Planet Demographics as a Function of Initial Disc Mass

Population Synthesis Models Compared to Observed Exoplanet Populations

Group 2:
Alexandria Gonzales (MIT)
John Biersteker (MIT)
Niraj Inamdar (MIT)
Alexandra Greenbaum (JHU)
Anael Wunsche (Univ. Grenoble)
Zachary Draper (Univ. Victoria)
Daisuke Suzuki (Univ. Notre Dame)
Xu Huang (Princeton)

31 July 2015
Sagan Summer Workshop 2015

Introduction

- Planetary population synthesis models are way of understanding how exoplanets form and evolve
  - ⟹ Observational comparison can be used to constrain planet formation models
- There are significant challenges in using this approach to understanding exoplanets
  - ⟹ Synthesis models are incomplete
    - Parametrization for computational efficiency decreases fidelity
    - Incomplete understanding of all relevant physics
  - ⟹ Observational biases complicate interpretation of comparison between modeled and observed exoplanets
- Nevertheless, such models are a powerful way to better understand and characterize **statistically** the observed population of exoplanets

Science Question

- ***How does disc mass affect planet formation and evolution?***
  - ⟹ Disc mass drives the availability of material from which planets are made
    - How efficiently cores are formed
    - How much gas is available for core gas accretion
  - ⟹ Disk mass also affects migration rates
  - ⟹ Accounting for poorly-understood correlation between host star mass and disc mass may have a meaningful impact on planet formation

Predictions

- Increase in disc mass leads to increase in core masses
  - ⟹ More efficient planetesimal accretion
  - ⟹ More efficient gas accretion
- Faster migration to inner disc for Type I migration, weaker dependence for Type II migration ($M_p \gtrsim \mathrm{M}_{\mathrm{Sat}}$)

- Key variables
  - ⟹ Gas disc surface density

    $$f_{\mathrm{g}}\Sigma_{\mathrm{d}}$$

  - ⟹ Inner and outer disc radius

    $$(a_{\mathrm{inn},}a_{\mathrm{out}})$$

  - ⟹ Host star mass

    $$M_{\star}$$

Simulations (1/2)

- We ran a set of simulations to investigate effect of disc-mass relevant parameters
- **Systematic study**

  f_g = [0.5,8] (×5, logarithmically-spaced)

  a_{inn}= [0.01,0.05] AU

  a_{out}= [30,300] AU
- **Population synthesis study**

  Study 1
  - f_g = {0.5,1,2,4,8}, fix (a_{inn},a_{out}) = (0.03,30) AU, other parameters nominal

