Constraining asteroid dynamical models using GAIA data

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In short...

- GAIA will provide extremely accurate orbits and spin information-solutions for a large number of asteroids.
- Combining with data (albedo, size) from other missions, we will have a complete physical/orbital picture for a large set of objects.

→ We could test dynamical models of the interplay between gravitational perturbations (chaotic diffusion in e, i) and Yarkovsky/YORP forces (drift in a).

→ Of special interest are: (i) groups of resonant objects (e.g. 2/1, 7/3) and (ii) asteroid families, hosting a significant component of chaotic motion (e.g. Veritas).

- We need to be able to run ***thousands*** of simulations

→ to match an observed distribution and, using optimization techniques,

→ to probe the Yarkovsky “law” ($da/dt \sim f(D,...)$), the initial ejection velocity field, etc...

Transport in action space: a statistical model

- We have introduced the use of a random-walk approximation, that describes chaotic diffusion in the space of proper elements (actions), as a tool to study the evolution of (chaotic) asteroid families:

→ compute the transport (diffusion) coefficient $D(e,i)$ on a grid covering the neighborhood of a family/group of asteroids
→ use D in a simple random-walk model to study the motion of fictitious family members
→ match the observed distribution → get the *age* of the family!

→ Only a few seconds for each realization of a 10 My evolution!!

- Successfully applied to the *Veritas* family (Tsiganis et al. 2007) – result agrees with Nesvorny et al. 2003

- Novakovic et al (2010a,b) extended the model by introducing evolution in a due to Yarkovsky (also YORP included)

- Here we will use the same model for studying a larger region of the asteroid belt (a 3-D cube of initial conditions)

Initial conditions and computational procedure

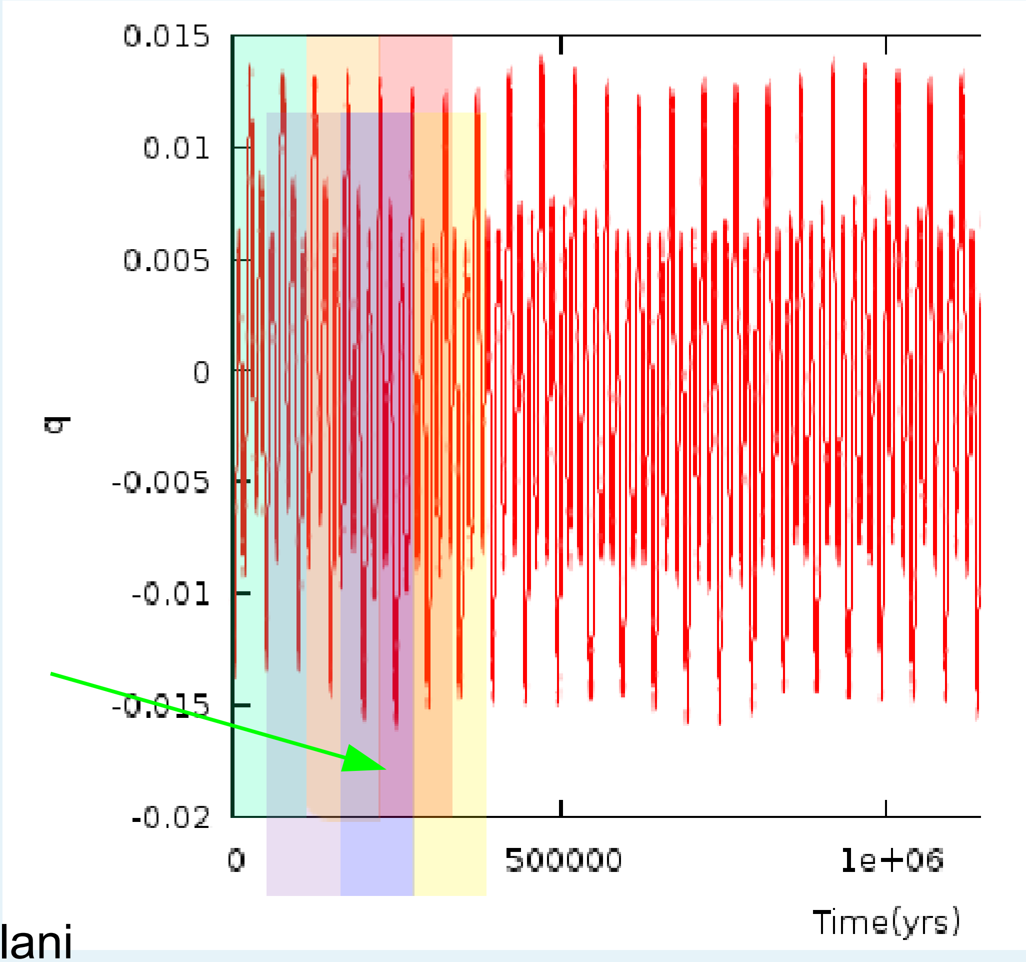
- We plan to study the region between the 5/2 and 7/3 mean motion resonances in the asteroid belt:

2.82 AU < a < 2.96 AU
$0 < e < 0.4$
$0 < i < 20$ deg

→ a sample of 100,000 orbits integrated for 2 My ! (a few days...)

