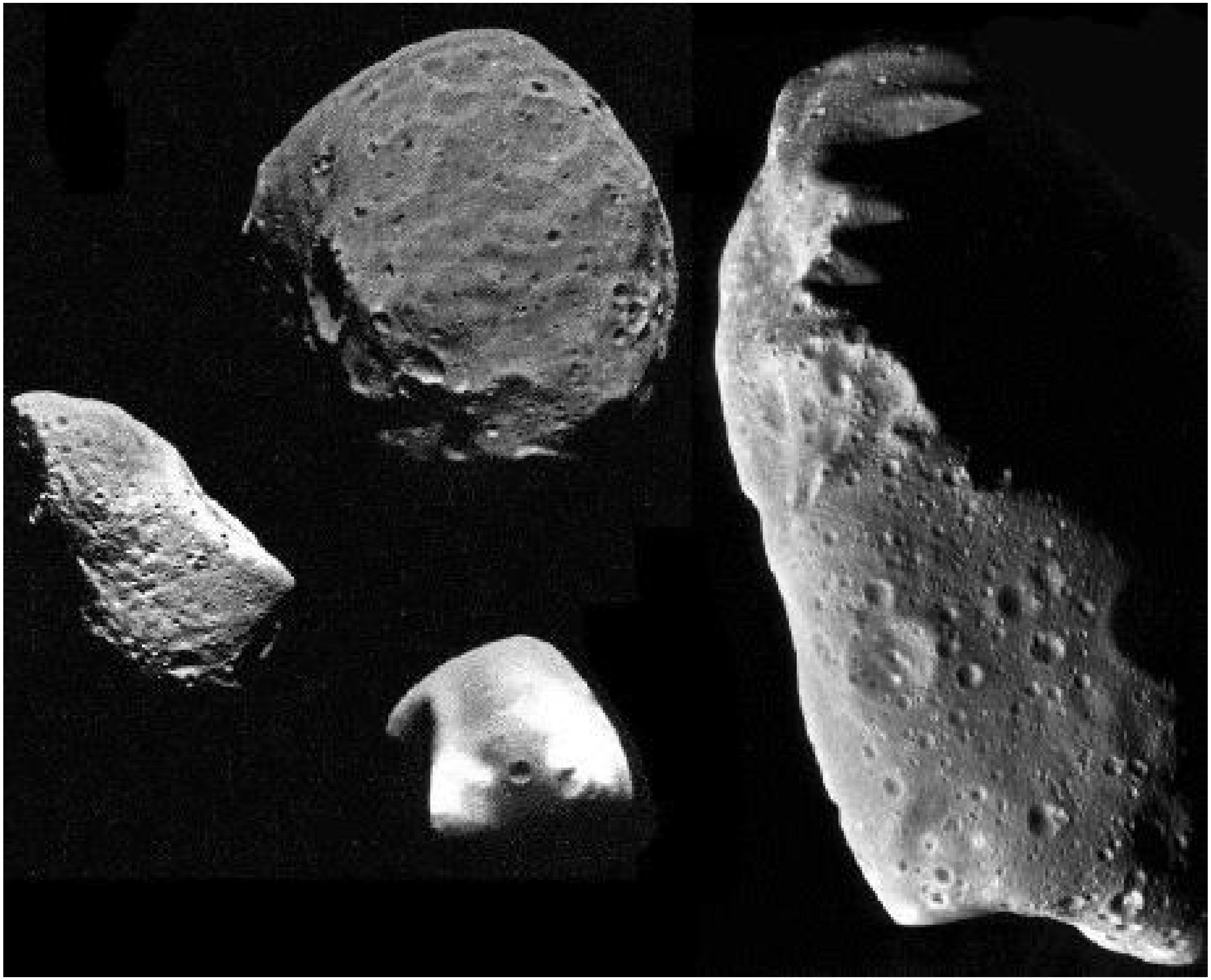
Astr 598: Astronomy with SDSS

Spring Quarter 2004, University of Washington, Željko Ivezić

Lecture 4:

Moving Objects Detected by SDSS



Asteroids as seen from spacecrafts

What is the significance of ground based asteroid studies in an era when spacecrafts can obtain such breathtaking photographs?

The answer is simple; the SDSS asteroid observations provide

- A sample 30,000 times larger than the one shown in previous figure

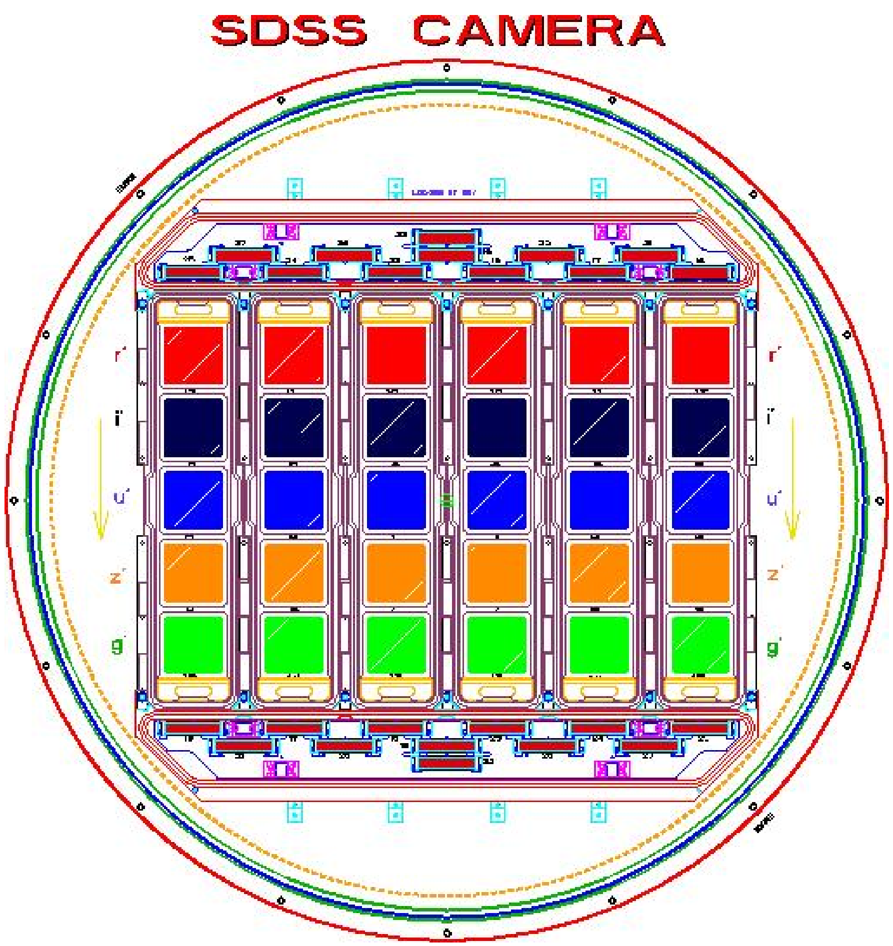
- Five-color images, rather than black-and-white images

- Sensitivity to detect asteroids smaller than the smallest craters visible on the four objects in previous figure

A 2.2' $\times$ 1.9' piece of sky (0.2s)

SDSS Asteroid Observations

Moving objects in Solar System can be efficiently detected out to $\sim$ 20 AU even in a single scan: 5 minutes between the exposures in the r and g bands



Asteroids move during 5 minutes and thus appear to have peculiar colors.

