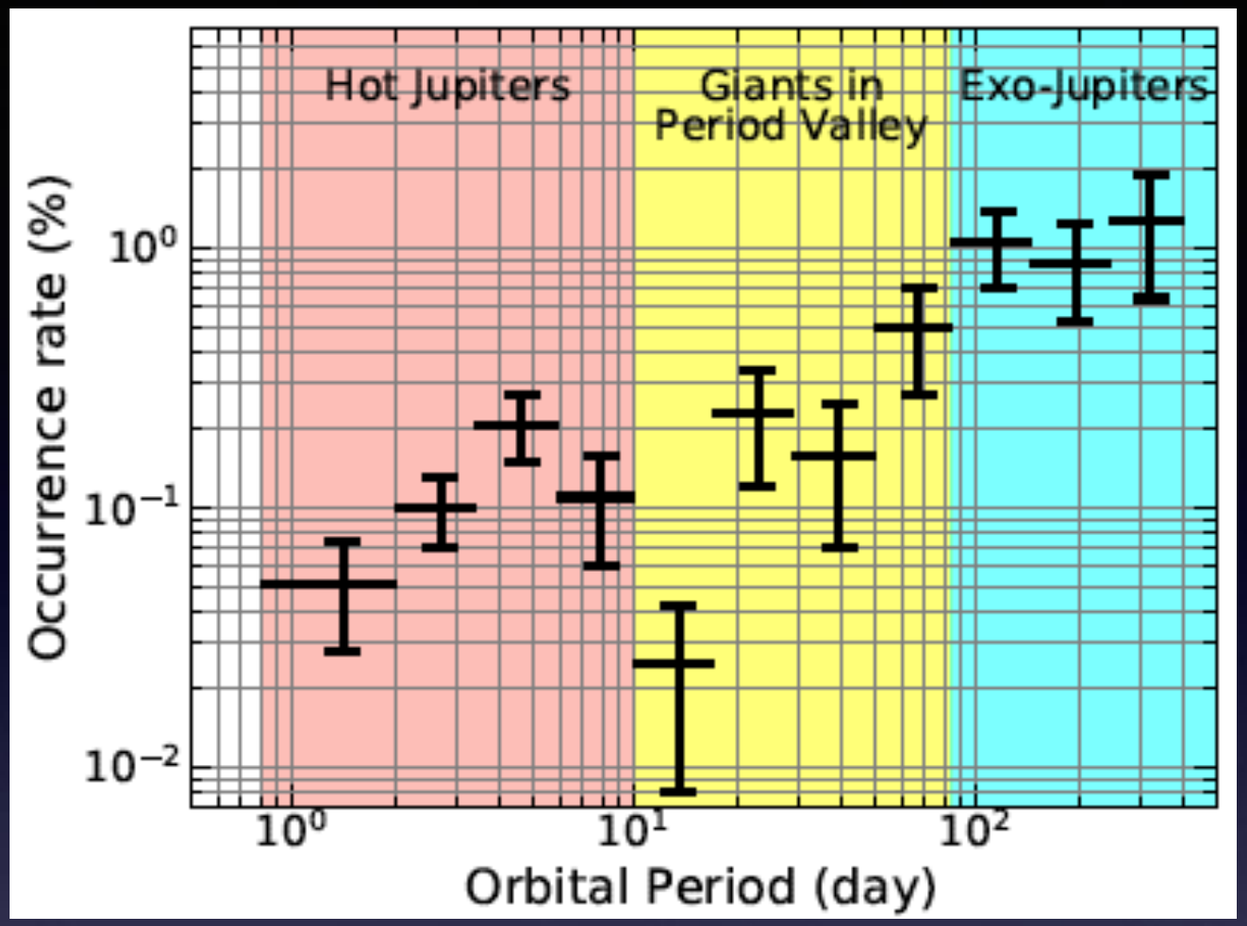


Santerne et al 2016

in collaboration with

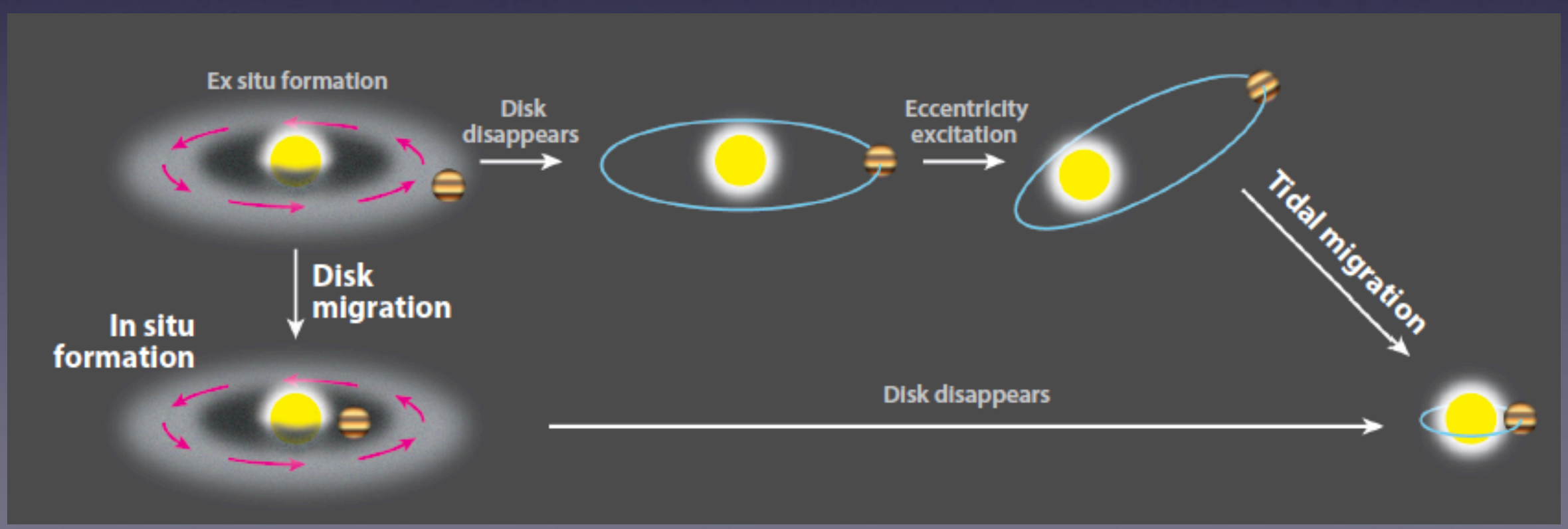