→ only need to be done once!

- Each time-series is split into 'windows', and proper elements are computed in each window
  → time-series of e_P, I_P



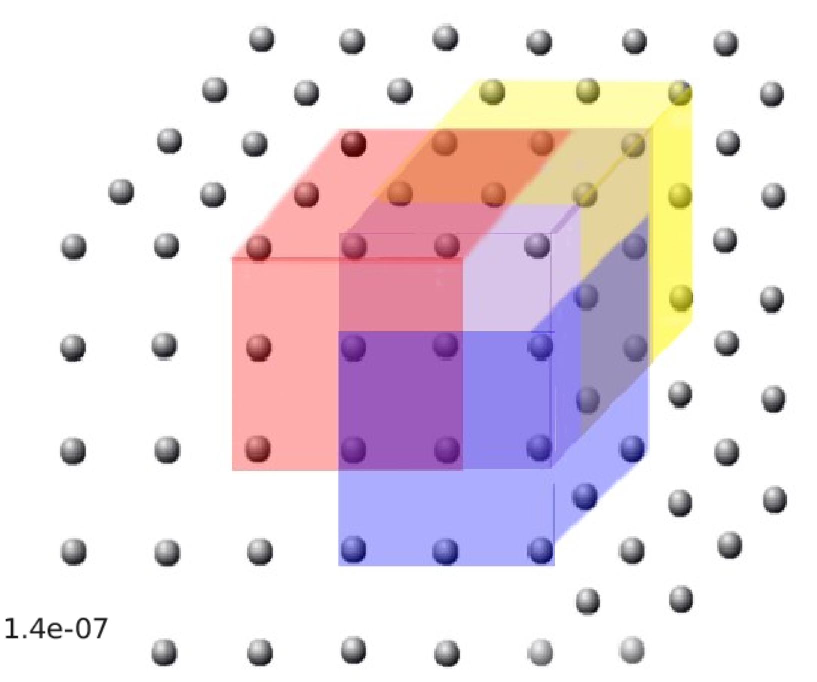
as in the synthetic procedure of Milani & Knezevic

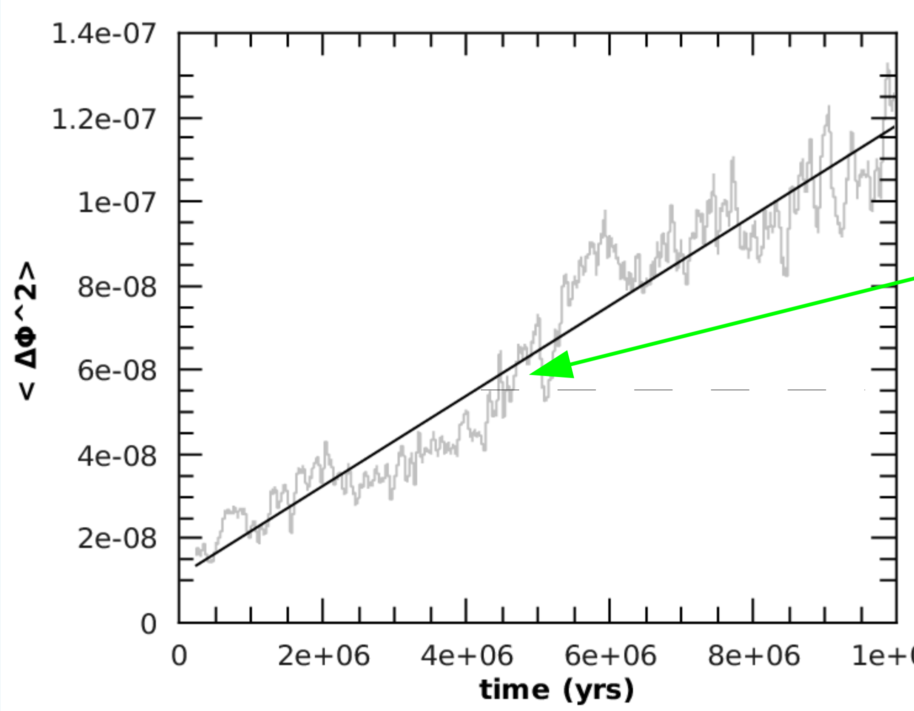
→ Group neighboring objects by ~30-100 and compute the ***mean squared displacement*** (msd) in each action as a function of time

