Giant Planet Instability:

Constraints from the Main Asteroid Belt

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Outline

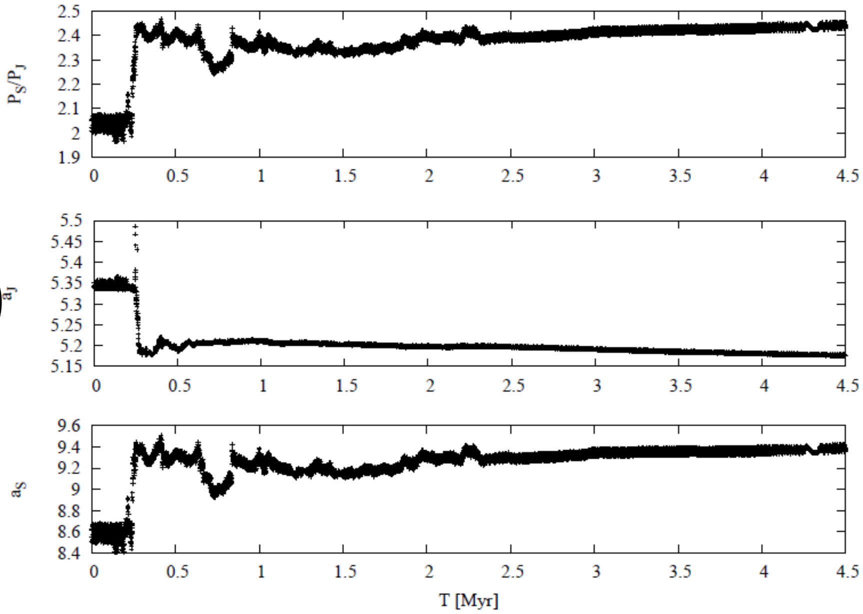
- Introduction
- Simulations
- Results
- Concluding remarks

Introduction

- Instability phase

  Jupiter and Saturn's orbits separated in an impulsive manner (Jumping Jupiter!)

- two main uncertainties
  - timing
  - magnitude



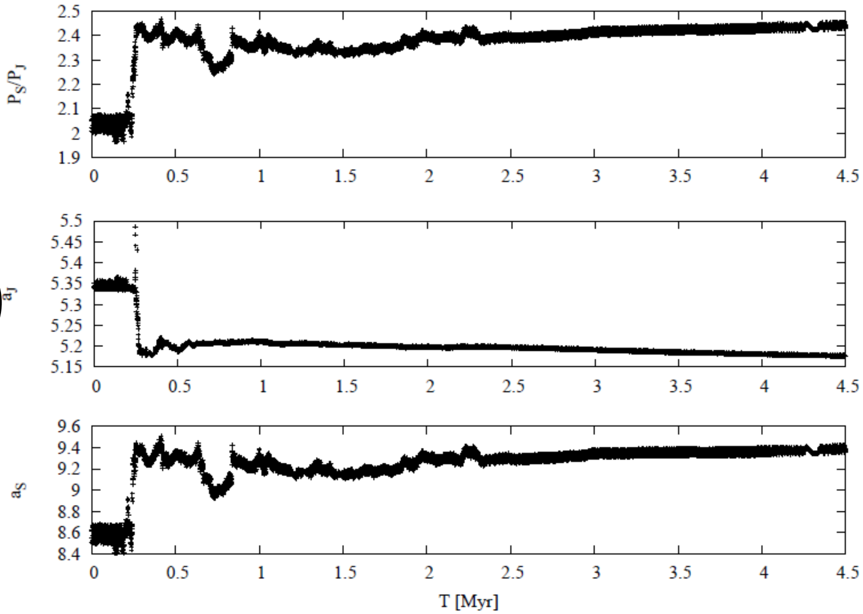
Brasser et al. (2009)

Introduction

- Instability phase

  Jupiter and Saturn's orbits separated in an impulsive manner (Jumping Jupiter!)