Mathew Yu (UCLA) Brad Hansen (UCLA)

Santerne et al 2016



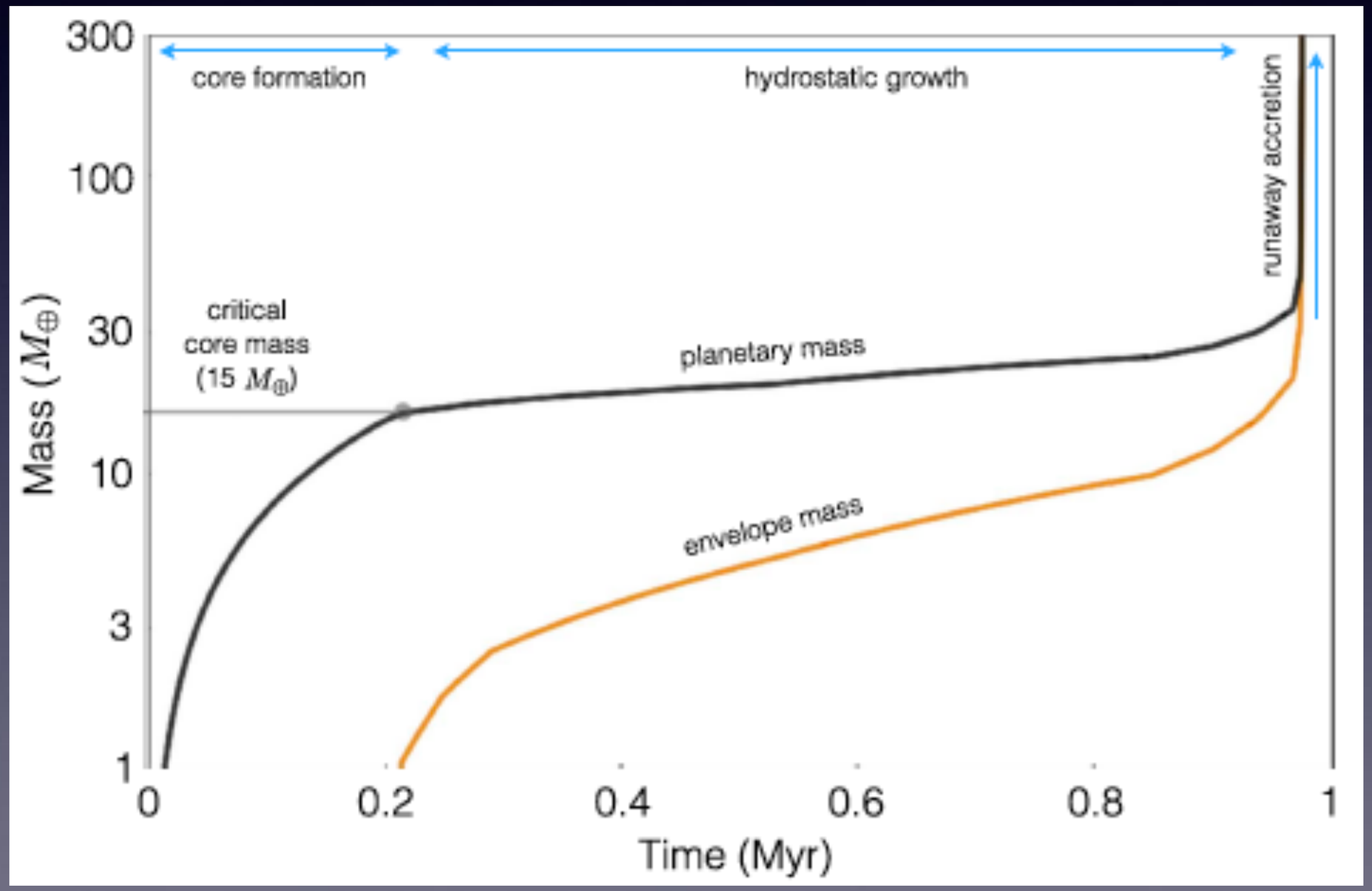
How to form close-in gas giants?