$$\langle(\Delta\Phi_i)^2\rangle=\langle[\Phi_i(t)-\Phi_i(0)]^2\rangle_N$$

$$\Phi_i \sim X_i^2 \quad [X_i=e_P, \sin(i_P)]$$

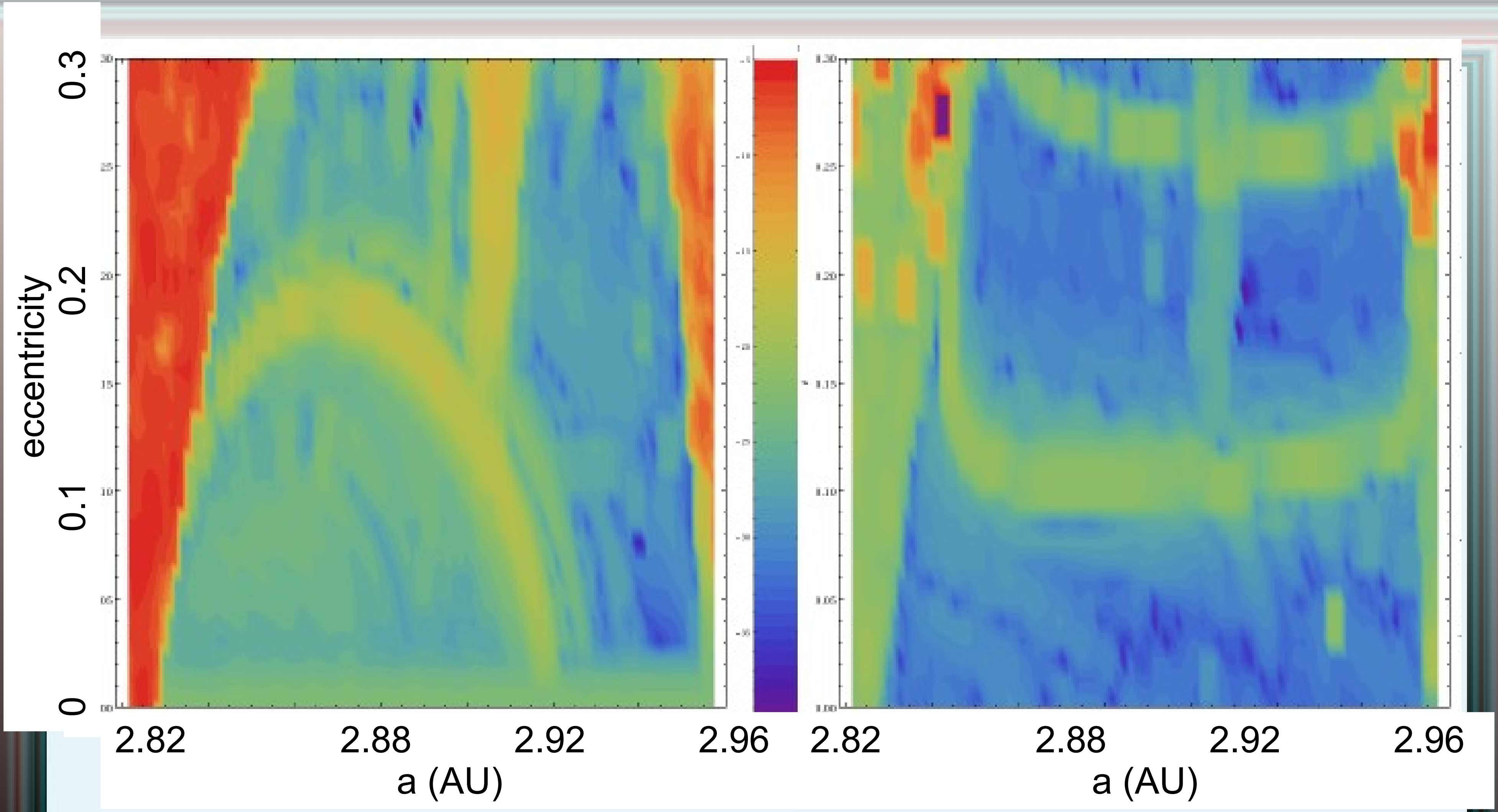
→ slide the cube (sphere..) through the data