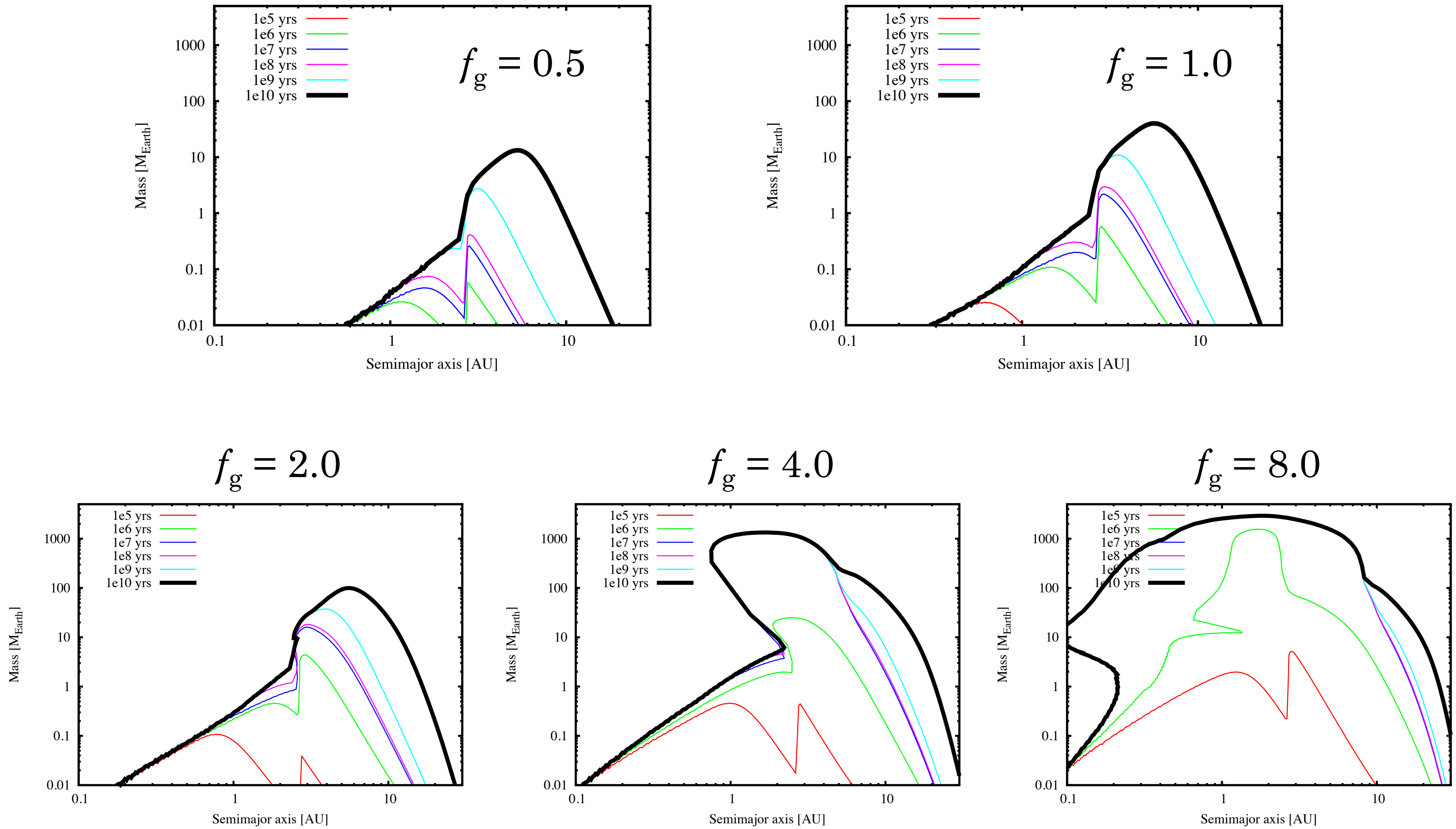
  Study 2
  - Fix f_g at 4, vary disc size , a_{inn} = [0.01,0.05] AU (linearly-spaced), a_{out}=[10,300] AU (logarithmically-spaced)

  Study 3
  - Vary disc mass with stellar mass, $M_\star$= {$0.1M_\odot$,$0.5M_\odot$,$2M_\odot$}

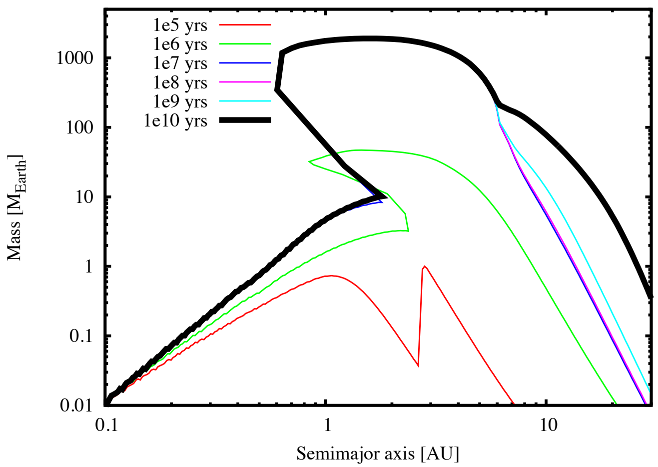
Simulations (2/2)

- Shortcomings/limitations
  - $\Rightarrow$ No dynamical interaction between planets
    - No planetesimal-driven migration
  - $\Rightarrow$ No pebble accretion
  - $\Rightarrow$ No post-disc dissipation thermal evolution
    - Important for final planet radius
  - $\Rightarrow$ Parametrized envelope accretion model
  - $\Rightarrow$ Viscosity—α model?
  - $\Rightarrow$ Migration?