The images map the i-r-g filters to RGB. The data is taken in the order riuzg, i.e. GR··B

SDSS Asteroid Observations

- Moving objects must be efficiently found to prevent the contamination of quasar candidates (and other objects with non-stellar colors)

- Detected as moving objects with a baseline of only 5 minutes

- The sample completeness is 90%, with a contamination of 3%

- The velocity errors 2-10%, sufficient for recovery within a few weeks

Major Asteroid Surveys:

- Mc Donald Survey (Kuiper et al. 1958): 1000 asteroids (m$<$16.5, 1,200 deg^2)

- Palomar-Leiden Survey (van Houten et al. 1970): 2000 asteroids (m$<$20, 200 deg^2)

- Spacewatch (Gehrels et al. 1991): 60,000 asteroids (m$<$21, 4,000 deg^2)

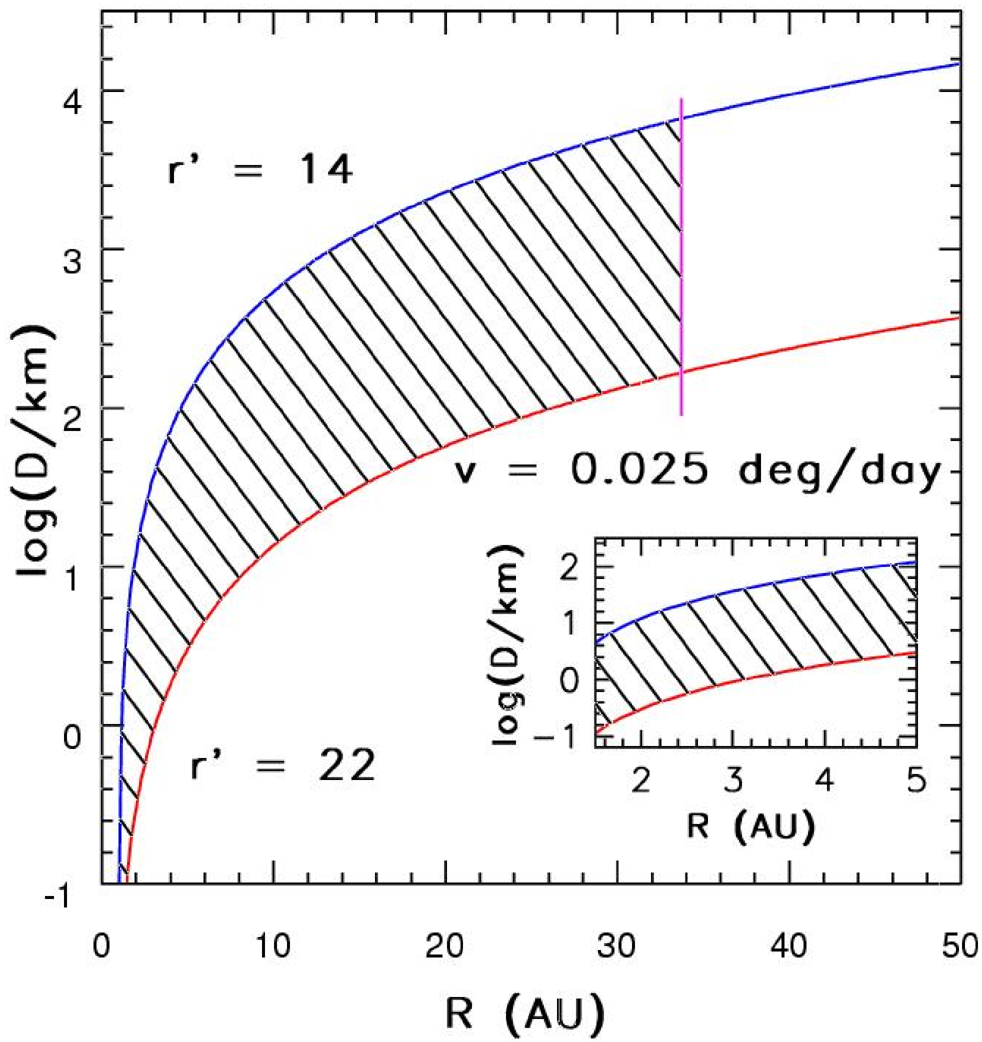
- SDSS: $\sim$140,000 asteroids (m$<$21.5, 6,000 deg^2) in five bands

SDSS measured $\sim$100 times more asteroid colors than all previous surveys together (the largest previous multi-color survey: ECAS, Zellner et al. 1985, with 600 objects)

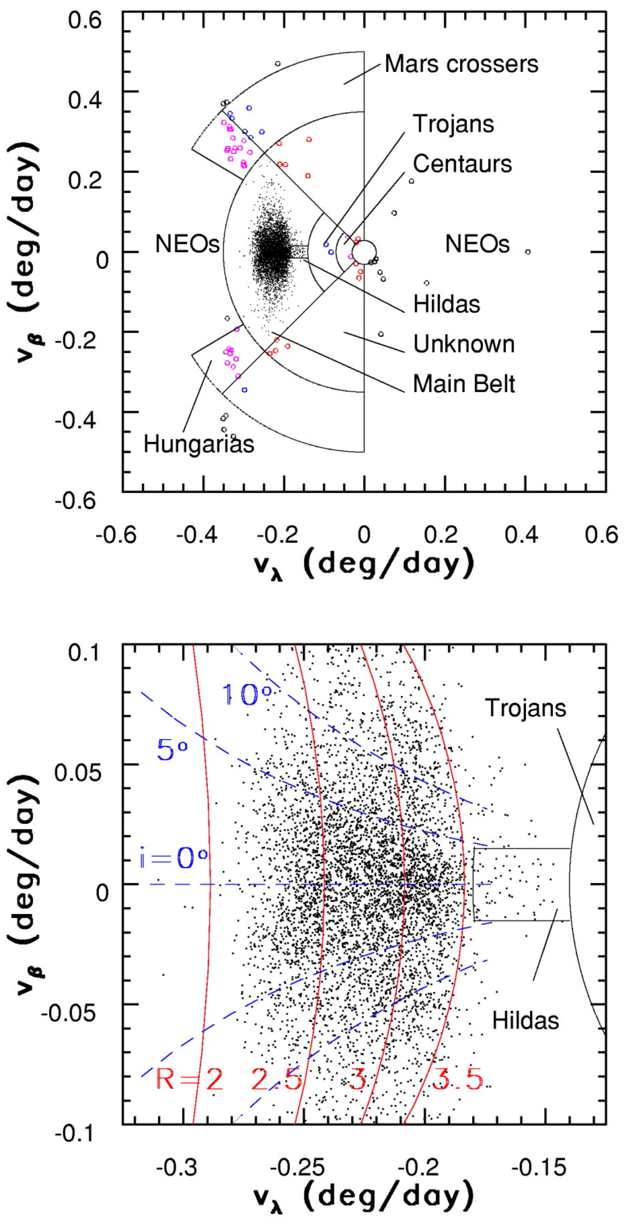
Main SDSS Asteroid Results

- A measurement of the main-belt asteroid size distribution to a significantly smaller size limit (< 1 km) than possible before

SDSS Sensitivity for Detecting Moving Objects



SDSS can detect a 100-mile object beyond Neptune, and a 100-yard object in the main asteroid belt