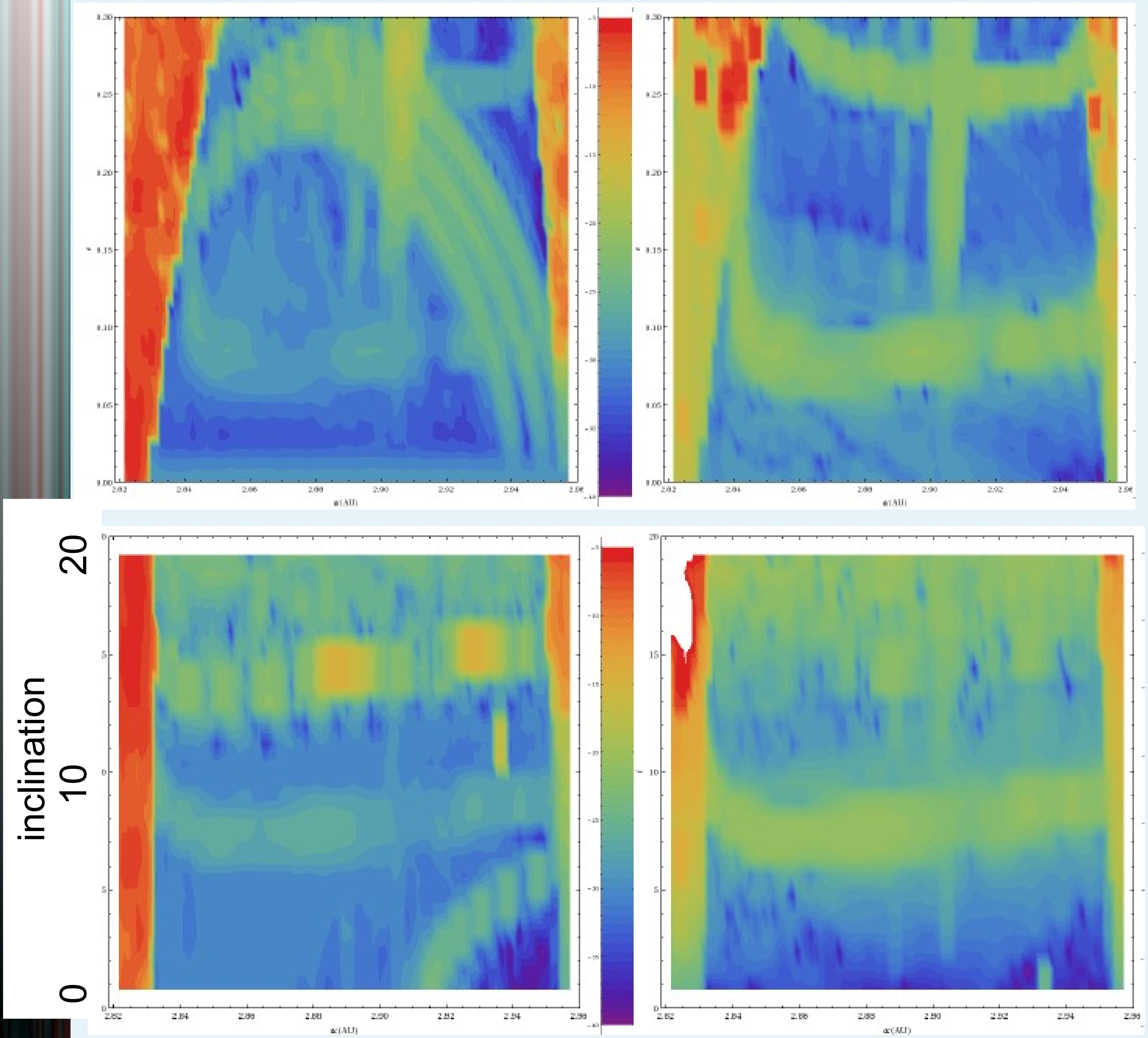
→ and get the 'local' value of *D* as the slope of the msd curve

→ create a ***chart*** of the *D* values



Diffusion coefficients D_e (left) and D_i (right) – 2-D projection for 0<*i*<2 deg

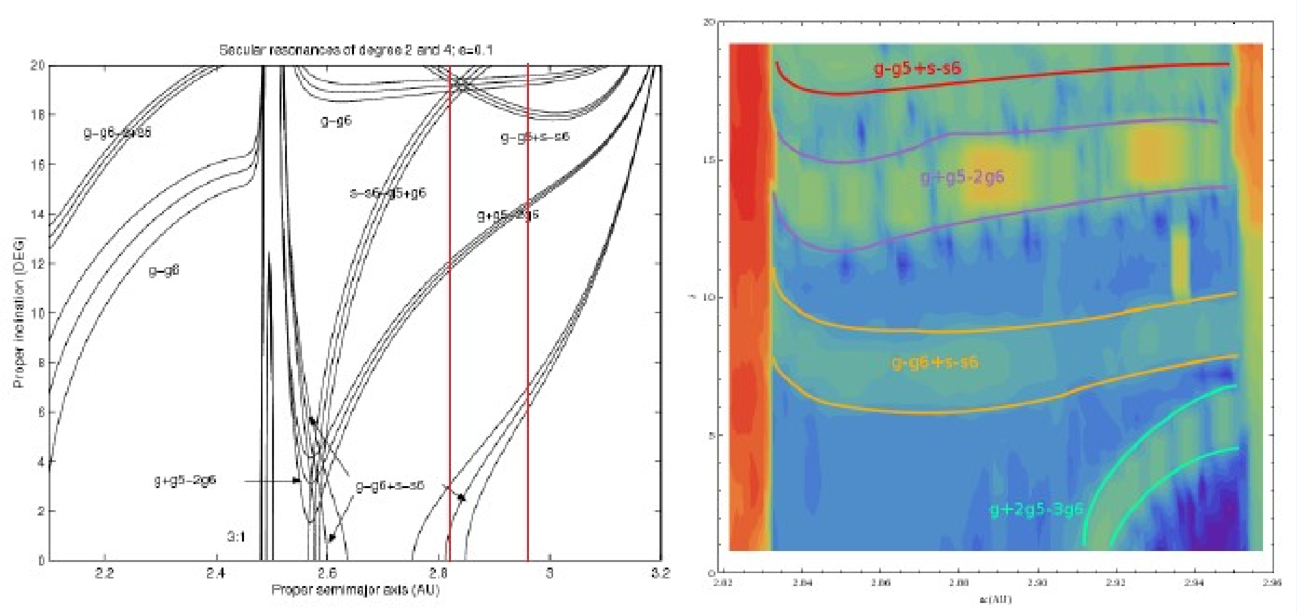
- NOTE characteristic bands coinciding with resonances (MMR and sec.)
- The values increase enormously inside the 5/2 and 7/3 MMRs → will be treated as 'sinks' at the borders of the diffusion area