Dawson & Johnson 2018



In-situ gas accretion IS possible in the vicinity of the central star

e.g., Bodenheimer et al 2000, Batygin et al 2016



Basic hypothesis

the occurrence rate ~ gas accretion onto planets

$$f_{\rm OR}(r) \equiv k_{\rm OR} \frac{\dot{M}_p}{\dot{M}_{\rm d}} \tag{3}$$

$$\simeq 4.6 \times 10^{-1} k_{\rm OR} \left(\frac{\alpha}{10^{-2}}\right)^{-1} \left(\frac{H_{\rm g}/r_p}{0.05}\right)^{-4} \left(\frac{M_p}{10 M_\oplus}\right)^{4/3},$$

$f_{\rm OR}$: the occurrence rate distribution of close-in giant planets

$$\dot{M}_p = 0.29 \left(\frac{H_{\rm g}}{r_p}\right)^{-2} \left(\frac{M_p}{M_*}\right)^{4/3} \Sigma_{\rm g} r_p^2 \Omega$$

Tanigawa & Ikoma 2007

Disk model

$$\dot{M}_{\rm d} = 3\pi\nu\Sigma_{\rm g},$$

$$\nu = \alpha c_{\rm s} H_{\rm g}$$

Ruden & Lin 1986

$$T_{\rm d}^4 = \frac{27\tau}{128\sigma_{\rm SB}}\Sigma\nu\Omega^2 = \frac{27\kappa}{128\sigma_{\rm SB}}\left(\frac{\dot{M}_{\rm d}}{3\pi}\right)^2\frac{\Omega^3}{\alpha c_{\rm s}^2}$$

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$$f_{\rm OR}(r) \equiv k_{\rm OR}\frac{\dot{M}_p}{\dot{M}_{\rm d}} \qquad (3)$$

$$\simeq 4.6\times10^{-1}k_{\rm OR}\left(\frac{\alpha}{10^{-2}}\right)^{-1}\left(\frac{H_{\rm g}/r_p}{0.05}\right)^{-4}\left(\frac{M_p}{10M_\oplus}\right)^{4/3},$$