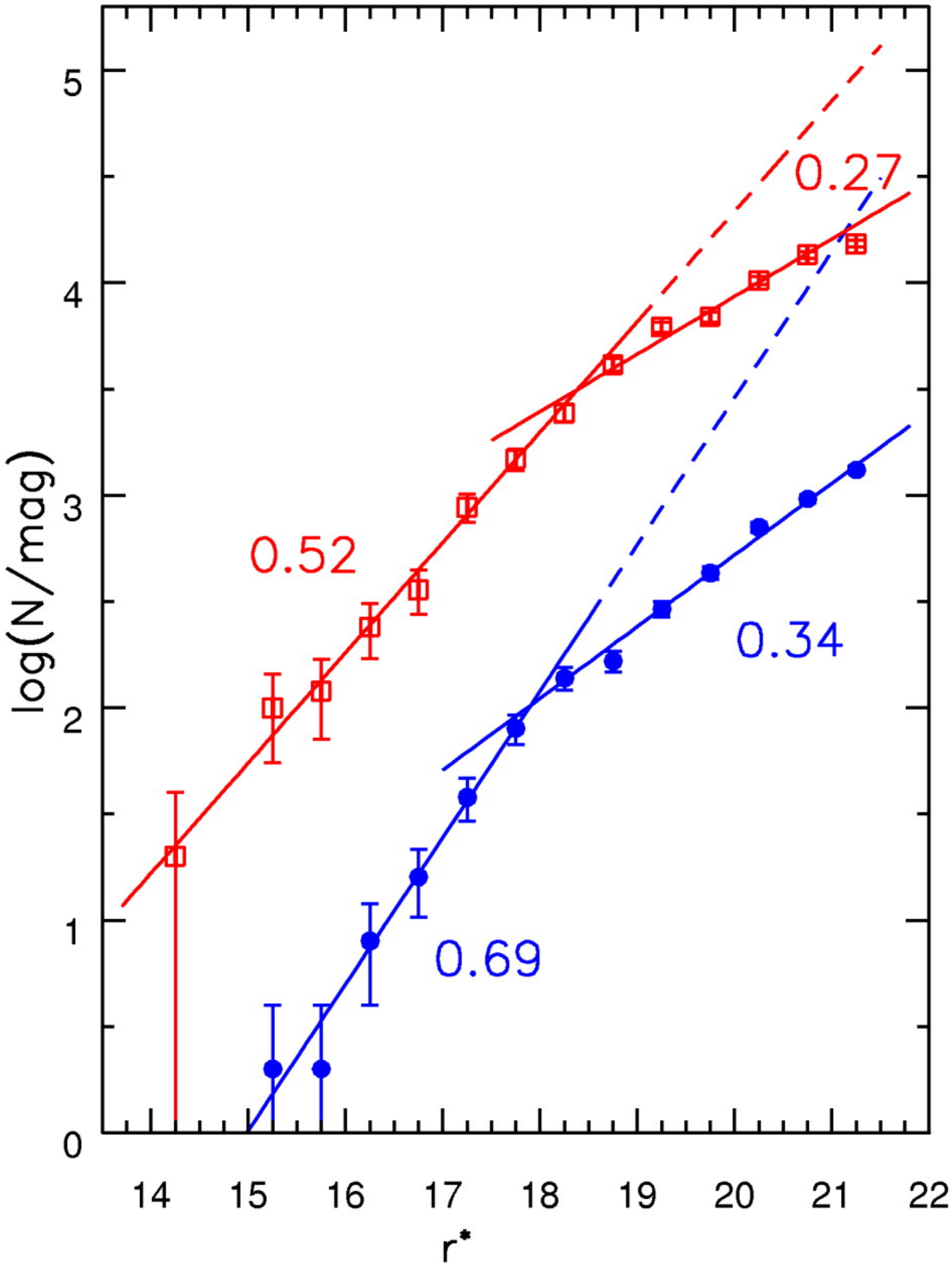
Observed Velocities

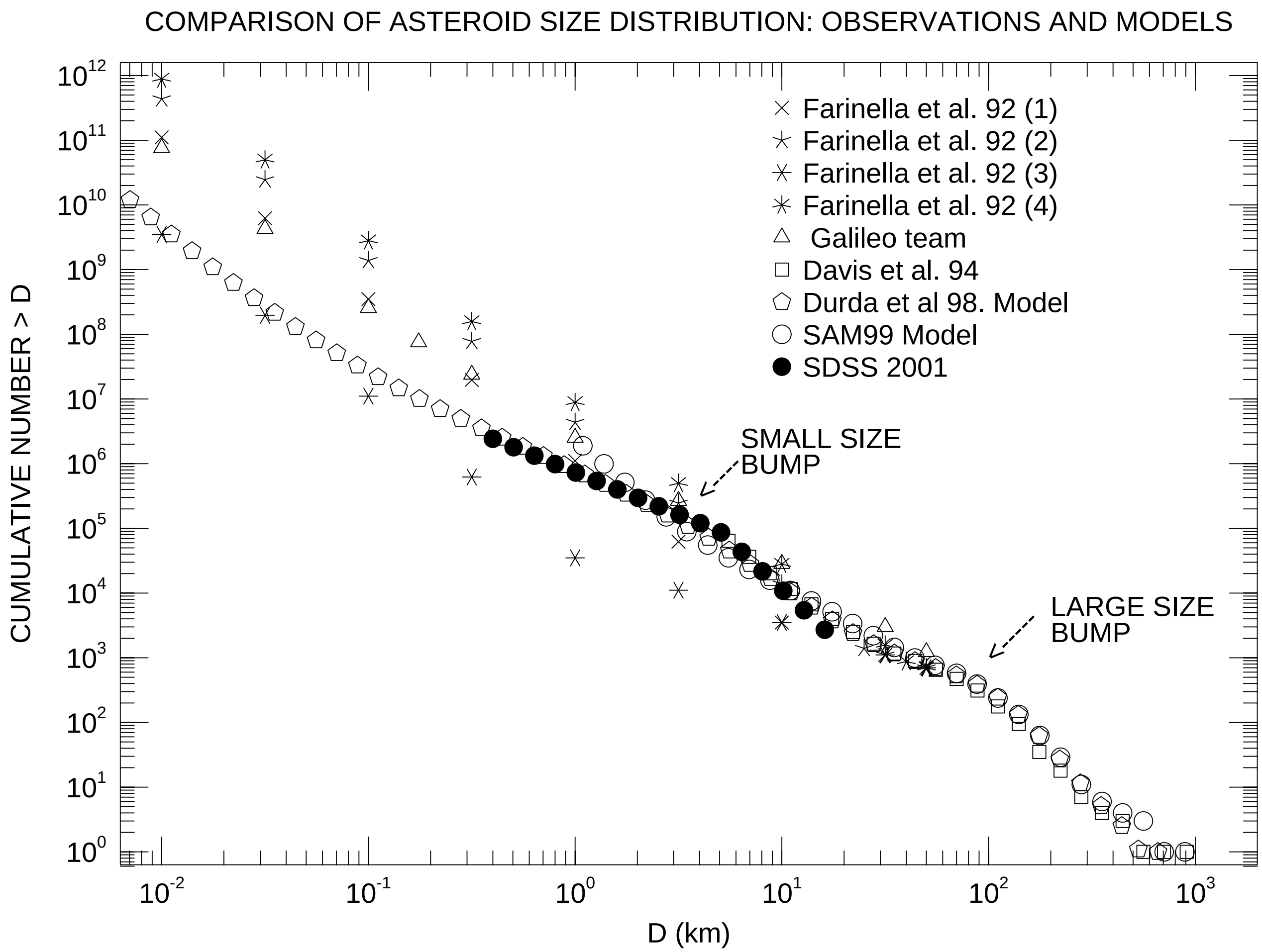
- v_λ - parallel to the Ecliptic plane, dominated by Earth's reflex motion, hence, v_λ is a good distance estimator, $v_\lambda \approx \frac{0.986}{R+\sqrt{R}}$ deg/day
- v_β - perpendicular to the Ecliptic plane, good estimator of the orbital inclination

Main SDSS Asteroid Results

- A measurement of the main-belt asteroid size distribution to a significantly smaller size limit ($<$ 1 km) than possible before

- Discovery of a break in the size distribution at $D \sim 5$ km


0.27
0.52
0.34
0.69
log(N/mag)
r*
0
1
2
3
4
5
14
15
16
17
18
19
20
21
22



The asteroid size distribution (Davis 2002, in Asteroids III).

SDSS results:

1) Extended the observed range to ∼300m

2) Detected the second break at ∼5 km

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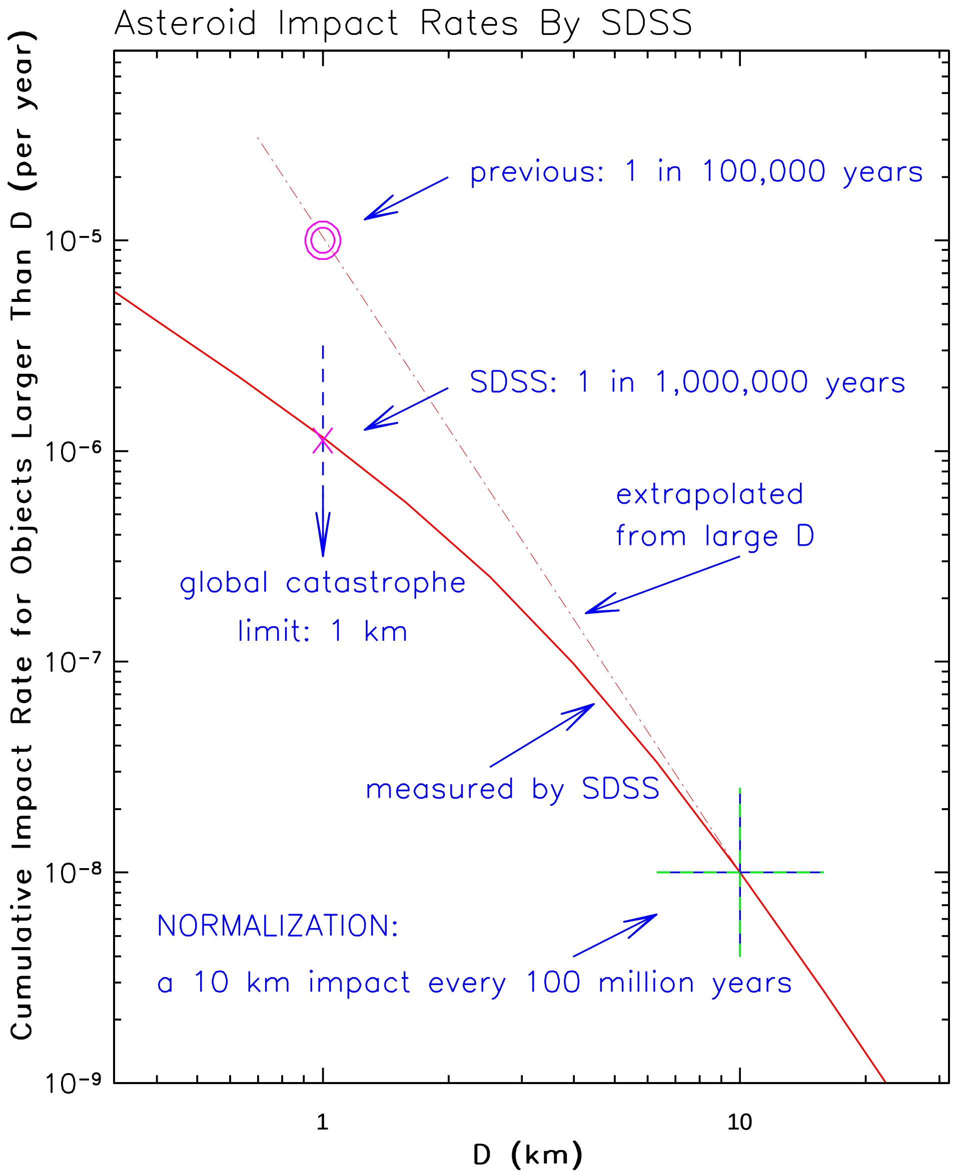
- A smaller number of asteroids compared to previous work: the number of asteroids with diameters larger than 1 km is about 0.75 million



The impact rate for D>1 km: once in a million years

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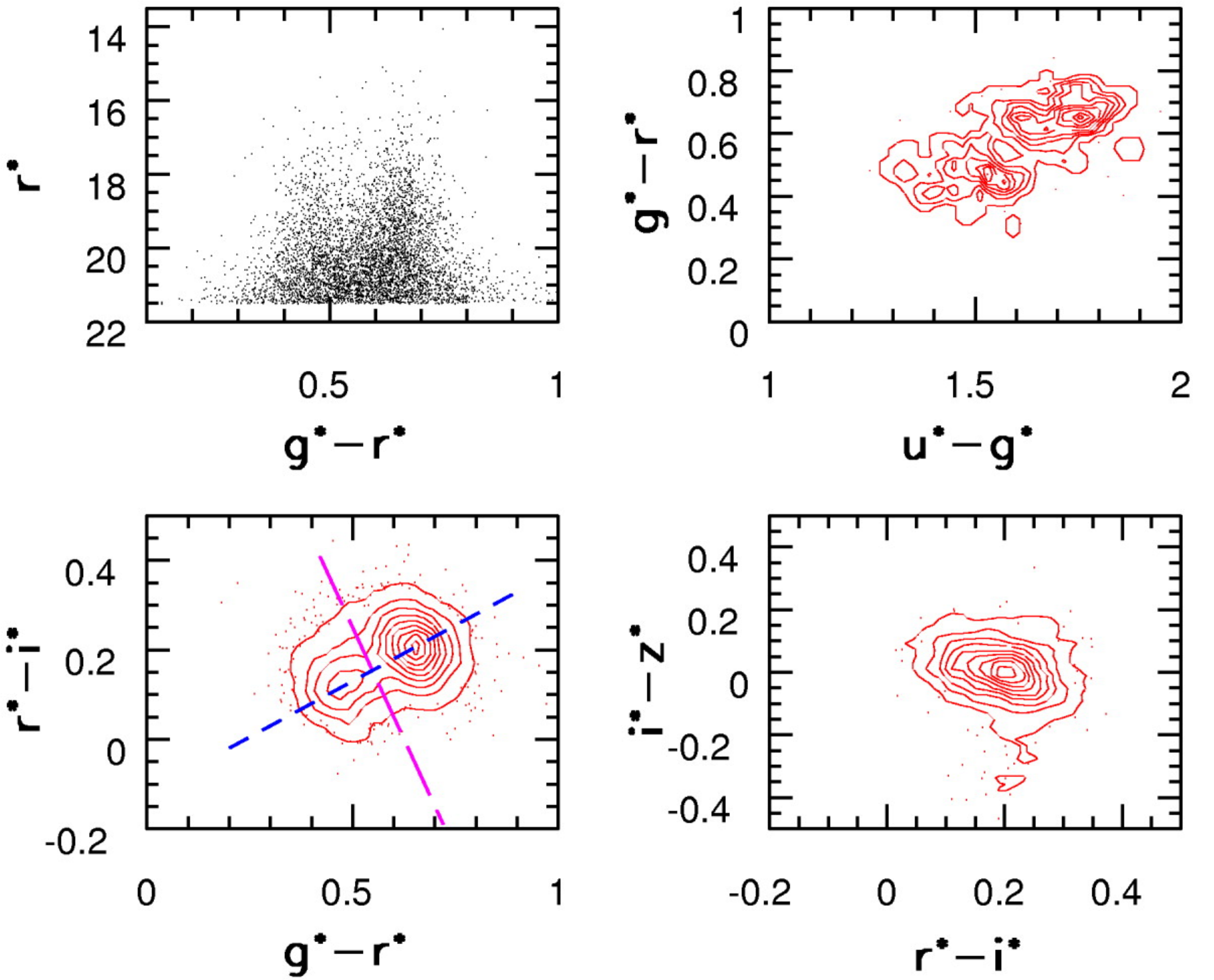
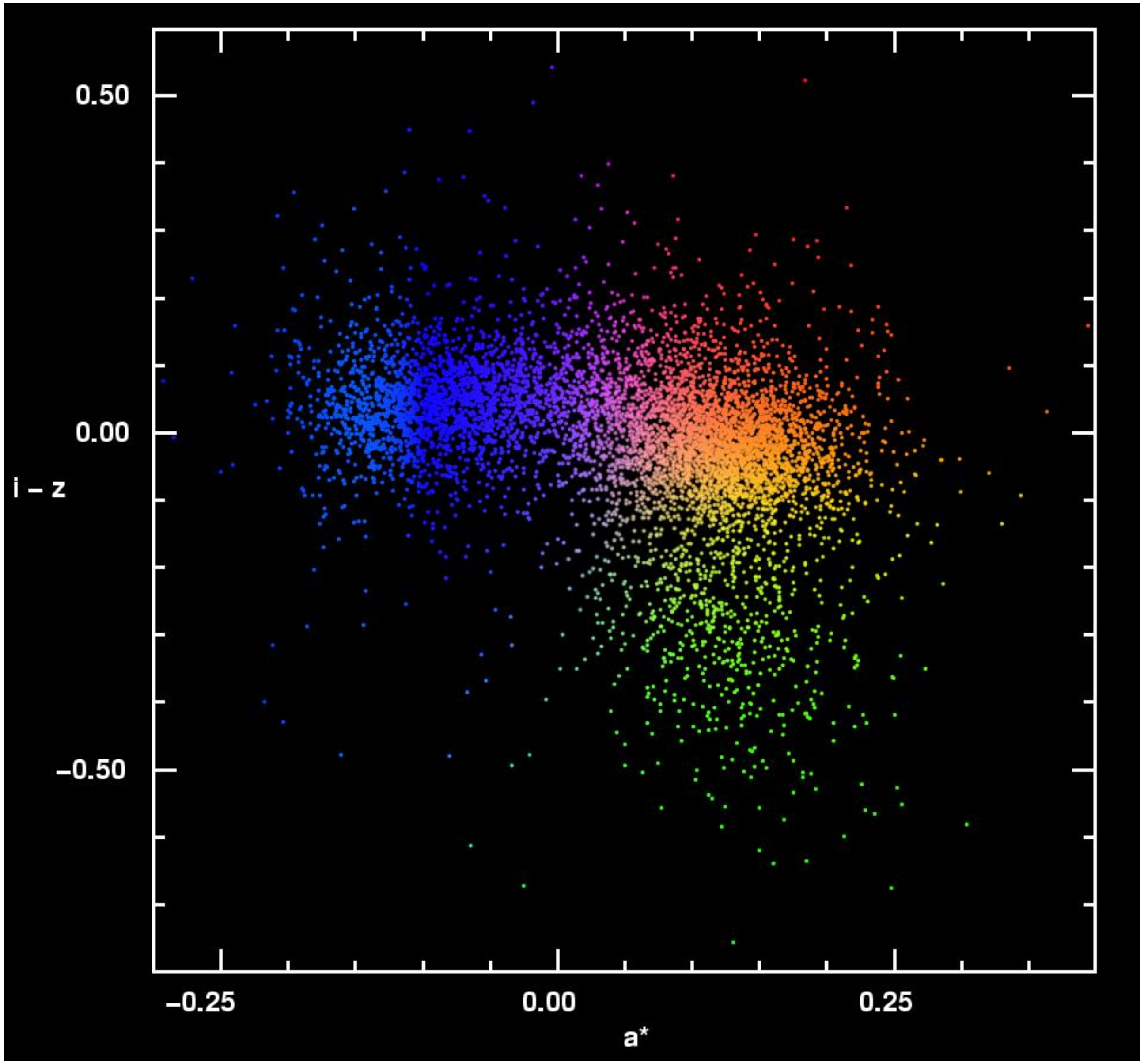
- A smaller number of asteroids compared to previous work: the number of asteroids with diameters larger than 1 km is about 0.75 million