- Same projection as before (a,e) but for i~5 deg

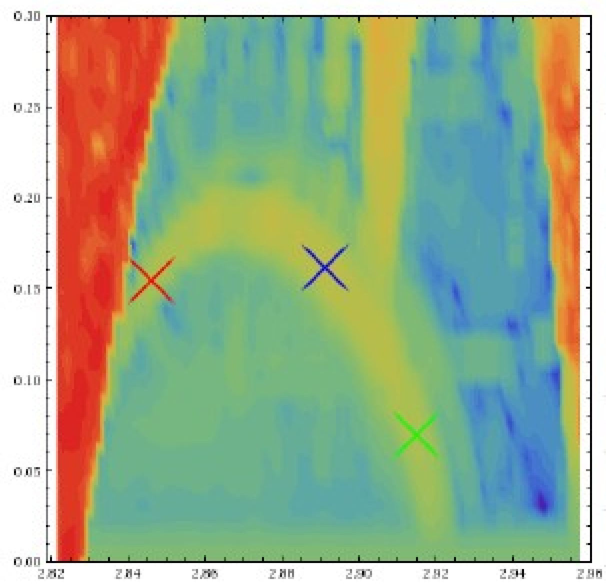
- Projection on the (a,i) plane, for e=0.1

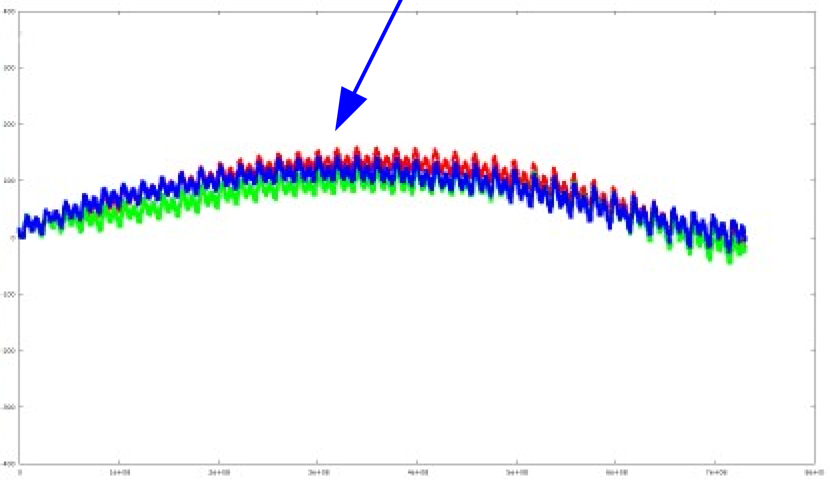
Identifying secular resonances



Comparing with the Milani & Knezevic secular theory (*a*-*i* charts)

Libration of the critical argument





$$\varphi = \varpi + 2g_5 - 3g_6$$

(*a*-*e* charts)

Use *D*s in a Random-Walk model

- Assume an asteroid undergoes random walk

→ 1st approximation = *normal diffusion* with the standard deviation of 'jumps' in e_P and i_P related to the local value of the diffusion coefficients