- two main uncertainties
  - timing
    - early
    - late (in favor of the LHB)
  - magnitude



Brasser et al. (2009)

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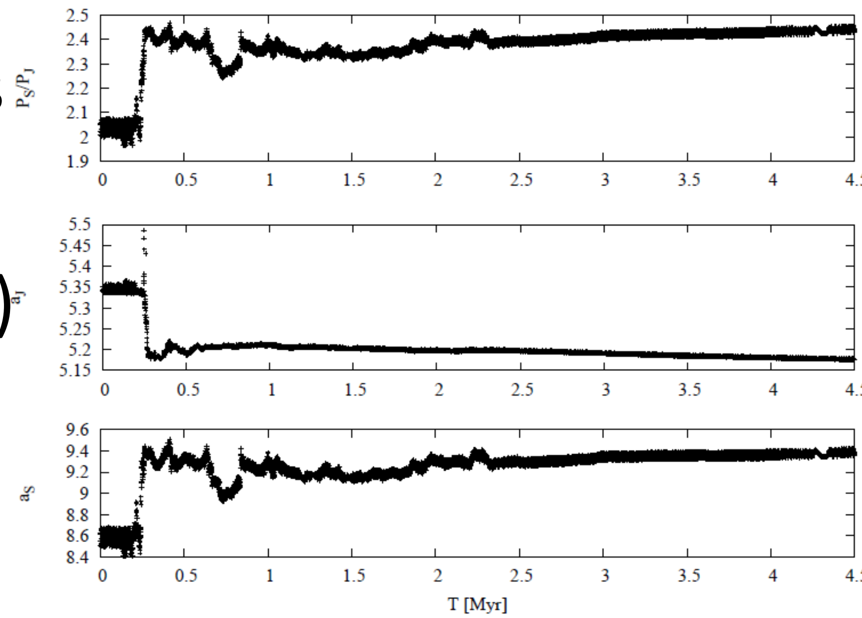
Introduction

- Instability phase

  Jupiter and Saturn's orbits separated in an impulsive manner (Jumping Jupiter!)
- two main uncertainties
  - timing
  - magnitude
    - short jump
    - large jump (low probability)



Brasser et al. (2009)

Introduction

- We must set constraints!
  - Terrestrial Planets

  small jump destabilizes or overexcites terrestrial planets' orbits ($g=g_5$)

  terrestrial planets formation processes can lower AMD

	EARLY	LATE
SHORT	✓	✗
LARGE	✓	✓

Introduction

- We must set constraints!
  – Main Belt

  for a dynamically cold disk of asteroids, a large jump is needed (Morbidelli et al., 2010) ($g=g_6$)

  sets no constraint on timing

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Introduction

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  - Main Belt

  for a dynamically cold disk of asteroids, a large jump is needed (Morbidelli et al., 2010) ($g=g_6$)

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…revisit Morbidelli et al. (2010) considering a post-Grand Tack initial distribution of asteroids.

Simulations

- initially dynamically hot distribution of asteroids
- planetesimal induced smooth migration of giant planets
- include planetary formation processes
- study the effect of secular resonance sweeping in the inner main belt

Simulations

- Giant planet migration
  - smooth migration using Malhotra (1995) recipe with initial separation corresponding to a small jump

$$a(t) = a_f - \Delta a \; exp(-t/\tau)$$

  - add extra acceleration in SyMBA

$$\Delta \ddot{\mathrm{r}} = \frac{\hat{\mathrm{v}}}{\tau} \left(\sqrt{\frac{GM_\odot}{a_f}} - \sqrt{\frac{GM_\odot}{a_i}} \right) exp\left(-\frac{t}{\tau} \right)$$