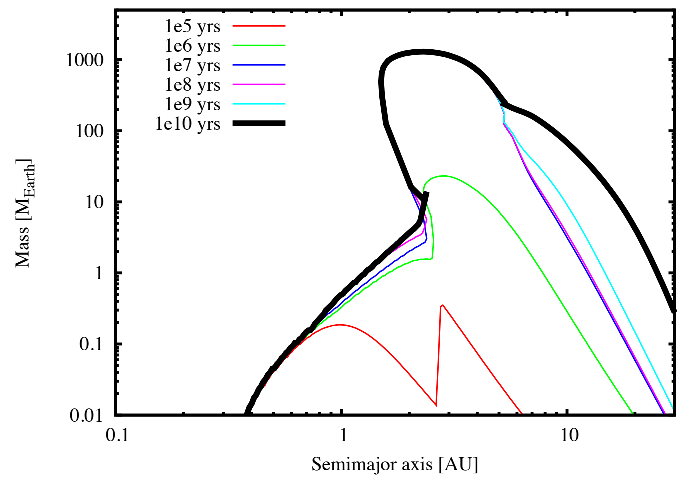
Results: Final a_p (systematic)



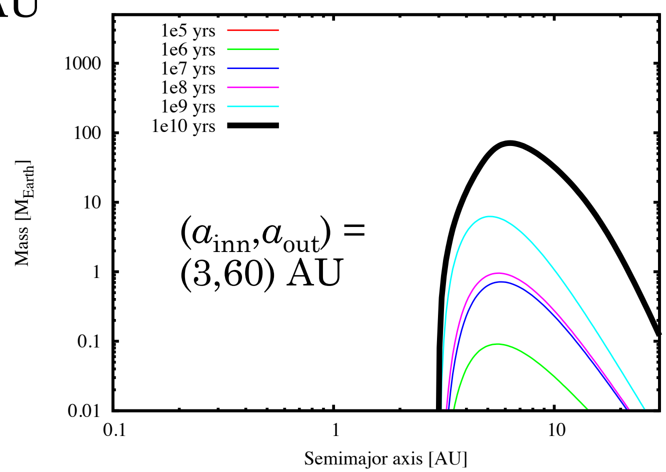
Results: Final a_p (systematic)