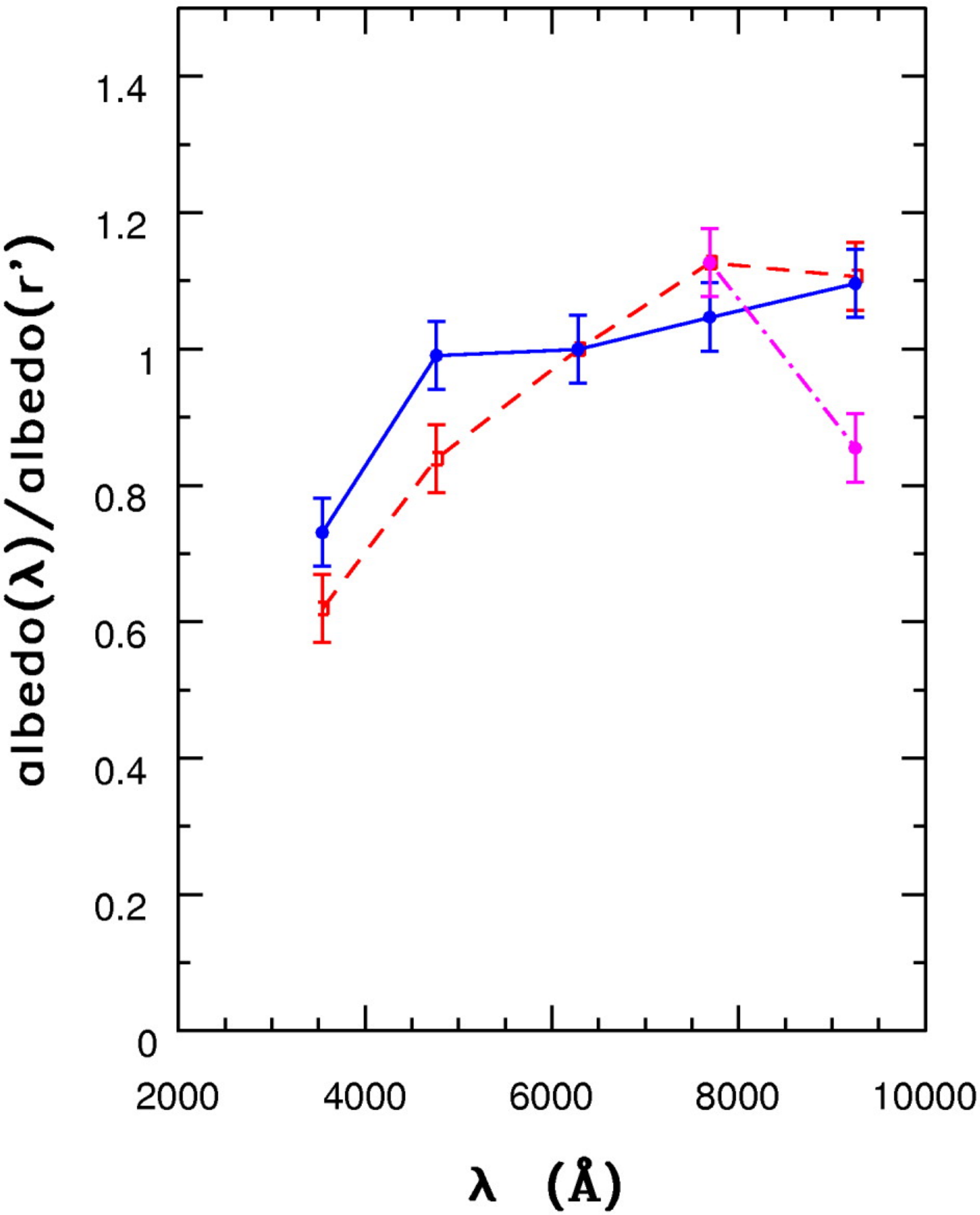
- The distribution of main-belt asteroids in 4-dimensional SDSS color space is strongly bimodal (rocky S-type and carbonaceous C type asteroids)



The colors of a sample of known asteroids observed by SDSS.



The colors of a sample of known asteroids observed by SDSS. The colors depend on asteroid surface reflectivity.


albedo(λ)/albedo(r')
1.4
1.2
1
0.8
0.6
0.4
0.2
0
2000
4000
6000
8000
10000
λ (Å)

Main SDSS Asteroid Results

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- A smaller number of asteroids compared to previous work: the number of asteroids with diameters larger than 1 km is about 0.75 million

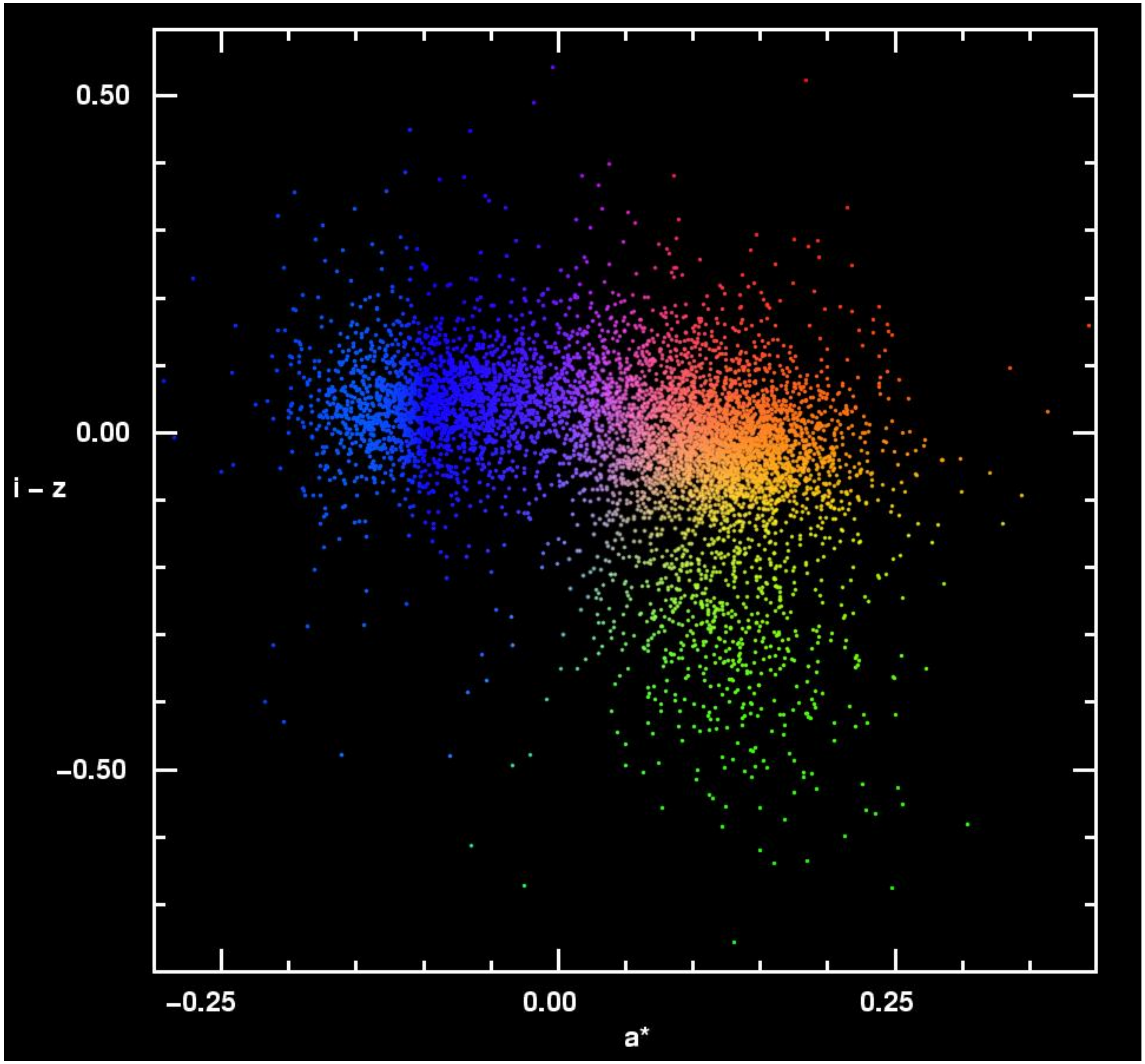
- The distribution of main-belt asteroids in 4-dimensional SDSS color space is strongly bimodal (rocky S-type and carbonaceous C type asteroids)