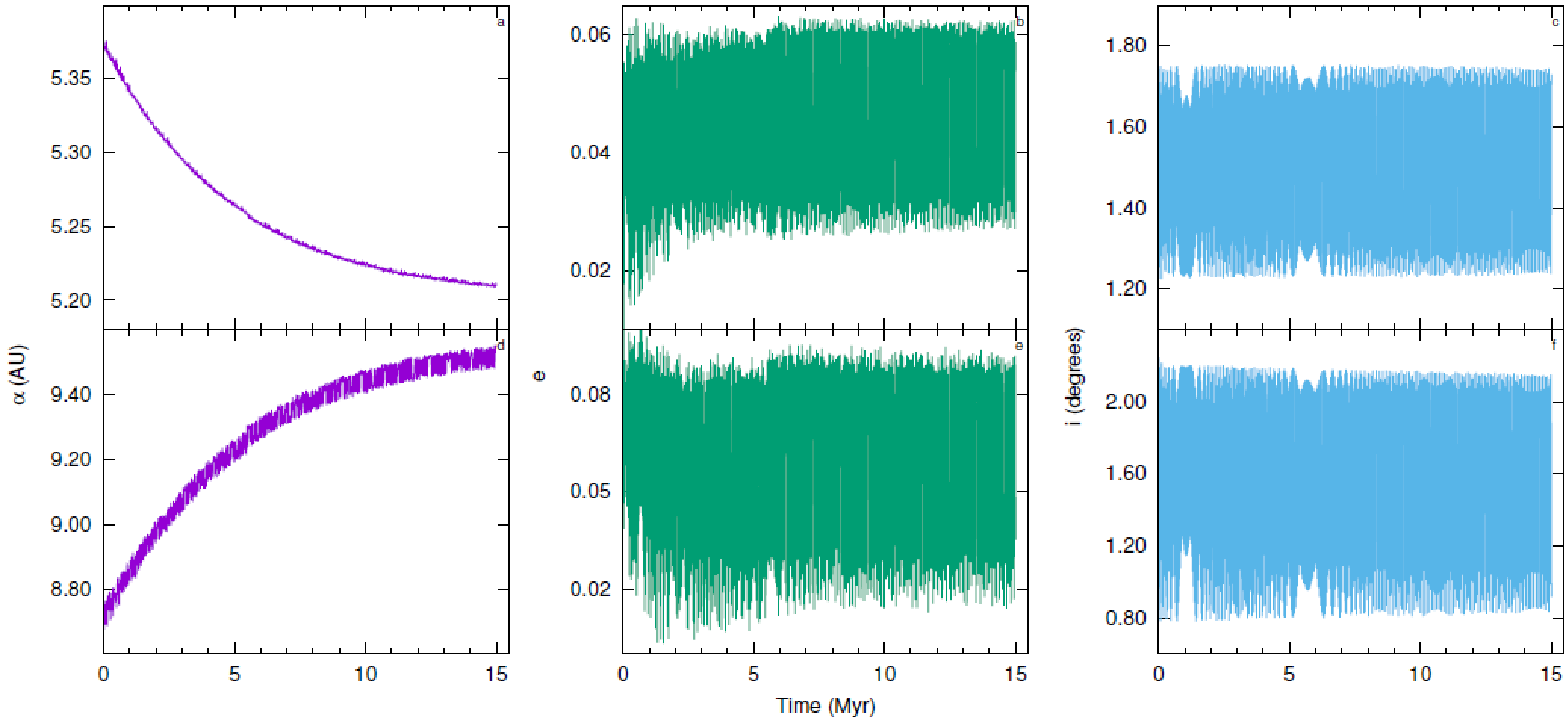
  - τ=5My, t_{total}=15My

Simulations

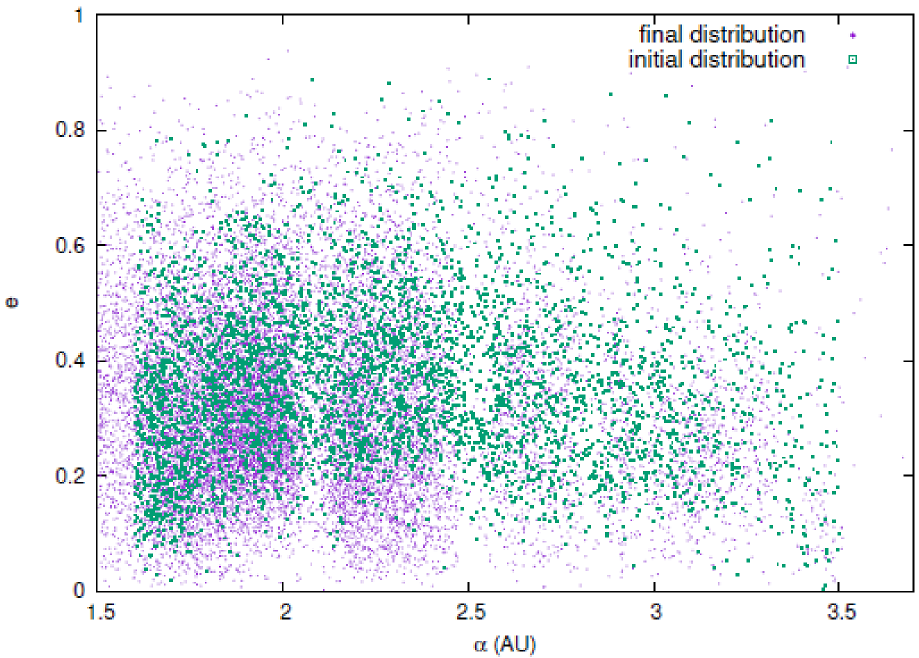
- Initial conditions taken from Jacobson & Morbidelli (2014)
  - Ten sets of simulations → 5500 bodies
    - **asteroids**: 4600 bodies with $1.6 < a < 3.5$ AU and mass $m_{ast}=3.8*10^{-6}\ M_{\oplus}$
    - **embryos and planetesimals**: ~900 bodies with ratio 8 in mass and one embryo of $0.8\ M_{mars}$
    - **giant planets:** Jupiter and Saturn just beyond their mutual 2:1 MMR. $a_J = 5.4$ AU, $e_J \simeq 0.04$, $i_J \simeq 1.71^o$ and $a_S = 8.7$ AU, $e_S \simeq 0.07$, $i_S \simeq 1.0^o$.