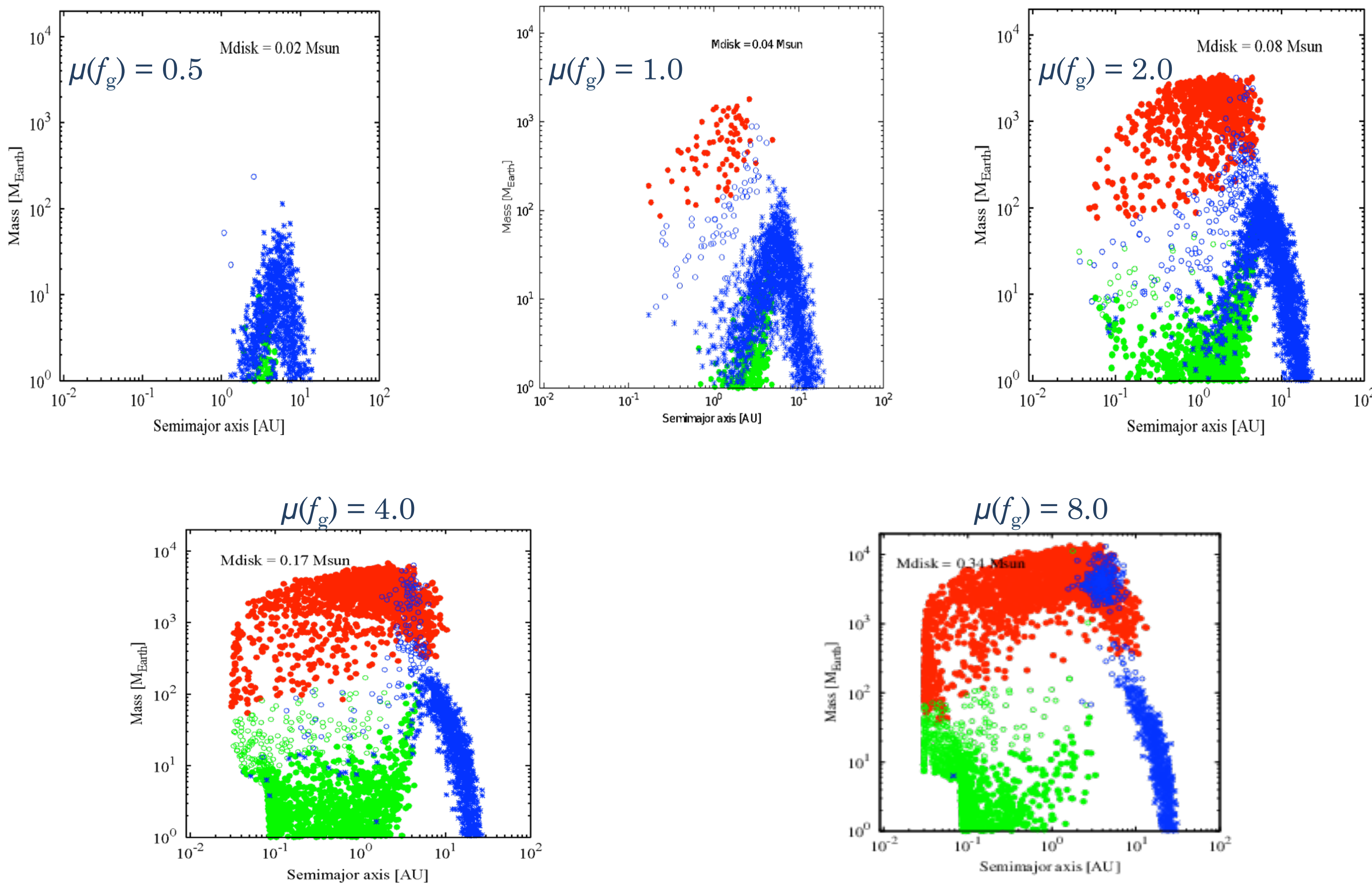
(a_{inn}, a_{out}) = (0.03,60) AU



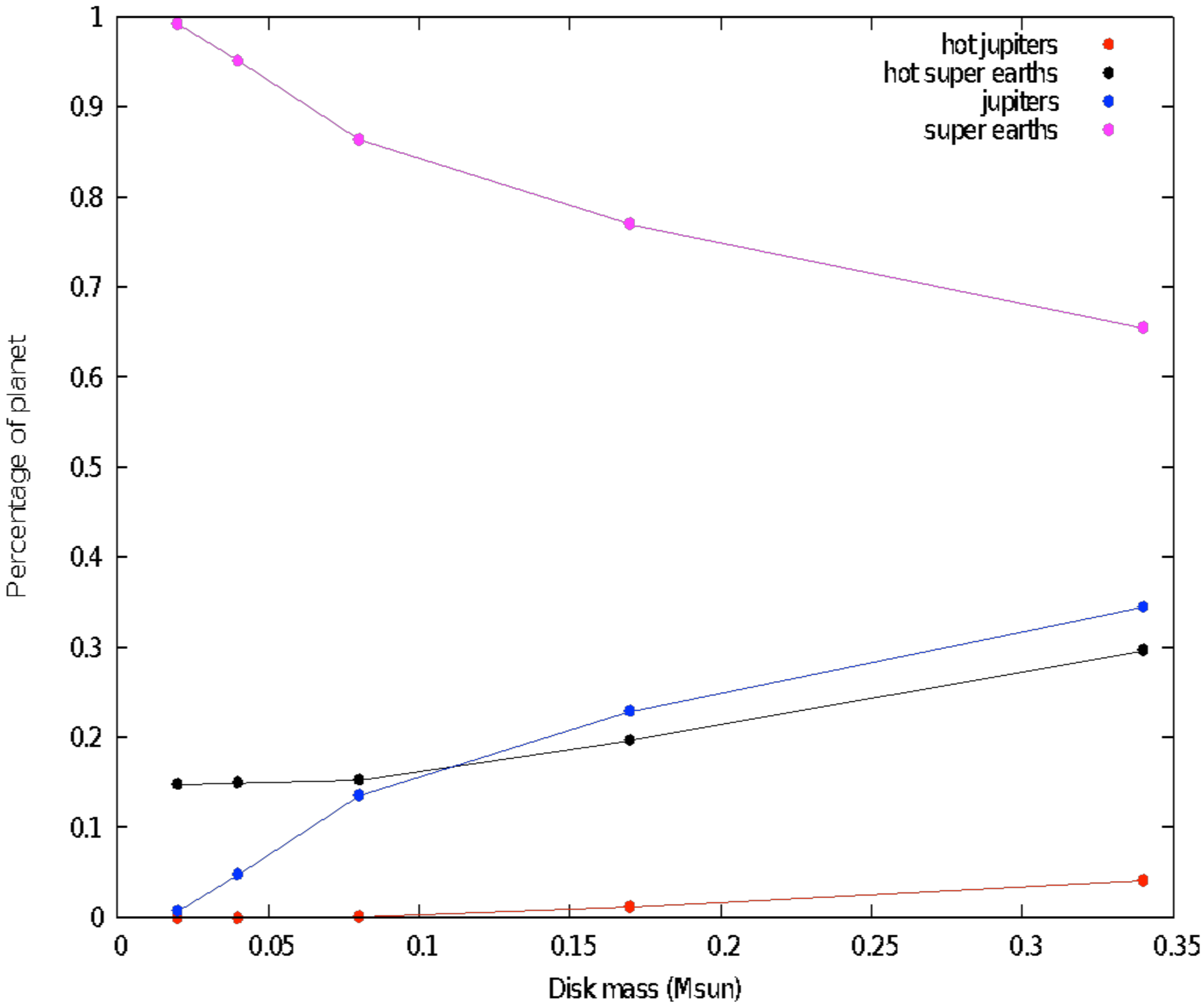
