Fuzzy Characterisation of Near-Earth-Asteroids



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NEA Dynamics

- NEAs have many close encounters with the inner planets
- close encounters result in drastic changes of orbital elements
- \rightarrow NEAs have highly chaotic orbits over long time scales



NEA Dynamics

• Chaotic orbits + long time scales = problems with statistics!



"Border Crossing Number"

(how many times does the NEA crosses a border of the Shoemaker classification in the a-e plane)



Fuzzy Logic

- developed 1965 by L.A. Zadeh
- Fuzzy sets are an extension of classical sets
- classical sets: an object either is or is not a memer of a group

• \rightarrow characteristic function: two values

 characteristic function of fuzzy sets can have all values between 0 and 1

 $f_A(x) = 1 \Leftrightarrow x \in A$ $f_A(x) = 0 \Leftrightarrow x \notin A$

→ membership function $\mu_A(x)$ defines to which "degree" x belongs to the fuzzy set A

Fuzzy Logic

• Example: the age of a person



Introduction :: Dynamics :: Fuzzy Logic :: NEA Classification :: Analysis

- 1. Definition of classes
- 2. Definition of membership functions
- 3. Classification
- 4. Analysis

Definition of classes

- NEAS can collide with inner planets → define classes to describe this properties
- as parameter for the membership function and the classification the number of close encounters is used.

• additional group to describe the mixing/motion in a-e plane

Definition of classes

- G1: NEAs that show almost no mixing
- G2: NEAS that can collide with Venus
- G3: NEAS that can collide with Earth
- G4: NEAS that can collide with Mars

Parameters

- G1: Border Crossing Number
- G2: close encounters with Venus
- G3: close encounters with Earth
- G4: close encounters with Mars

Membership Functions

- Investigate the statistical distribution of the parameters
- (numerical integration of the real NEAs for 500,000 years)





convert distribution into membership function
the more close encounters, the larger

the degree of membership to G3

Name	a	e	i	G1	G2	G3	G4
2000GD2	0.757928	0.4765	32.14639	1	0.7585	0.9407	0
2000HB24	0.815912	0.4302	2.669175	1	0.9852	0.9895	0
2000HO40	0.743917	0.5241	5.981537	1	0.9951	1	0
2000LG6	0.916167	0.1121	2.829914	0.0164	0	0.9973	0
2000NL10	0.914292	0.8171	32.51204	1	0.3271	0.436	0.0147
20000K8	0.984809	0.2211	9.985352	0.7272	0	0.9299	0.6993
2000PH5	1.000608	0.2301	1.71175	0.1708	0.9962	0.9792	0
2000PJ5	0.8727	0.3736	51.18267	1	0.9742	0	0
2000QP	0.847462	0.4631	34.7466	0.9008	0.9559	0	0
2000RH60	0.825892	0.5513	19.64366	1	0.9403	0.9191	0
2000RN77	0.951245	0.3184	16.0945	0.8264	0.9503	0.7779	0.7791
2000SG344	0.977357	0.0669	0.109731	0.0113	0.9929	0.9972	0
2000SP43	0.811372	0.4669	10.35569	1	0.9558	0.9378	0
2000SY2	0.858743	0.6426	19.23634	1	0.7415	0.7198	0.8302
2000SZ162	0.929366	0.1674	0.896554	0.2561	0.0126	0.9818	0.7287
2000UH11	0.870267	0.4223	32.21665	1	0.7179	0.6956	0
2000UK11	0.884688	0.2482	0.776174	0.9256	0.4127	0.9816	0.4049
2000UR16	0.903661	0.4387	11.74411	1	0.9341	0.8863	0
2000WC1	0.879512	0.2626	17.40797	0.8512	0.9356	0.8146	0
2000WO107	0.911347	0.7806	7.784174	1	0.9192	0.91	0.9963
2000WP19	0.854492	0.2886	7.678904	0.6033	0.9773	0.9227	0
2000YS134	0.85736	0.2242	3.500566	0.8264	0.9981	0.7895	0
2001AF2	0.953982	0.5953	17.8175	0.0692	0.7104	0.6852	0.8186
2001BA16	0.940225	0.1374	5.768623	0.3057	0.9977	0.9806	0
2001BB16	0.854463	0.1723	2.026138	0.6033	0.9919	0.9797	0
2001BE10	0.823508	0.369	17.50827	1	0.9358	0.9119	0
2001CK32	0.725401	0.3826	8.137319	0.3553	0.9747	0.7198	0
2001CP36	0.714308	0.4077	10.53547	0.4545	0.9642	0.955	0

Classification

• Data is available online

• verify and analyse data:

• Comparison with the *Project Spaceguard* (Milani et. al classification)

• Analysis with α -cuts

http://www.celestialmechanics.eu/neas/

• compare the classification data with the Spaceguard classes

Geographos group	Oljato group			
 many close approaches with Earth 	chaotic orbits			
• some close approaches with Venus	large eccentricities			
• semimajor axis almost constant	close encounters with all planets			
(1620) Geographos:	<u>(2201) Oljato:</u>			
	• G1 (no mixing): 0.04			
• G1 (no mixing): 1	• G2 (Venus): 0.38			
• G2 (Venus): 0.03	• G3 (Earth): 0.36			
• G3 (Earth): 0.76	• G4 (Mars): 0.28			



Longterm fate of NEAs

- what happens with the NEAs?
- close encounters with planets → NEAs orbit everywhere between ~Mars and ~Venus
- \rightarrow collision probability with Venus should be highest.
- ratio of mean motion of Venus and Earth: 1.38



ratio of collision probabilities of NEAs with Venus and Earth: ~1.3

• α-cut Analysis of G2, G3, G4:

• determine $G2^{>0.9}$, $G3^{>0.9}$, $G4^{>0.9} \rightarrow$ investigate the mutual group membership

Longterm fate of NEAs

• what happens with the NEAs?



Conclusions

- the chaoticity of NEA dynamics makes a statistical treatment difficult/impossible (mixing)
- fuzzy logic methods can overcome this problems
- a fuzzy characterisation of NEAs can incorporate the existing classifications (Project Spaceguard)
- using fuzzy groups allows a quantitative statistical analysis over long time scales
- the analysis has showed the importance of close encounters/collisions with Earth over long time scales

Future work

- new orbital data \rightarrow refinement of membership functions
- define and analyse additional groups (resonances, ...)