Simulations

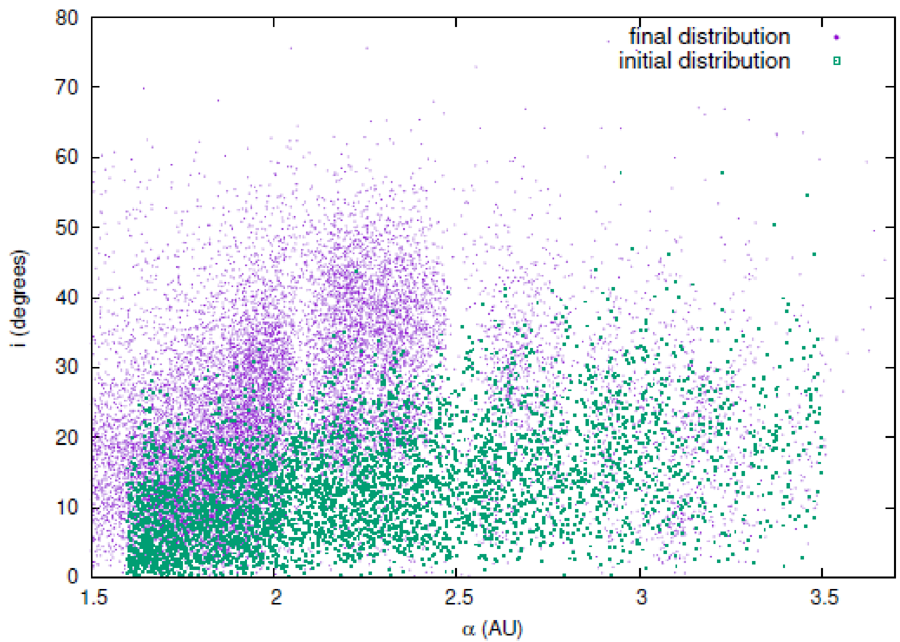
- Giant planet migration-typical evolution