- A bimodality is also seen in the heliocentric distribution of asteroids: the inner belt is dominated by S type asteroids centered at $R \sim 2.8$ AU, while C type asteroids, centered at $R \sim 3.2$ AU, dominate the outer belt.

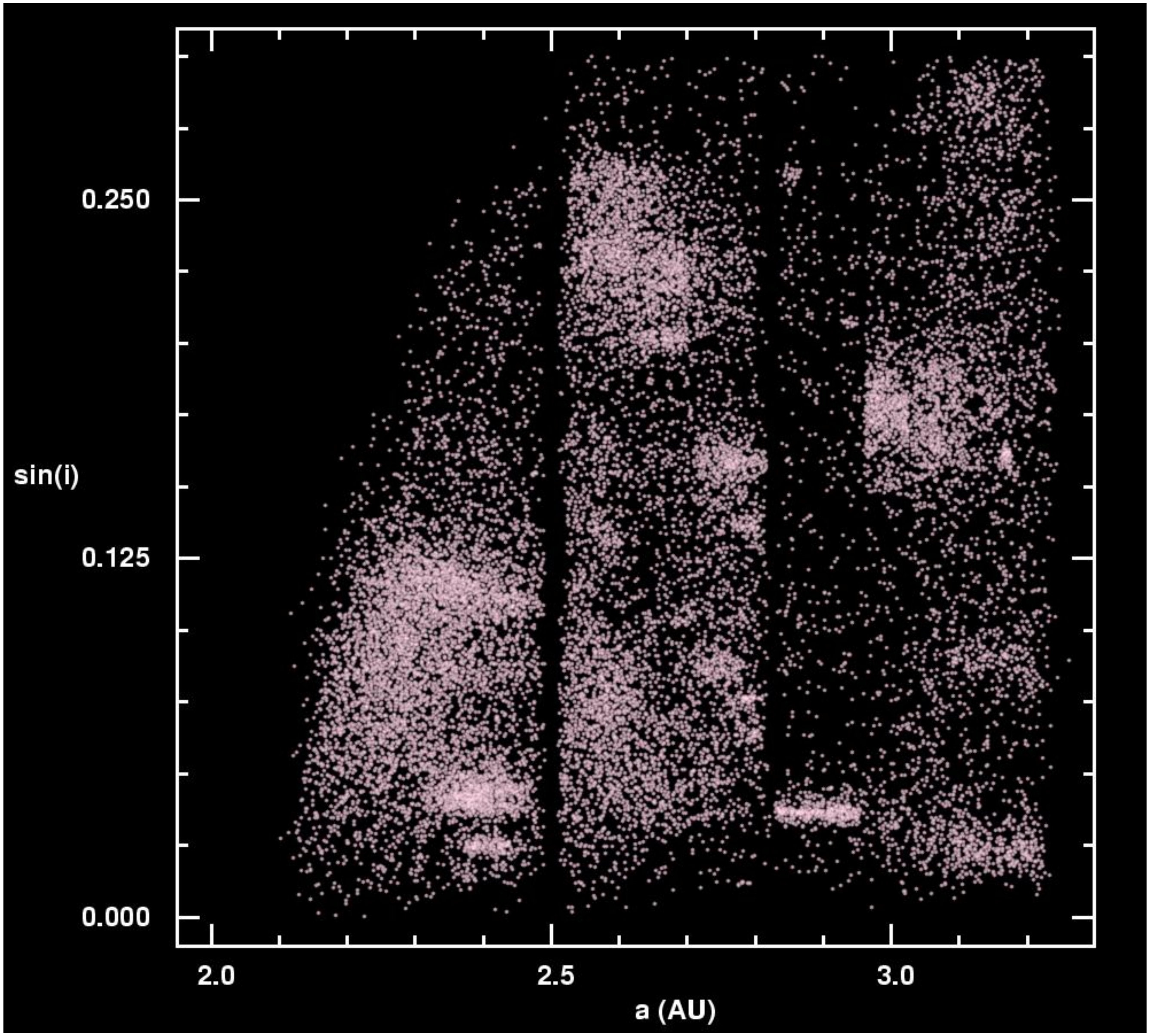
How do we know this? We cannot estimate orbits from our data.

- We cannot estimate orbits, but we can get (crude) distances from the apparent motion of our asteroids

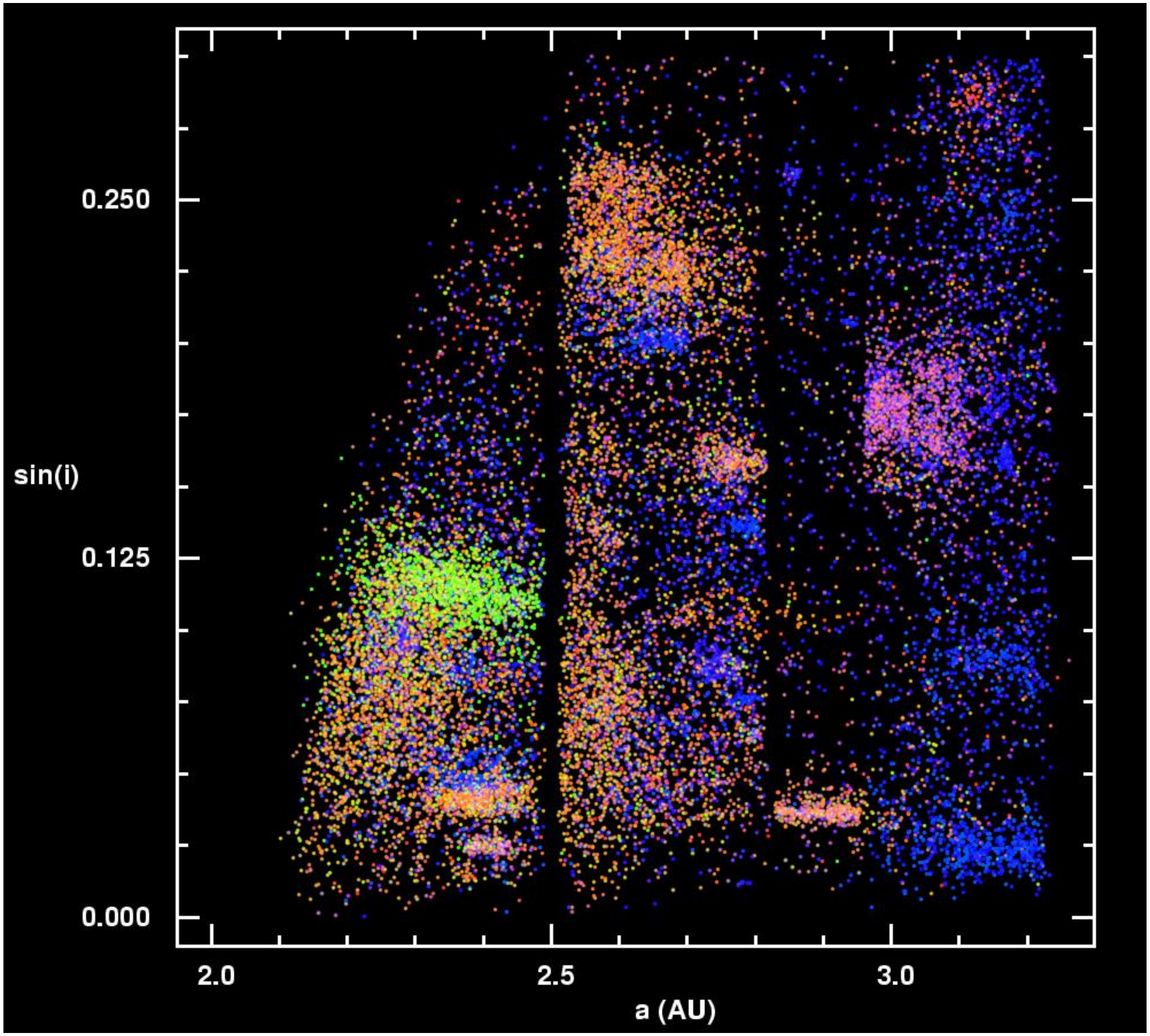
- We can use catalogues of *known* asteroids, and find them in SDSS imaging data.



