Structure and migration in stellar irradiated Discs

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Motivation

- Migration of small mass planets is affected by entropy gradients (Paardekooper & Mellema, 2006; Baruteau & Masset, 2008). A realistic model of disk structure is needed to compute where planets would migrate.
- Including stellar irradiation changed the disc structure and promoted outward migration in shadowed regions of the disc (Bitsch et al., 2013).
- Migration of cores is important to know where giant planets could form in the disc.
- Opacity and metallicity have important influences on the disc structure, as they are responsible for shadowing effects (Bitsch et al., 2013).
- We investigate the influences of opacity and metallicity on the disc structure and migration.

Conclusions

- High metallicity increases H/r in inner regions of the disc and increases the shadowed regions.
- Outward migration is stronger and can reach farther out in high metallicity discs.
- As the disc evolves in time, so does the migration rate and the possible formation sites of giant planets. The disc composition matters!

Equations and Opacity

Equations for energy density E_R and thermal energy density ϵ:

$$\frac{\partial E_R}{\partial t} + \nabla \cdot \mathbf{F} = \rho \kappa_P(T,P)[B(T) - cE_R] \quad (1)$$

$$\frac{\partial \epsilon}{\partial t} + (\mathbf{u} \cdot \nabla)\epsilon = -P\nabla \cdot \mathbf{u} - \rho \kappa_P(T,P)[B(T) - cE_R] + Q^+ + S$$

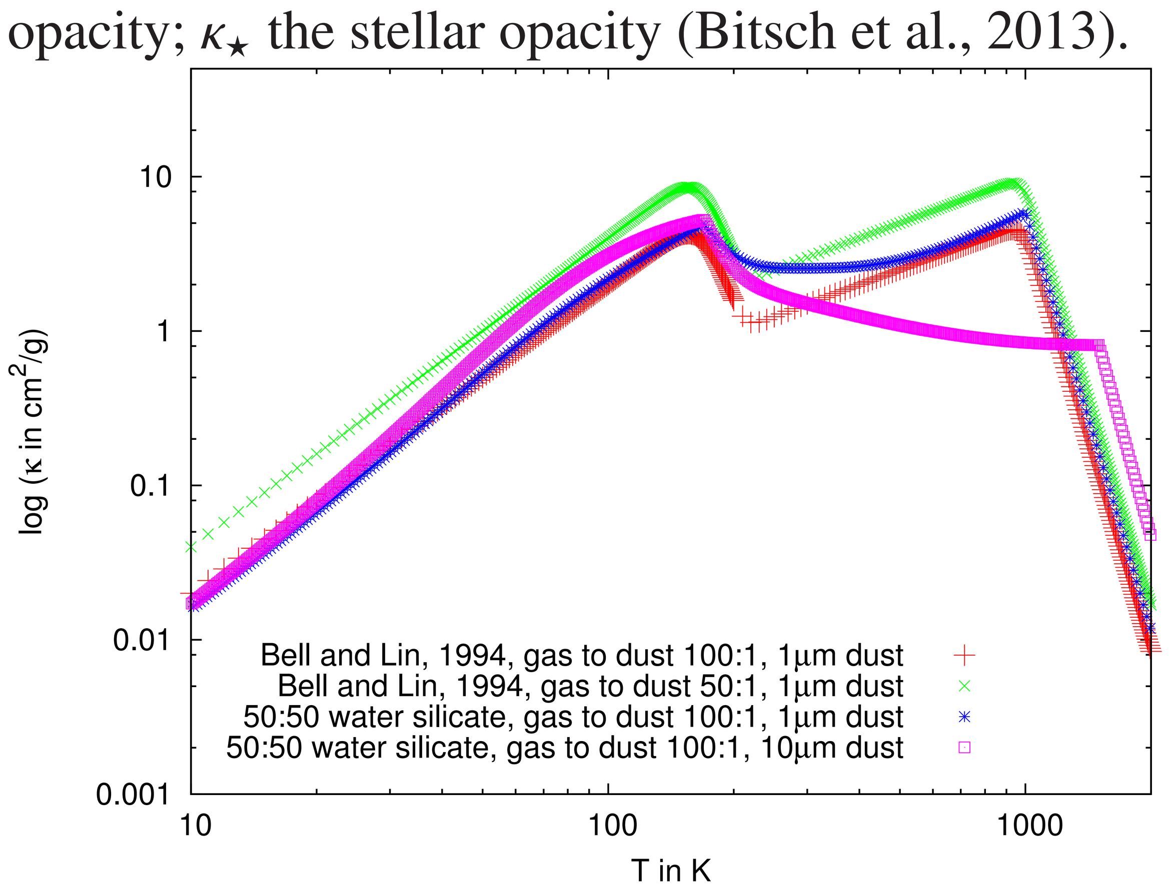
Q^+ viscous dissipation function; S stellar heating; $\mathbf{F}$ radiative flux, which is