(a_{inn}, a_{out}) = (0.3,60) AU



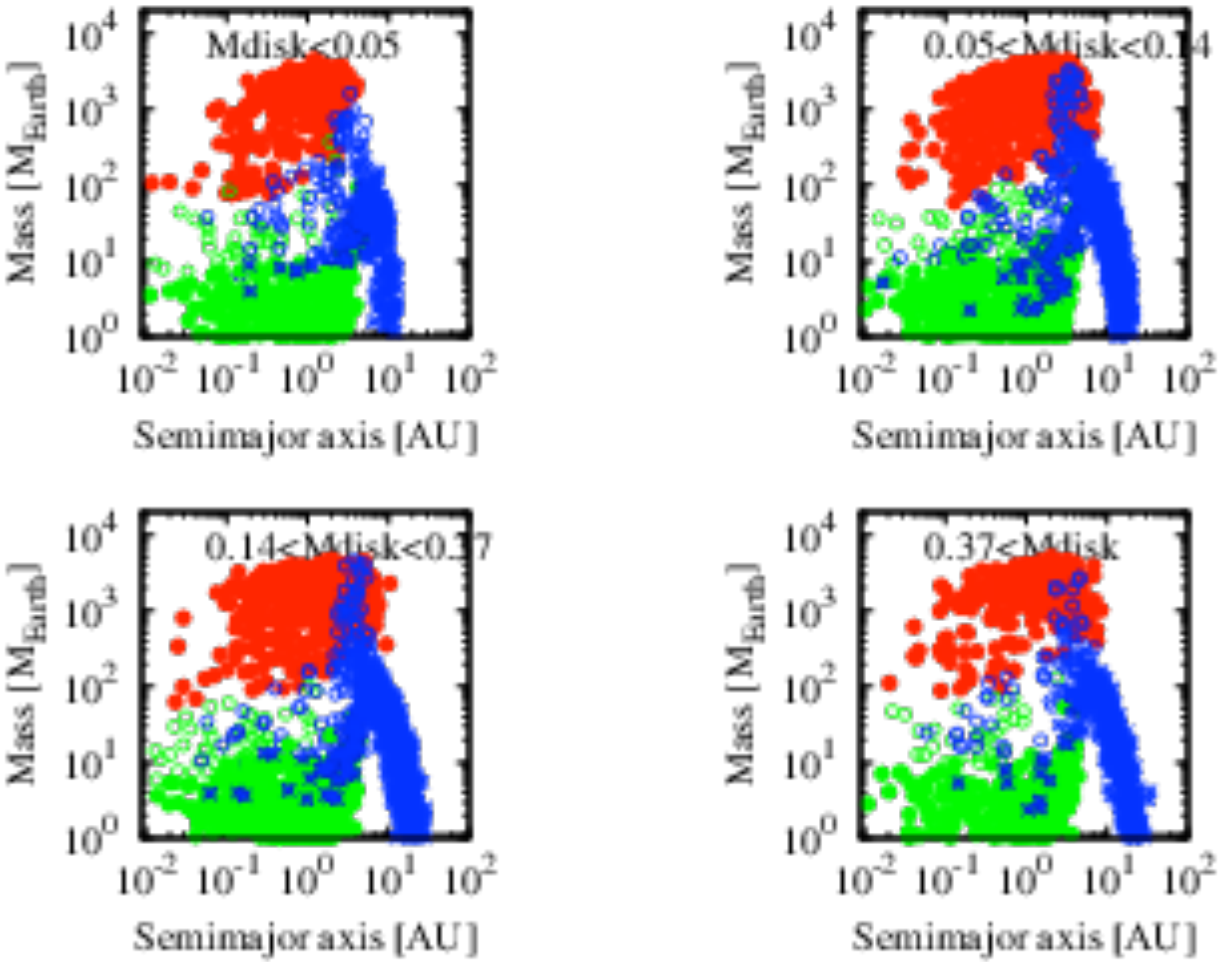
Results: a_p vs. M_p (population synthesis)