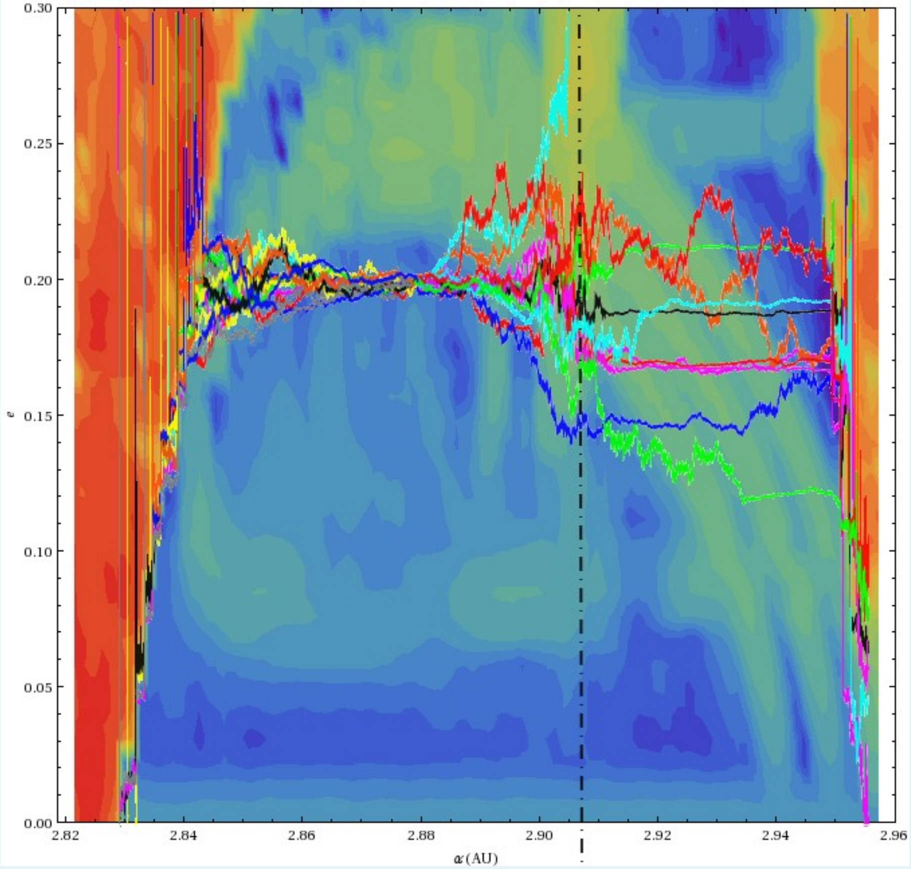
→ this can be modified (more complex random-walks) if needed

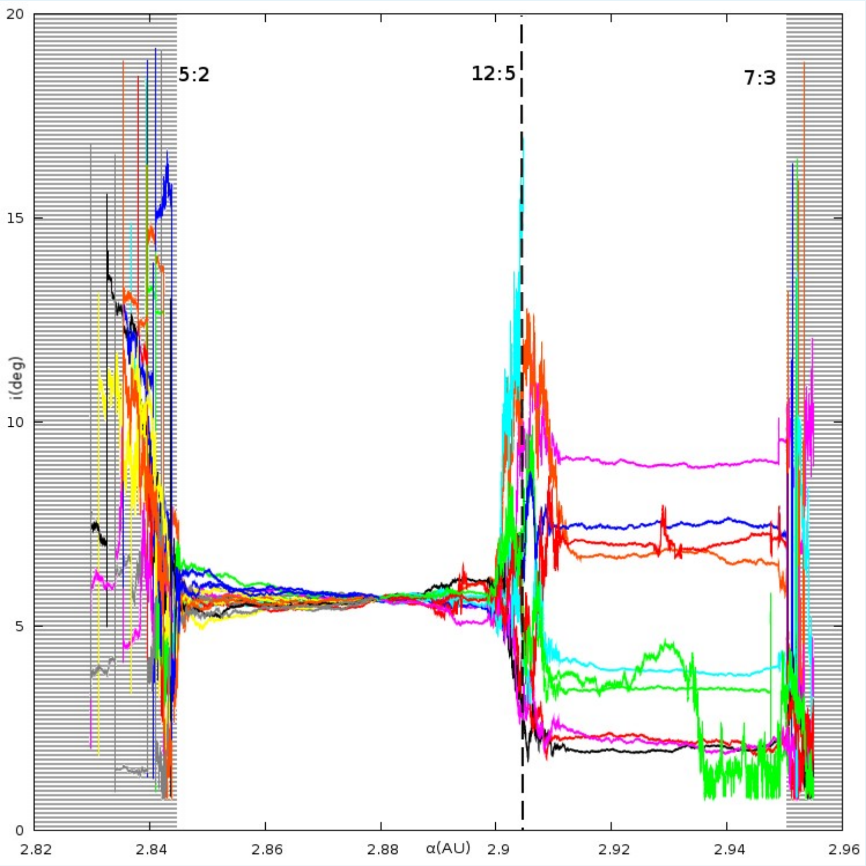
- Combine diffusion in (e_P , i_P) with drift in a (Yarkovsky) and evolution of the spin axis → at different values of a we use properly weighted values for *D*s

→ at each time-step perform a jump in (e_P , i_P) according to a (local) Gaussian distribution, plus a displacement in a.
→ *dt* can be as large as a few 100 yrs, but should be small enough (according to *D* values) also, so that da/dt can be considered slow

- We give an initial distribution of “asteroids” and follow the evolution for 500 My (a few tens of seconds ...)