$$F = -\frac{\lambda c}{\rho \kappa_R} \nabla E_R \,, \quad (2)$$

while the stellar irradiation is given by

$$S = F_\star e^{-\tau_i} \frac{1 - e^{-\rho \kappa_\star \Delta r}}{\Delta r} \quad \text{with} \quad F_\star = \frac{R_\star^2 \sigma T_\star^4}{r^2} \,. \quad (3)$$

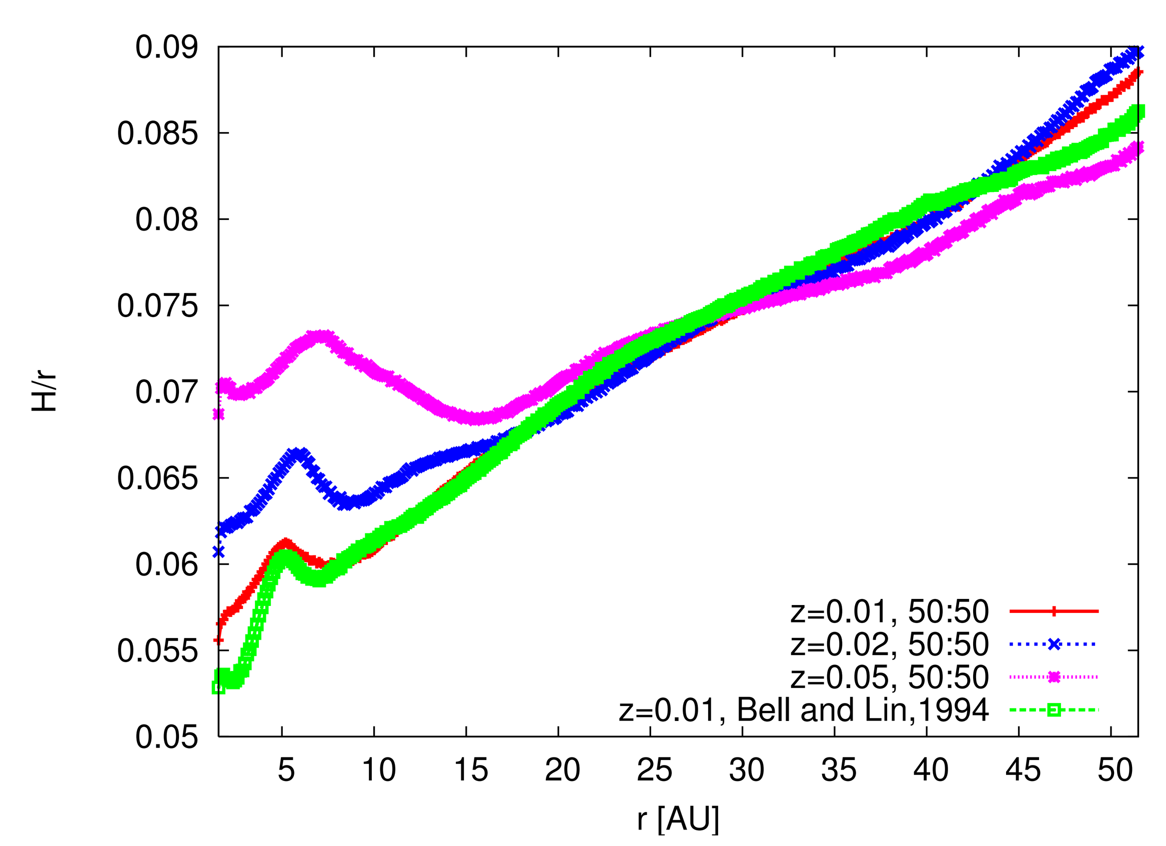
All these equations feature different opacities: κ_R Rosseland mean opacity; κ_P the Planck mean opacity; $\kappa_\star$ the stellar opacity (Bitsch et al., 2013).