Opacity comes from Table of Bell et al 1997

Results

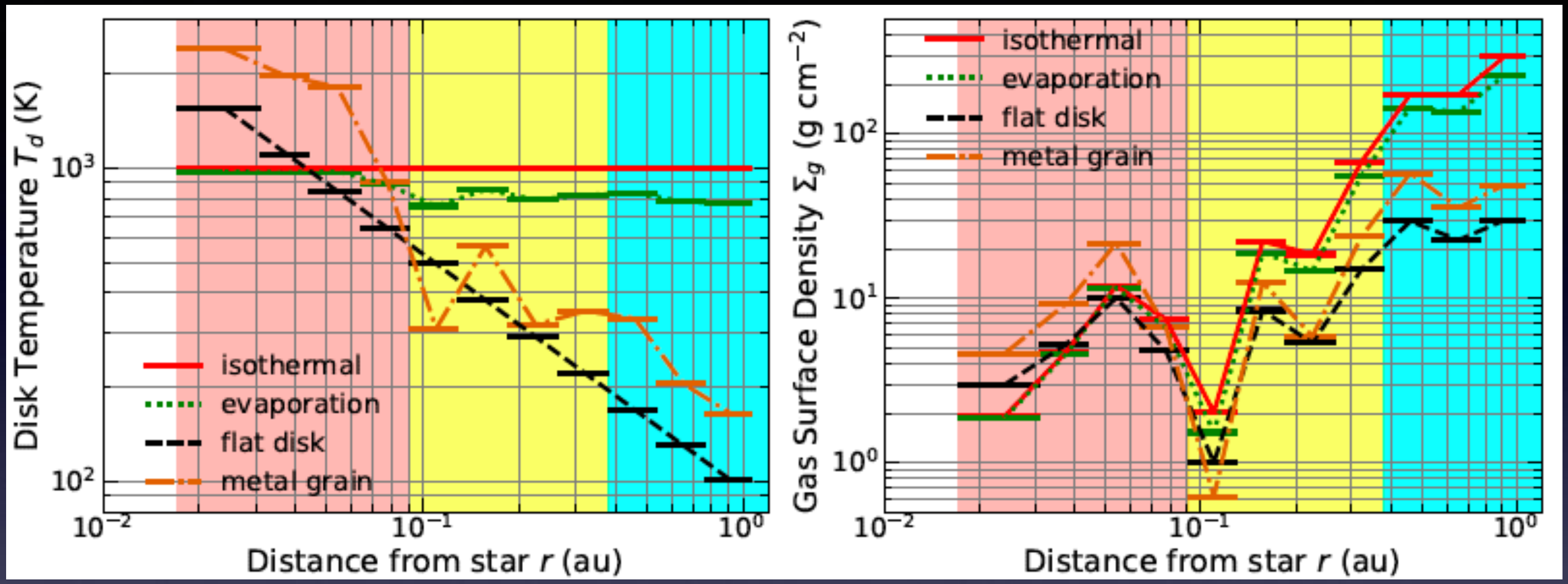
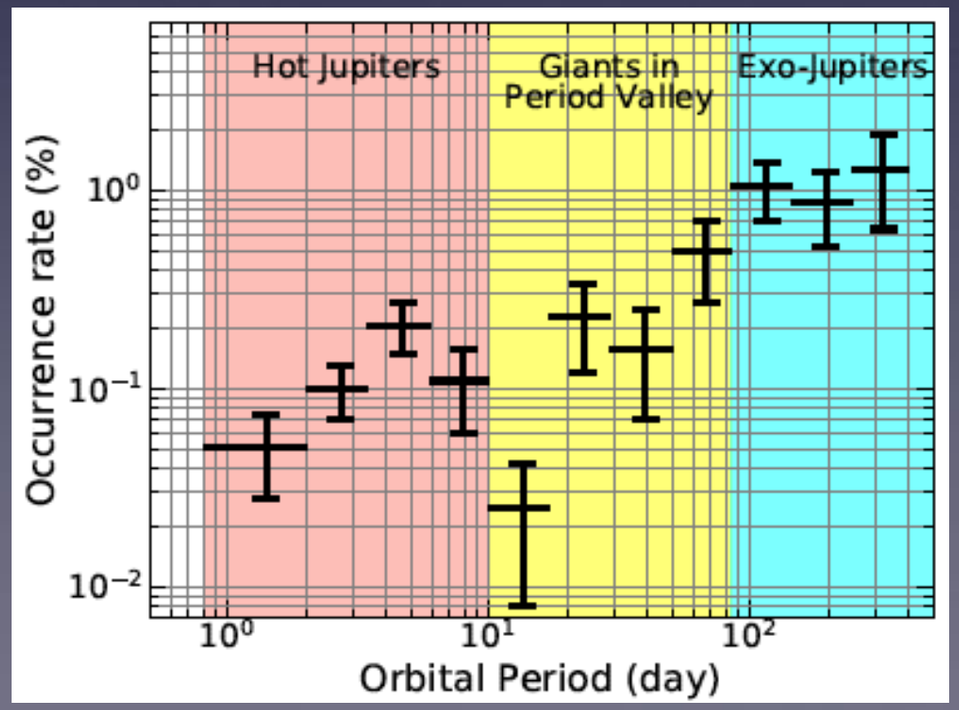