Results

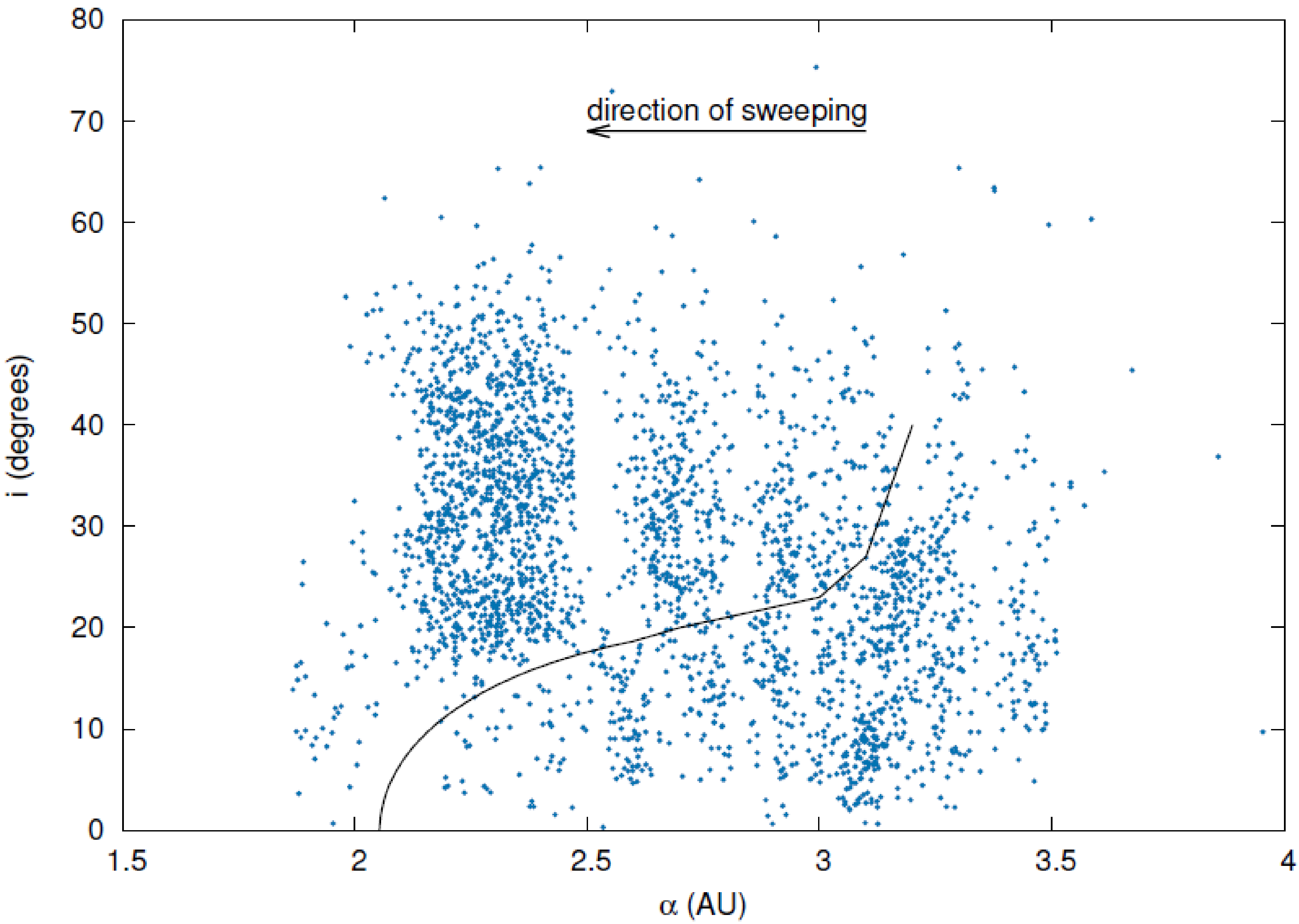


initial and final inclination of asteroids for all 10 sets



initial and final eccentricity of asteroids for all 10 sets

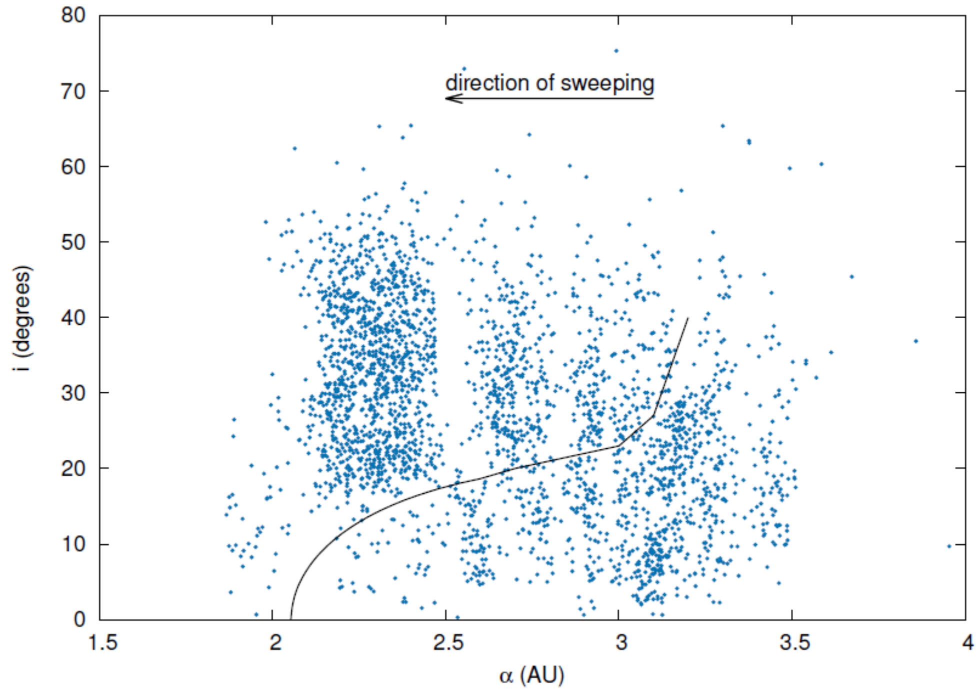