Rosseland mean opacities by Bell & Lin (1994) and a 50 : 50 ice-silicate mixture for different size grains and gas-to-dust ratios.

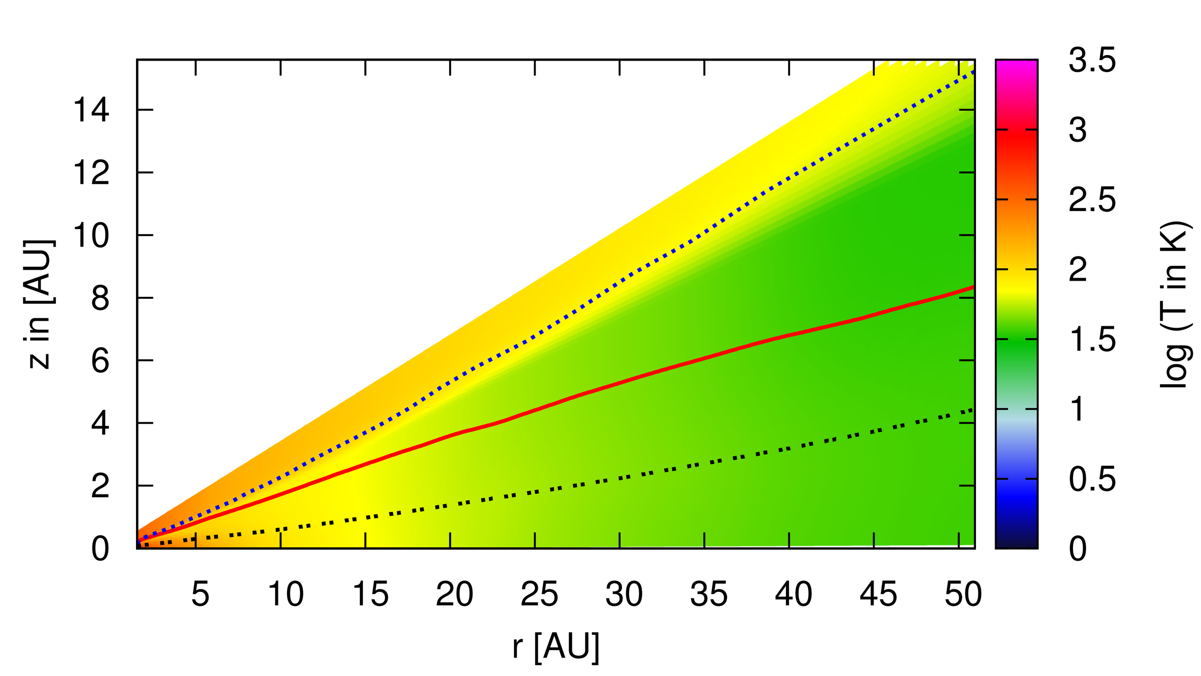
- Opacity changes with gas-to-dust ratio linearly.
- Different dust compositions change slope of opacities.
- Opacity important for the disc structure, because of eq. 1, 2 & 3.