TABLE 2

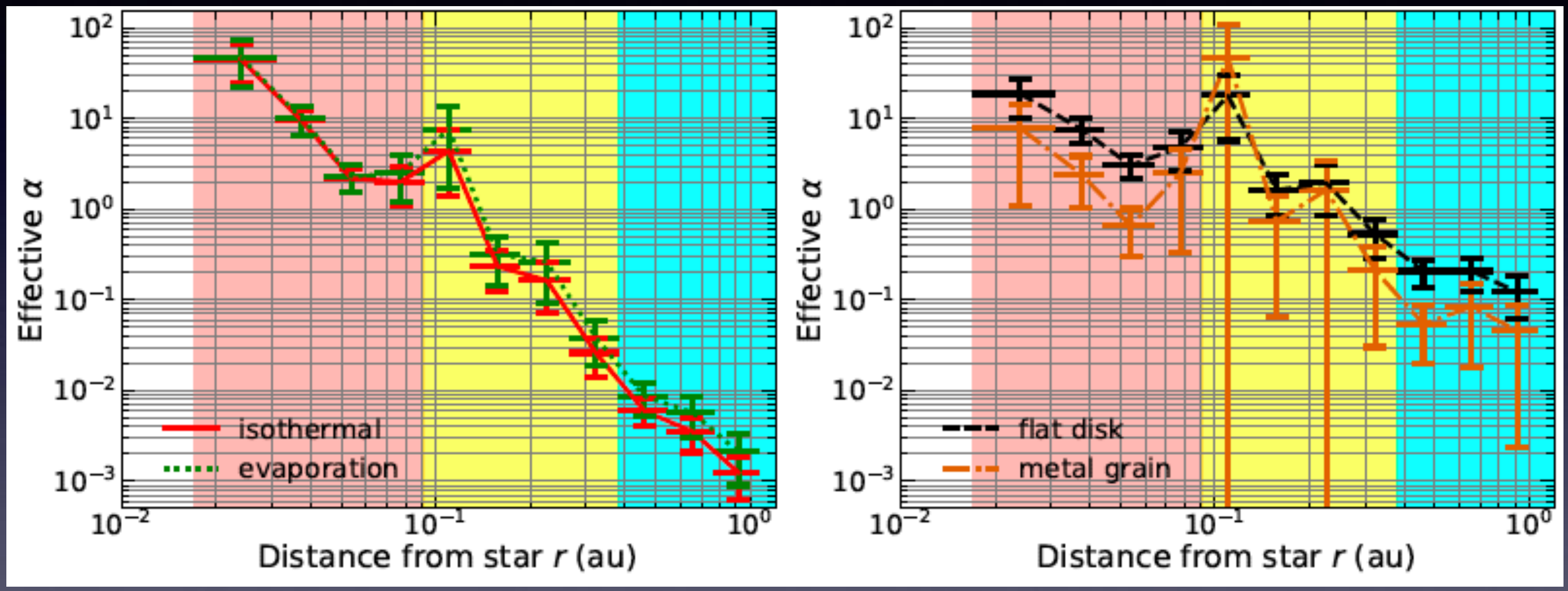
ANALYTIC ROSSELAND MEAN OPACITY IN (cm^2 g^{-1}): $\kappa = \kappa_n \rho^{\alpha_n} T^{\beta_n}$.

n	κ_n	α_n	β_n	Max. Temp. (K)	Reference
1.....	1×10^{-4}	0	2.1	132	HS
2.....	3×10^{0}	0	−0.01	170	HS
3.....	1×10^{-2}	0	1.1	375	HS
4.....	5×10^{4}	0	1.5	390	HS
5.....	1×10^{-1}	0	0.7	580	HS
7.....	2×10^{-2}	0	0.8	960[a]	HS
8.....	2×10^{81}	1	−24	1570[a]	BL
9.....	[illegible]	2/3	3	[illegible]	BL

[a] Transition temperatures are found by setting $\kappa_n \rho^{\alpha_n} T^{\beta_n} = \kappa_{n+1} \rho^{\alpha_{n+1}} T^{\beta_{n+1}}$ and solving for T. These values require specification of ρ; we use $\rho = 10^{-9}$ g cm^{-3}. The density dependence is weak; its exponent is given by $(\alpha_{n+1} - \alpha_n)/(\beta_n - \beta_{n+1})$ and is, respectively, 0.0403, 0.0123, and 0.0476 for $n = 7$, 8, and 9.