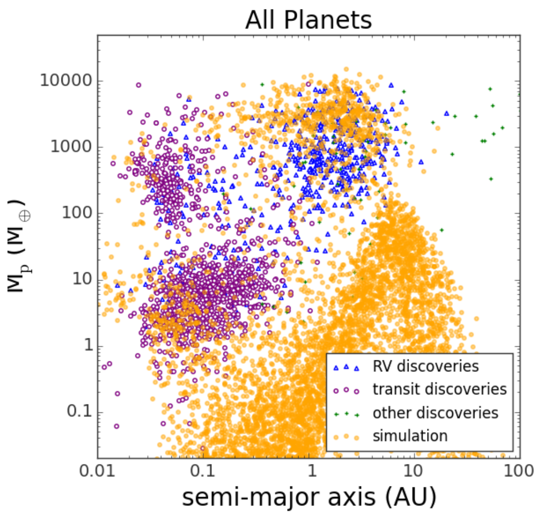
Results: a_p vs. M_p (population synthesis)



Results: a_p vs. M_p (population synthesis), $\mu(f_g) = 3.0$ varying disk boundaries

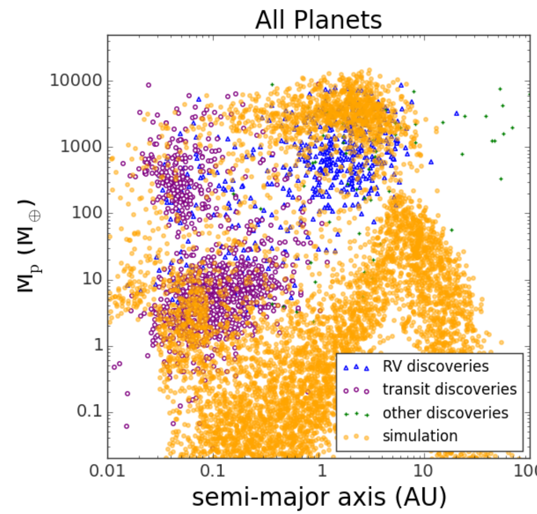


Results: a_p vs. M_p (population synthesis)