Influence of Metallicity on Planetary Migration



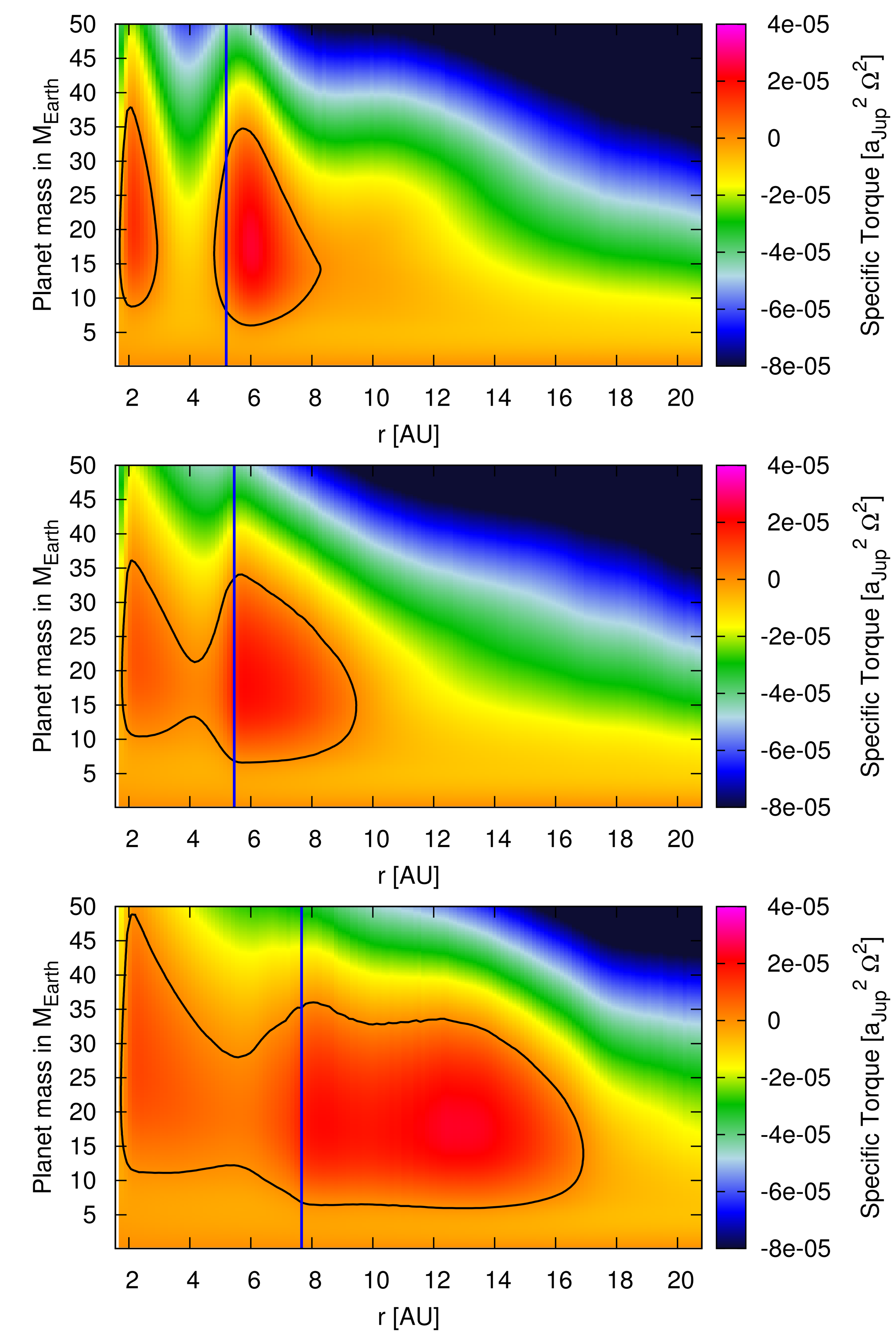
Aspect ratio for discs with different metallicity (z) with μm size dust for the opacity law.

- Inner disc dominated by viscous heating, outer disc by stellar heating.
- The innermost bumps in the disc (at 5 − 7AU) is related to the ice line opacity transition (at 170K).
- Increasing opacity increases the temperature (and H/r) in the inner parts of the disc, as cooling becomes less efficient.
- Bigger bumps cast larger self-shadowed regions in the disc.
- The outer parts of the disc are not affected by the change of opacity and remain flared ($H/r \propto r^{2/7}$).



2D Temperature map for the z = 0.01 (50 : 50) disc model.

Black line: H; **Blue** line: radially integrated $\tau = 1$; **Red** line: vertically integrated $\tau = 1$



Migration maps using the Paardekooper et al. (2011) formula for the Bell & Lin (1994) z = 0.01, z = 0.01 (50 : 50) and z = 0.05 (50 : 50) disc models (top to bottom). The black lines encircle the regions of outward migration and the blue line indicate the ice line (at 170K) in the disc.

- Outward migration is strongest when H/r decreases (inside a shadowed region) and is weakest (or non-existent) if H/r increases (in the flaring part of the disc).
- As the heating in the disc increases with metallicity, the ice line moves farther out.
- Different disc structures result in different migration zones, that might result in different sizes and distributions of exoplanets.

Methods

- Nirvana-Code (Resolution 386 × 66 active cells in r, θ-direction
- 2D radiation hydrodynamics, including viscous heating
- Flux limited diffusion approximation for radiation transport, SOR for radiation transport
- Treatment of stellar heating (Bitsch et al., 2013)

References

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