Example 1: a group of “asteroids” crossing the 12:5 MMR





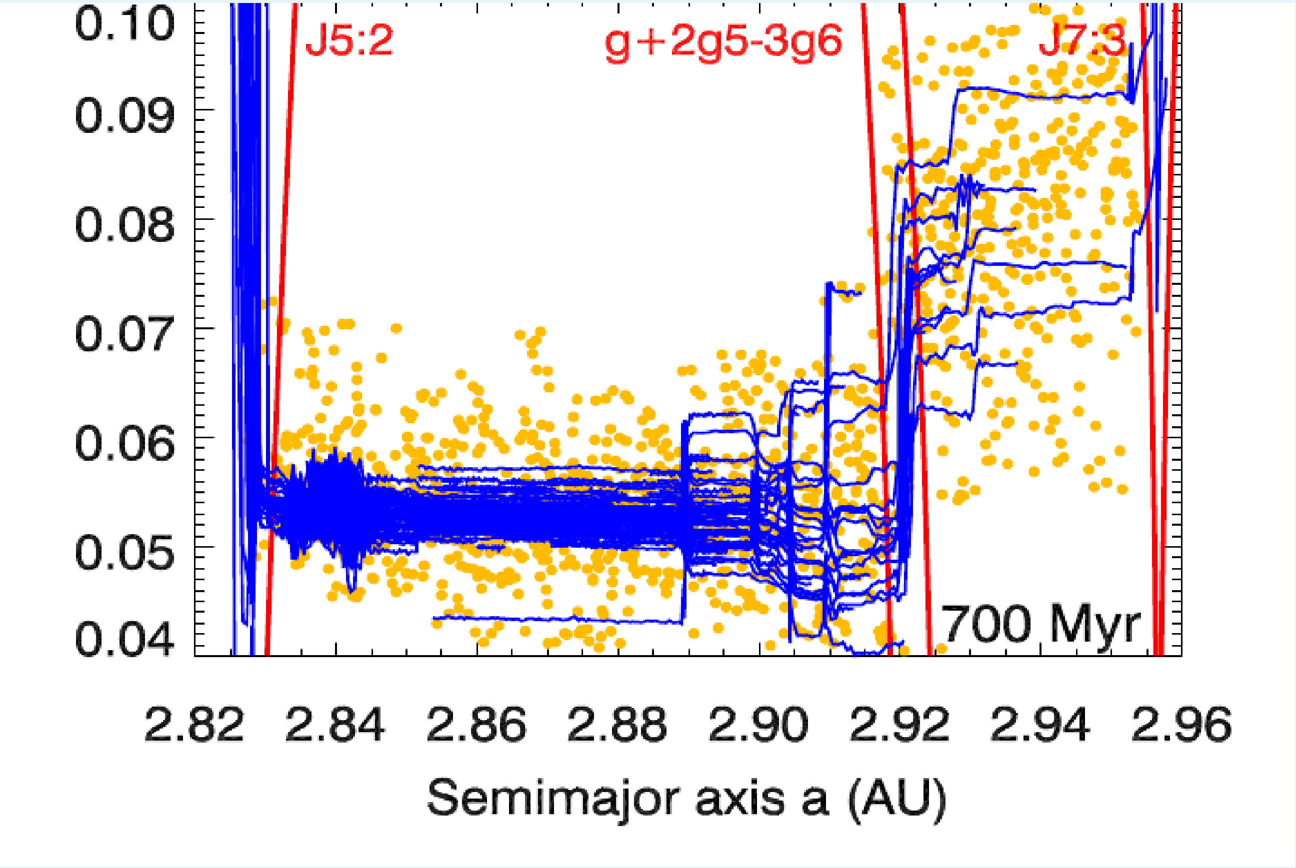
- Asteroids suffer 'jumps' in both *e* and *i* when they cross the 12/5 MMR

- Everything reaching the 5/2 and 7/3 MMRs goes 'out of the box' shortly (escape)