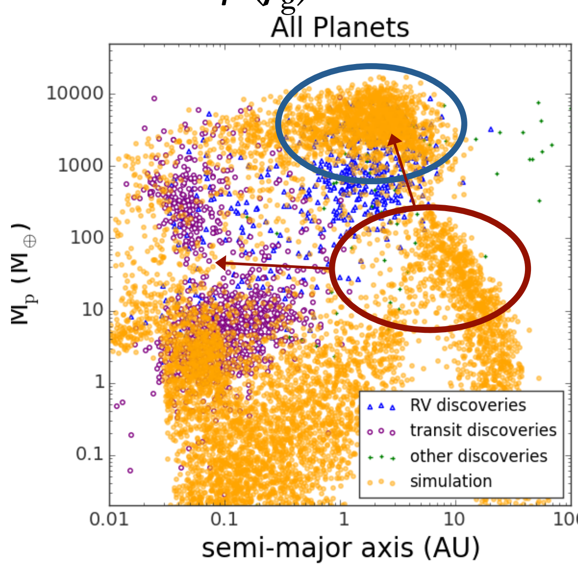


$\mu(f_g) = 0.125$

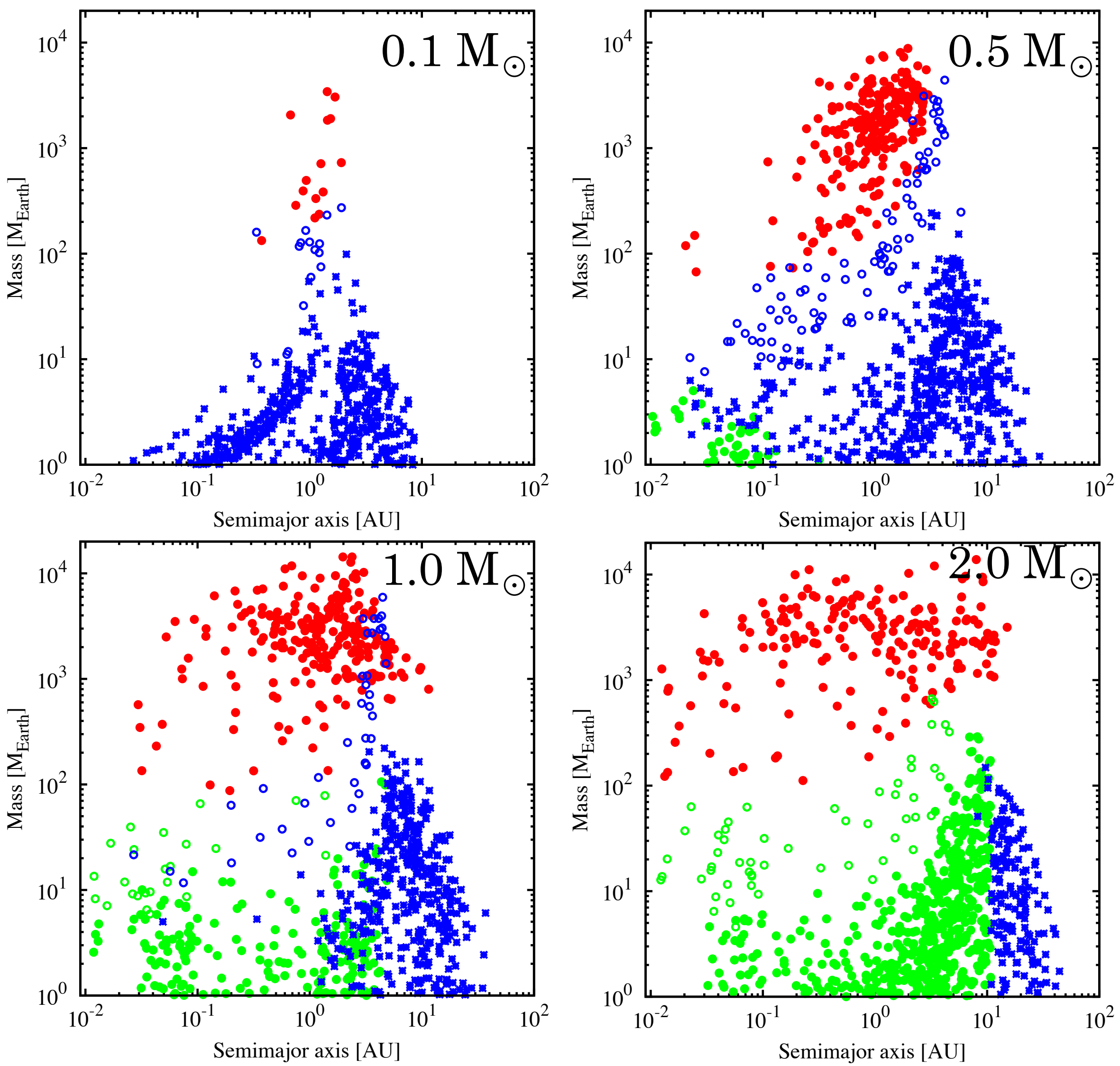
$\mu(f_g) = 1.0$



$\mu(f_g) = 0.5$



Results: a_p vs. M_p (population synthesis)
$M_\star = \{0.1, 0.5, 1.0, 2.0\}\ M_\odot$