Use these colors to color-code symbols and plot the distribution of orbital elements...



The semi-major axis v. (proper) inclination of a sample of known asteroids detected by SDSS



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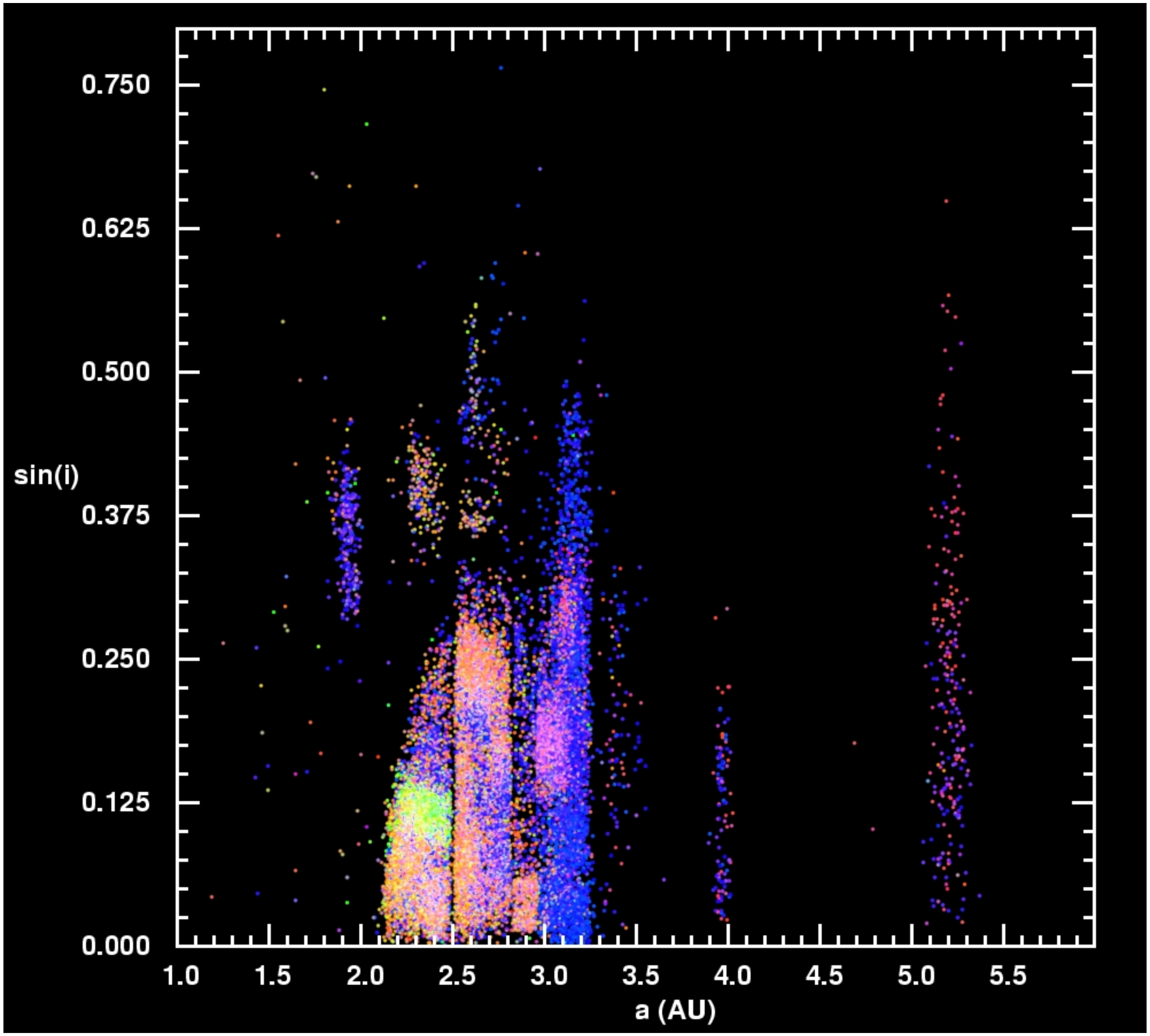
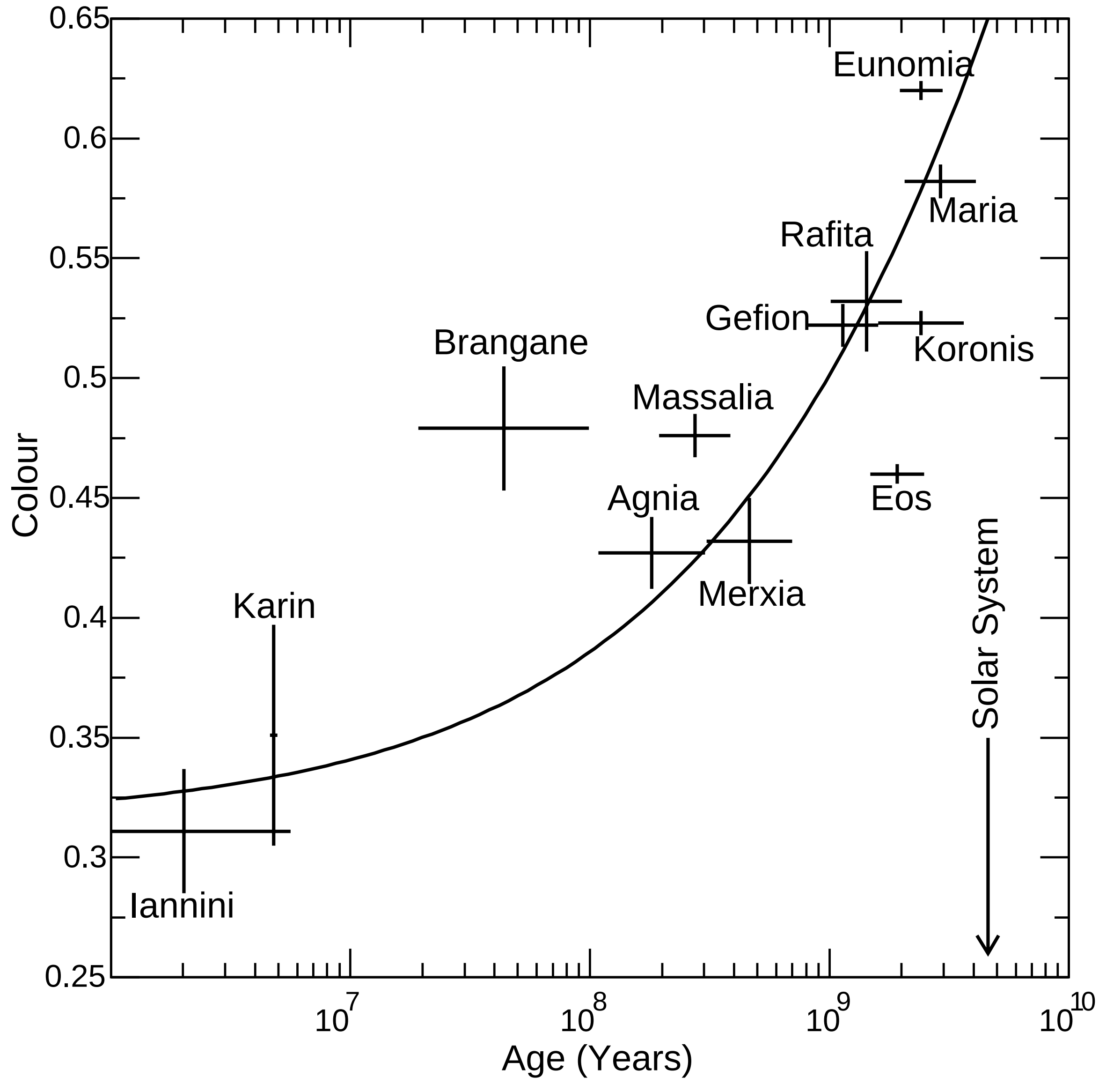