Results



q >1.8 AU

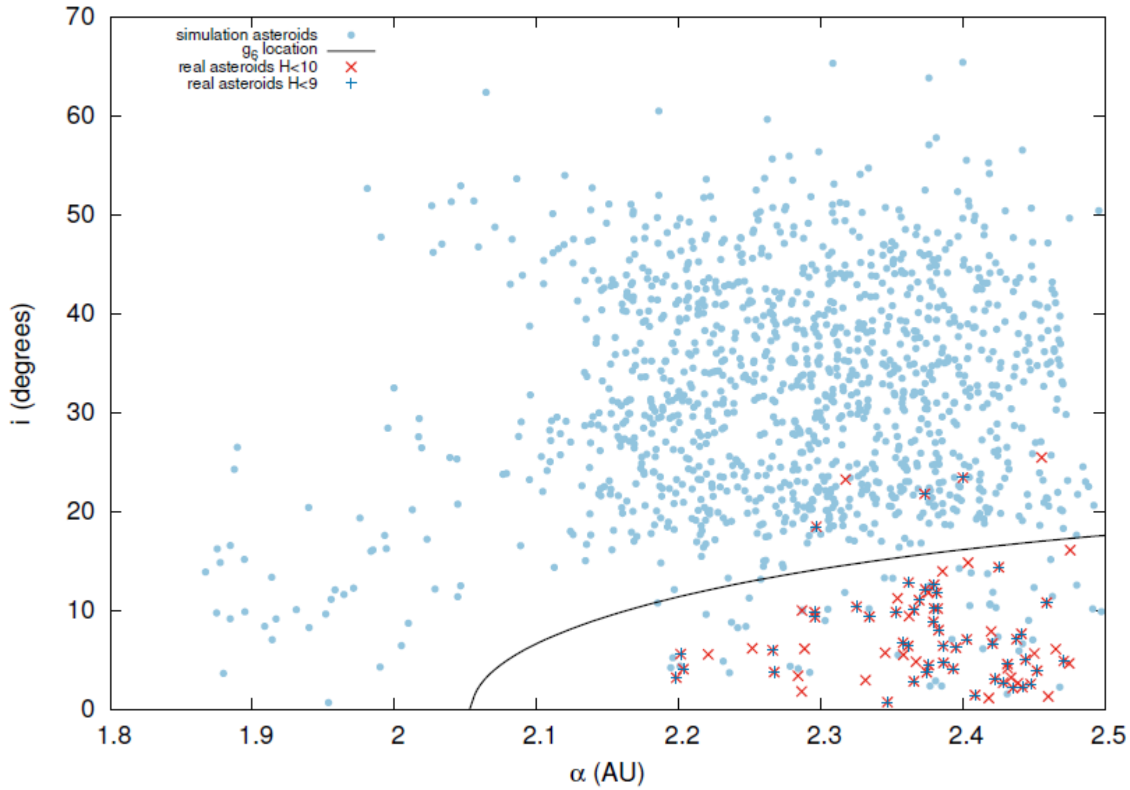
Results

- Mechanism
  - $g=g_6$ secular resonance lands on inner main belt
  - it sweeps towards a=2AU
  - affects low inclination asteroids