- Vary stellar mass linearly with the mean of the disc mass distribution
- Other parameters held at nominal values
- Competing effects
  - ⟹ Feeding zone width inversely proportional to $M_\star$
  - ⟹ Interaction rates proportional to Ω

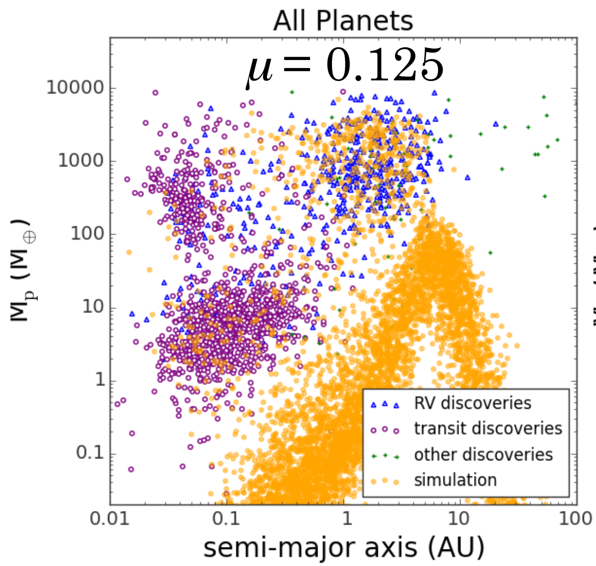
Conclusions

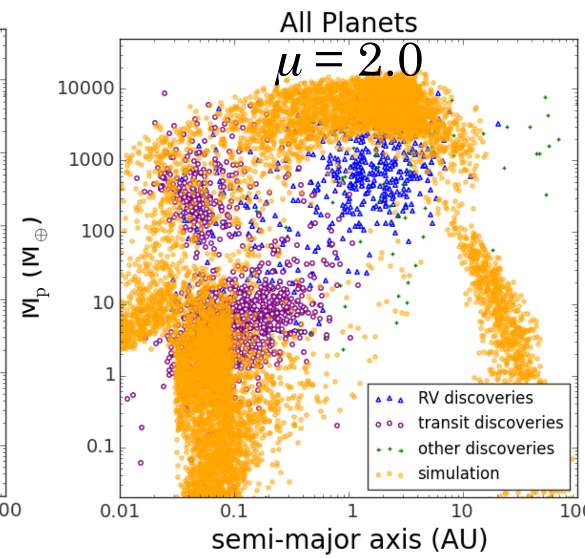
- Increase in f_g leads to overall **increase in planet mass** and **migration inwards** for lower mass planets
  - $\Rightarrow$ Less dramatic migration for larger mass planets
- Co-varying f_g and $M_\star$ produces similar results

Backup Material

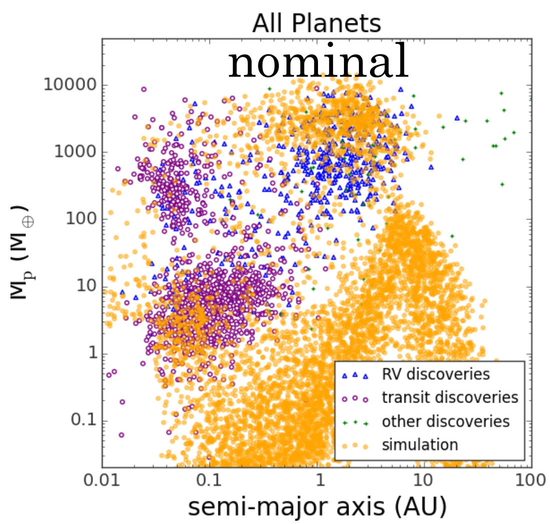
Changing the variance, still hard to match detected planet population

Smaller variance for small and large average disk mass – *exaggerates some effects of low and high disk mass*





Large variance for nominal average disk mass – *smooths out the distribution for lower mass, large separations.*



VS.