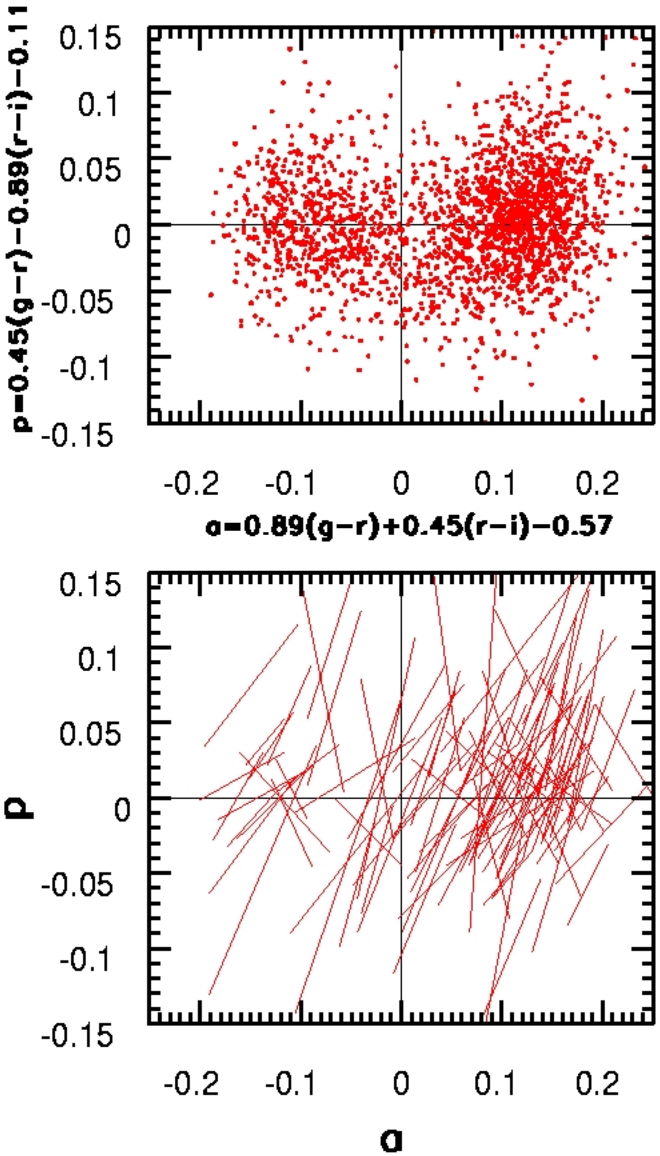
The osculating inclination vs. semi-major axis diagram.

What is the meaning of different color shades?



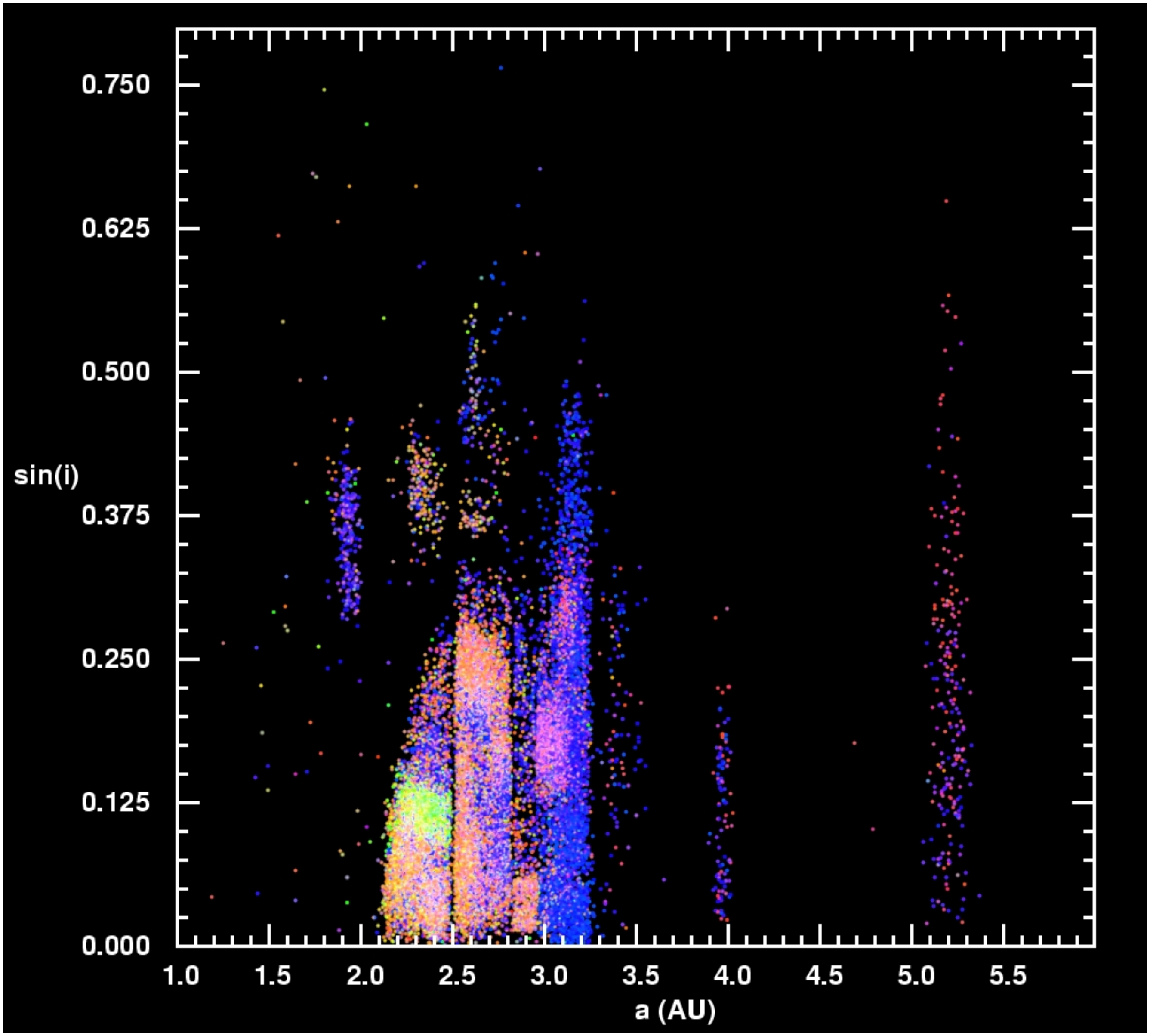
0.65
0.6
0.55
0.5
0.45
0.4
0.35
0.3
0.25
Colour
10^7
10^8
10^9
10^10
Age (Years)
Eunomia
Maria
Rafita
Gefion
Koronis
Brangane
Massalia
Agnia
Eos
Merxia
Karin
Iannini
Solar System

SDSS colors are correlated with the family ages => space weathering!



Color Variability also Implies Space Weathering

- The color variation is nearly perpendicular to the principal axis
- Thus, the color variation is NOT due to a mixture of C and S type material on the same asteroid
- The color variation is NOT correlated with any other measureable parameter
- Fairly large patches with different color than their surroundings exist on a significant fraction of asteroids.



Trojans' ($a \sim 5.2$) color depends on inclination!.

The Properties of Jovian Trojan Asteroids

- Trojans' color depends on inclination
- The leading and trailing swarm have different color distribution
- There are more objects in the leading swarm
- A break in the size distribution, similar to the main belt, but with a larger characteristic size ($\sim$40 km)

The leading and trailing swarms have different properties!