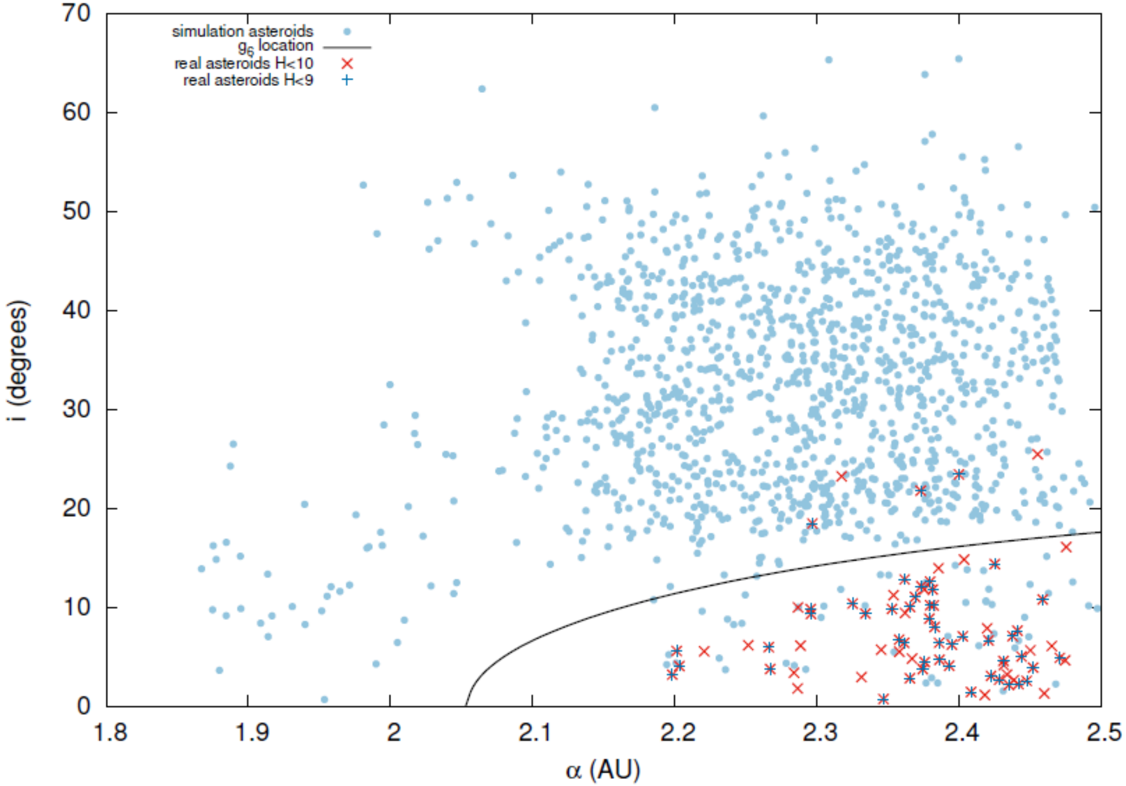
Results

- Comparison with real observed asteroids
  - selected from AstDys catalogue all asteroids with H < 9 and H < 10 (corresponding to diameter > 50km) with q > 1.8 AU and a < 2.5 AU