Results



$$\dot{M}_{\rm d} = 3\pi\nu\Sigma_{\rm g},$$

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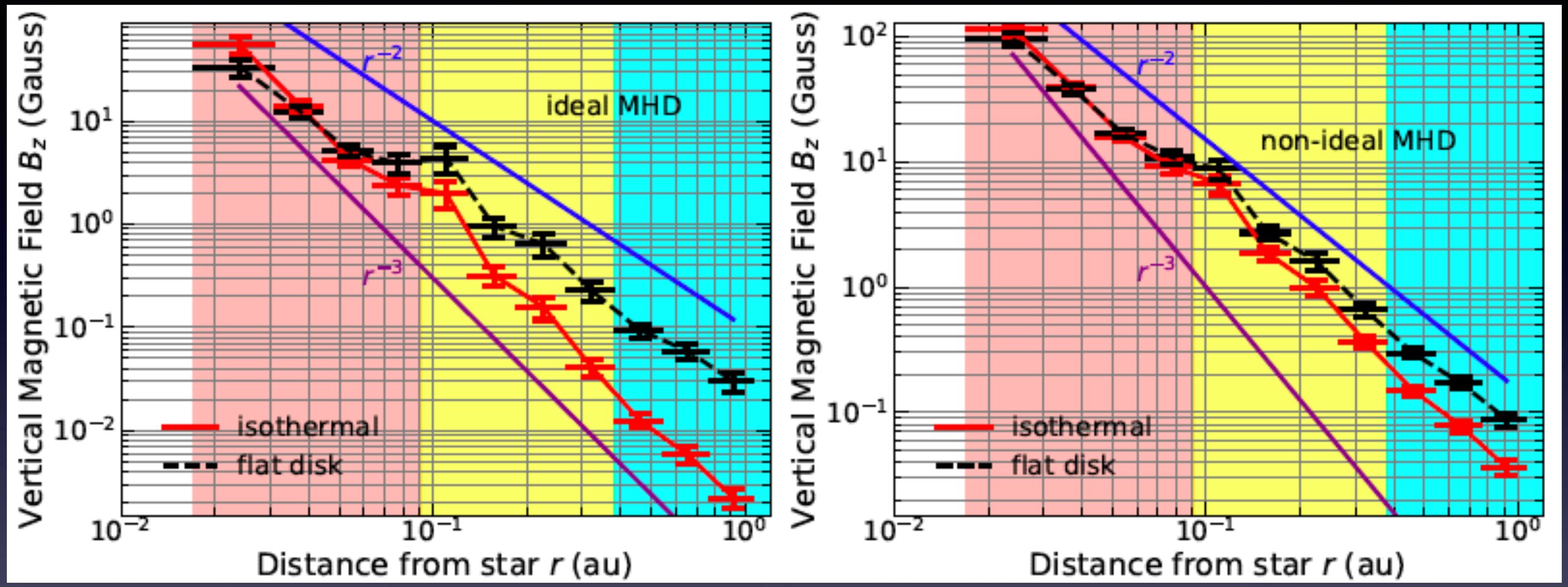
Results



$$\alpha_{\rm S16} = 11\beta_z^{-0.53}$$

Salvesen et al 2016

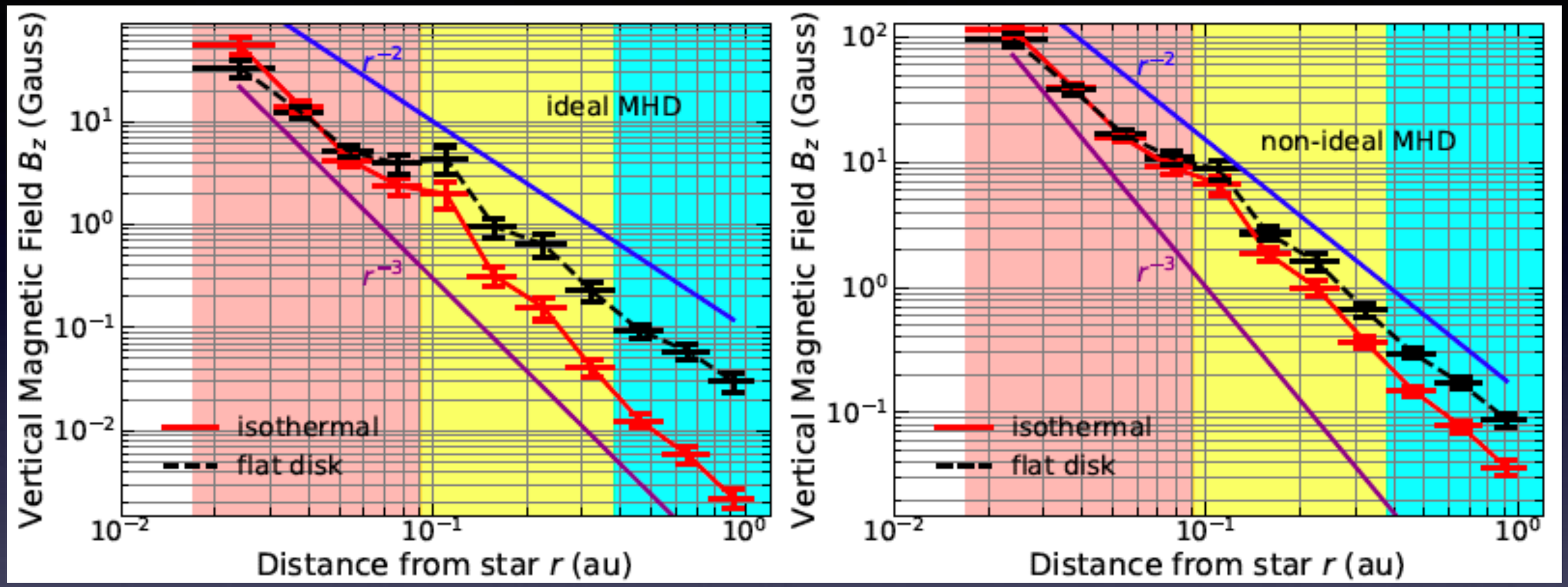
$$\beta_z = \frac{\rho_{\rm g} c_{\rm s}^2}{B_z^2/8\pi},$$

$$\alpha_{\rm B13} \equiv \frac{4r}{3\sqrt{\pi}H_{\rm g}} W_{z\phi}^{\rm B13}$$

$$W_{z\phi}^{\rm B13} = 0.23\left(\frac{r}{1\ {\rm au}}\right)^{0.46}\beta_z^{-0.66}$$