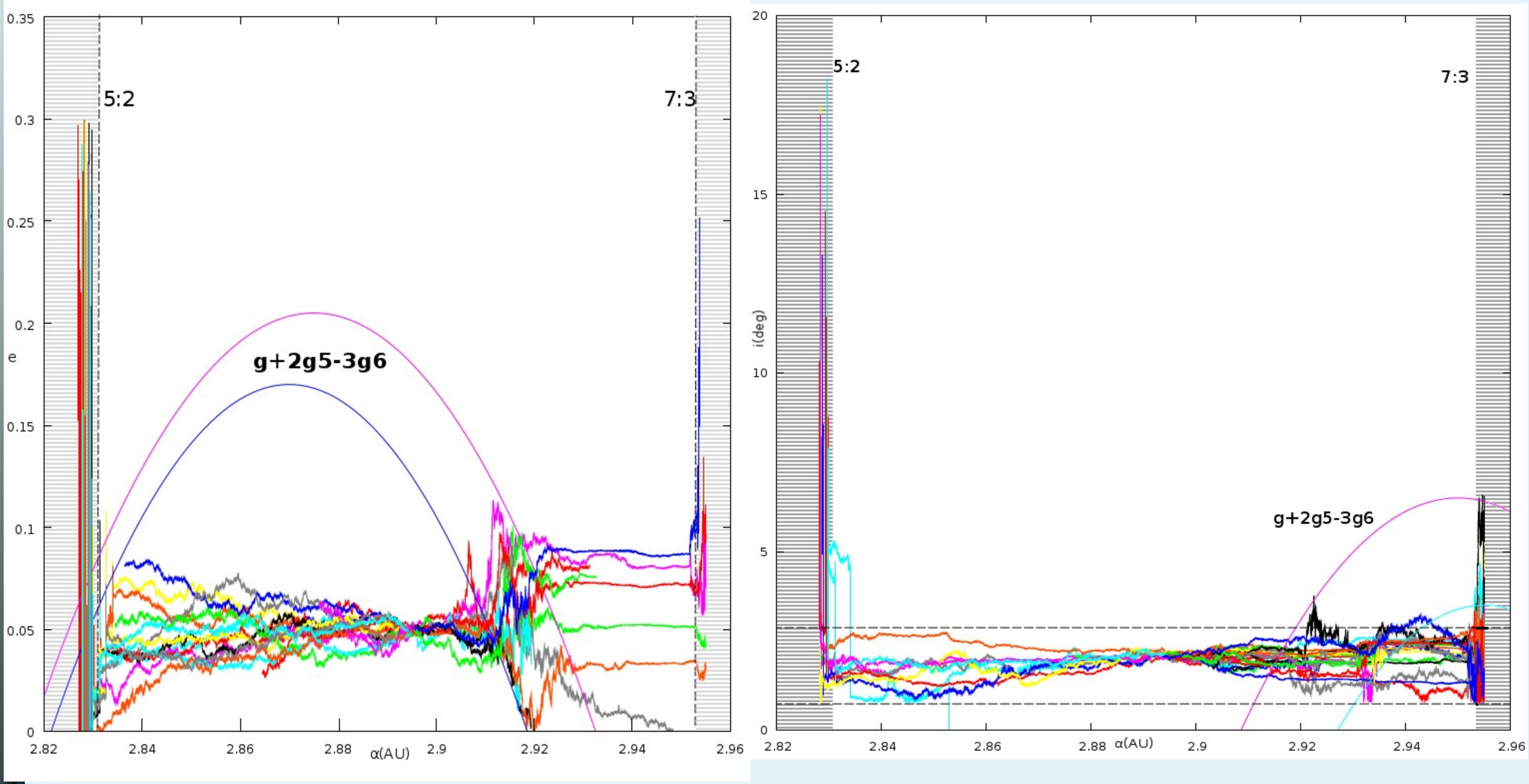
- Orbits with *da*/*dt*<0 have only slight variations in (*e*, *i*) → no important resonances...

Example 2: application to the Koronis family (intricate shape...)

- Bottke et al. (2002) explained the shape of the Koronis family as the result of crossing the *g*+2*g*5-3g6 secular resonance due to Yarkovsky-induced drift in *a*



Our result (700 My simulation)



- We reproduce the 'jump' in e with $e_{max} \sim 0.1$
- We don't introduce artificial jumps in inclination (this SR does not excite inclinations) → same Δi on both sides...
- We need to reduce our “noise” level (many steps with small D)...

In sum...

- WE PLAN

to use GAIA data for asteroids (a, e, i, spin), in connection with information from other missions (albedo-size), to calculate -through an optimization process-

  - (a) the *functional form of the Yarkovsky law*
  - (b) the *age of families*,
  - (c) the *velocity field ejection*

•METHOD

• Simulate the diffusion (in e and i) and Yarkovsky transport (in a) of an asteroid, through a random walk process, governed by

•(i) the tabulated local diffusion coefficient (e, i)

•(ii) the Yarkovsky law (a)

- EFFICIENCY

• FAST method: FIRST produce tabulated values of the diffusion coefficient $D(e, i)$ through short-time numerical integration of orbits, THEN simulate long-time asteroid evolution through a random walk (essentially a mapping).

• FUTURE IMPROVEMENTS

• OPTIMIZE the “selection rule” for each step, in order to attain a better match with numerical integrations.

• Reduce the noise

• Select carefully the time step...