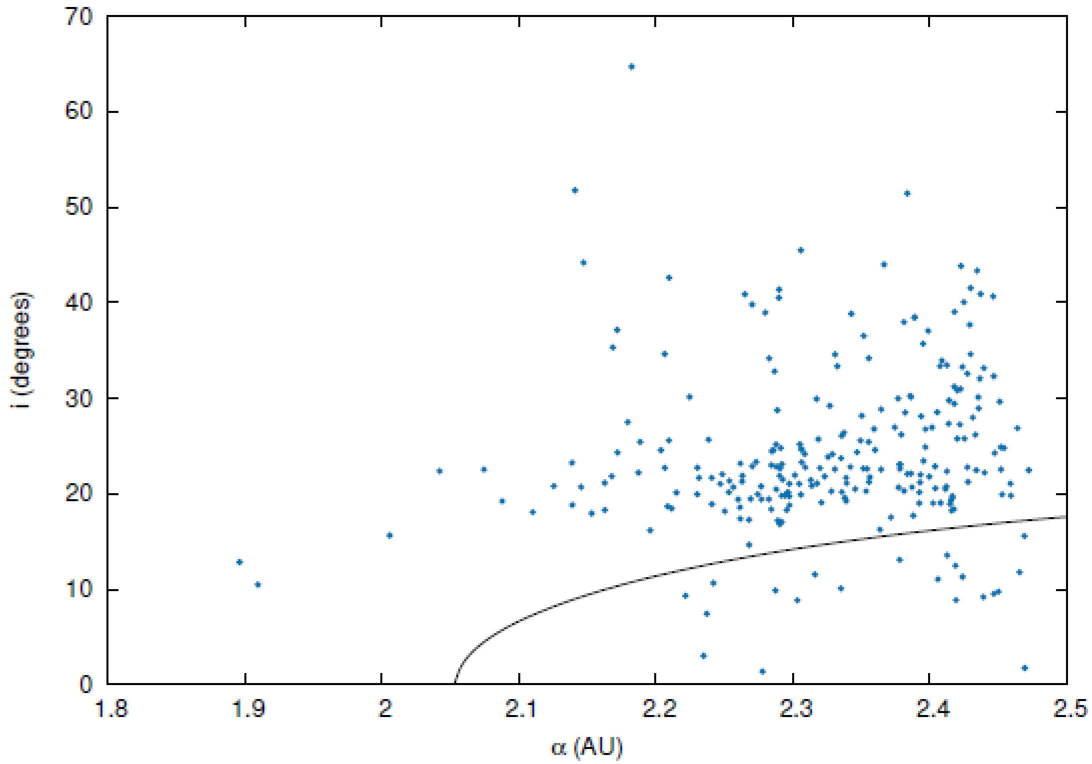
Results

- Comparison with real observed asteroids
  - 51 out of 1276 asteroids end up below $g=g_6$ (4%)
  - for real asteroids it is 93.88% for H<9 and 93.42% for H<10



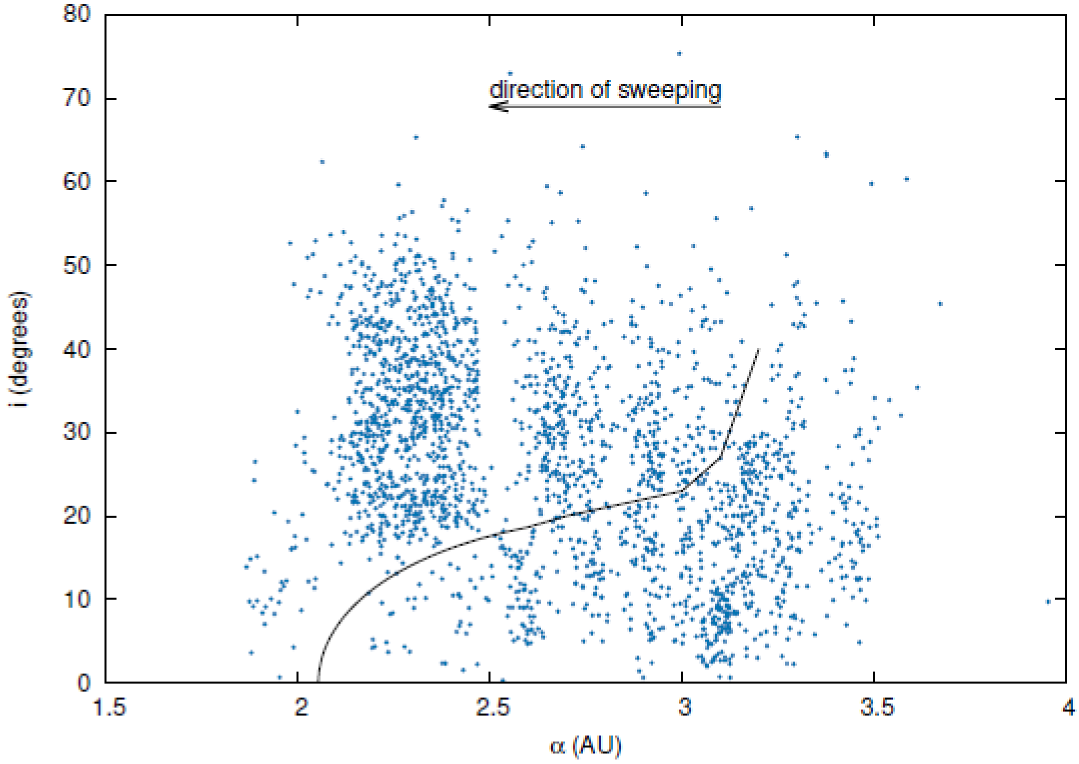
Results

- Resumed all integrations until t=200My
  – new value is 8.44%



Results

- Consider particles that had initial $i<20^o$
  - new value is 4.07%



$s=s_6$ sweeps first

Concluding remarks

- considered a short jump just beyond 2:1 MMR
- $s=s_6$ and $g=g_6$ sweep through the main belt
- ratio of asteroids below and above $g=g_6$ is much smaller than the observed ratio
- also true after evolving the system for 200My or considering initially asteroids with $i<20^o$
- even though a short jump is a higher probability event, it does not reproduce the asteroid belt under any assumption for its initial distribution

Thank you!