Bai 2013

Implication



Stellar dipole fields

$$B_s = 10^3 \left(\frac{r}{1.5R_\odot}\right)^{-3} \text{G}$$
$$\simeq 41 \left(\frac{r}{2\times10^{-2}\ \text{au}}\right)^{-3} \text{G}$$

Disk fields

$$B_d = 0.1 \left(\frac{r}{1\ \text{au}}\right)^{-2} \text{G}.$$

Okuzumi et al 2014

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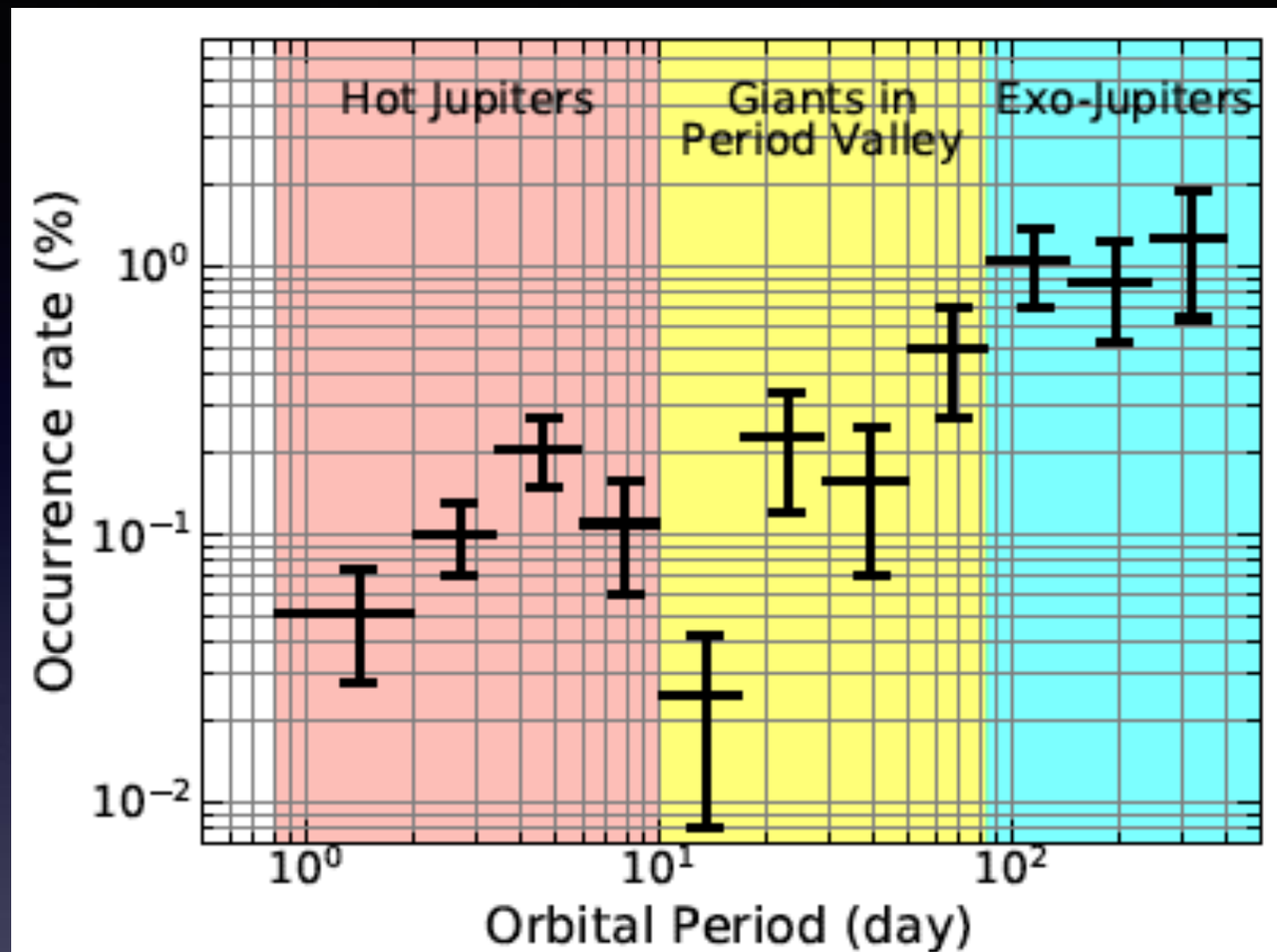

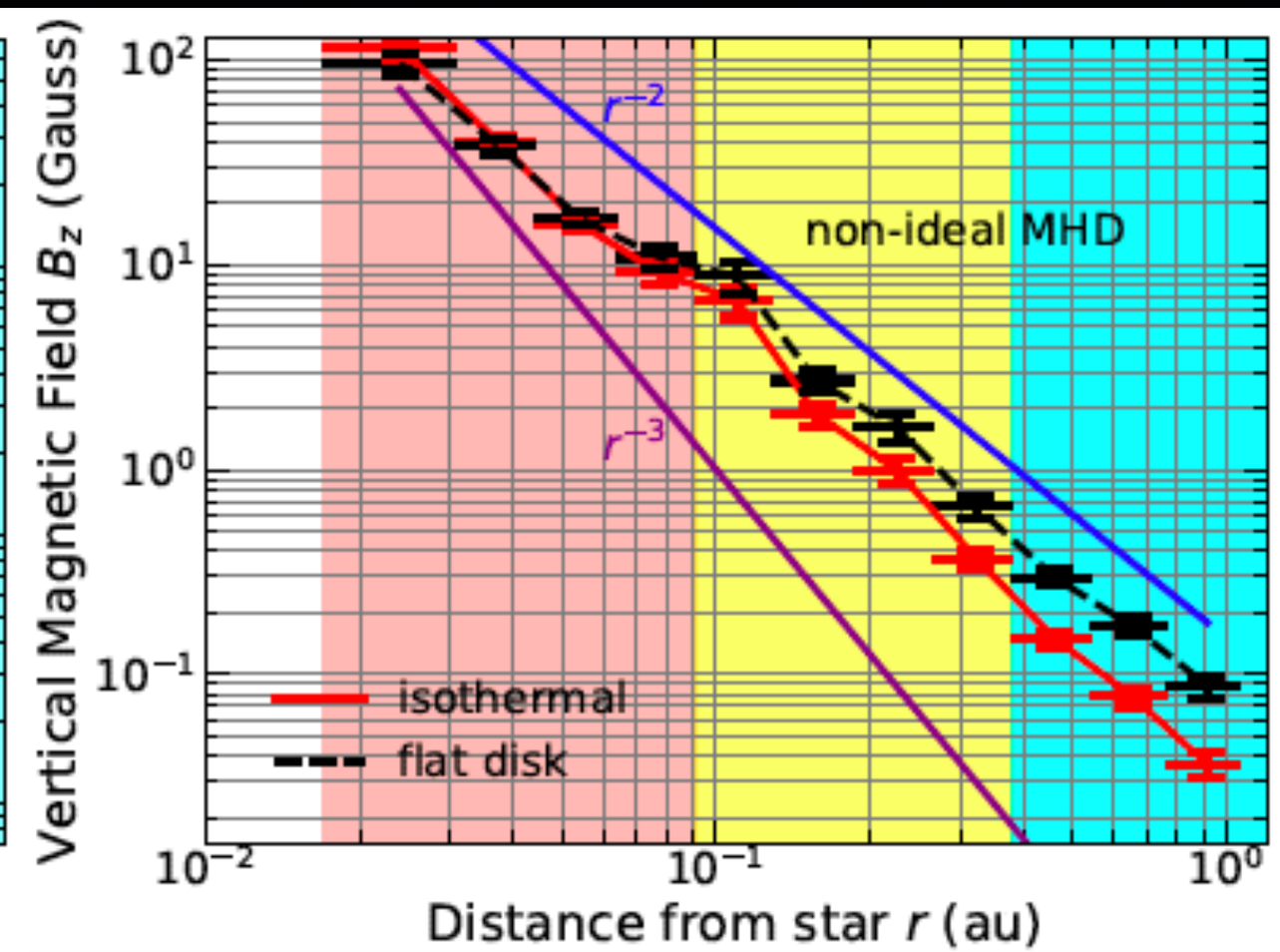

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Okuzumi et al 2014

Summary

Hasegawa et al, submitted ApJL

- The origin of close-in giant planets is still unclear
- The occurrence rate distribution has some intriguing structure
- Developed the simple, semi-analytical model, focusing on gas accretion onto protoplanets
- The gas surface density traces the occurrence rate - it increases with increasing the distance from the central star
- The occurrence rate distribution may trace the magnetic field profile - stellar dipole fields dominate at $r < 0.1$ au and the large scale field may be important at $r > 0.1$ au