NCU-CPS Japan-Taiwan Planetary Science Workshop 2009

# A Wide-field Survey for Small Main-belt Asteroids in High Inclination

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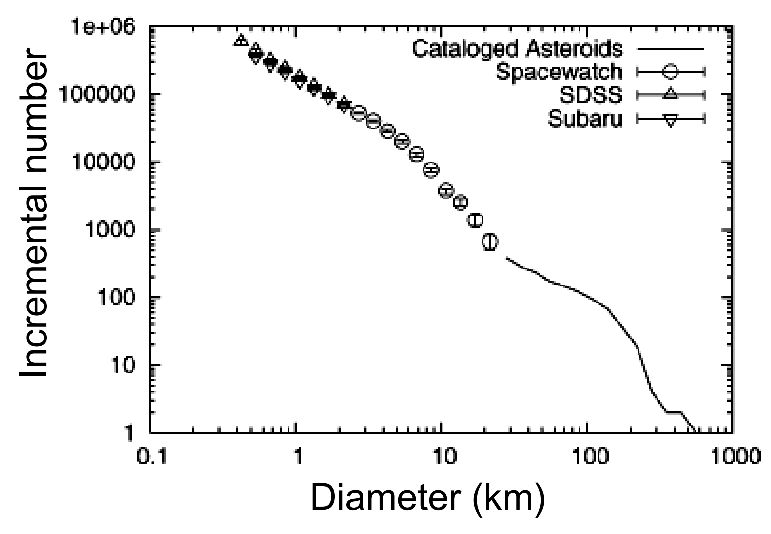
# Size Distribution of MBAs

**Size frequency distribution ( SFD )**
**of main-belt asteroids ( MBAs )**

- Clues for the collisional evolution among small bodies in the inner Solar system

- The slope depends on diameter



(O’Brien & Greenberg 2005)

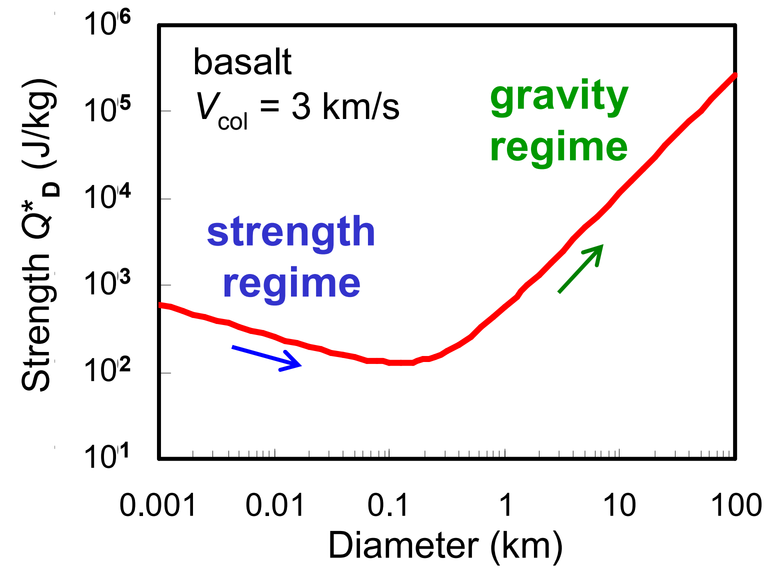
**Strength against disruption ( $Q^*_D$ )**

Different scaling laws in the two regimes

(e.g. Durda et al. 1998)

“Wavy” structure of the SFD

(e.g. O’Brien & Greenberg 2003 )



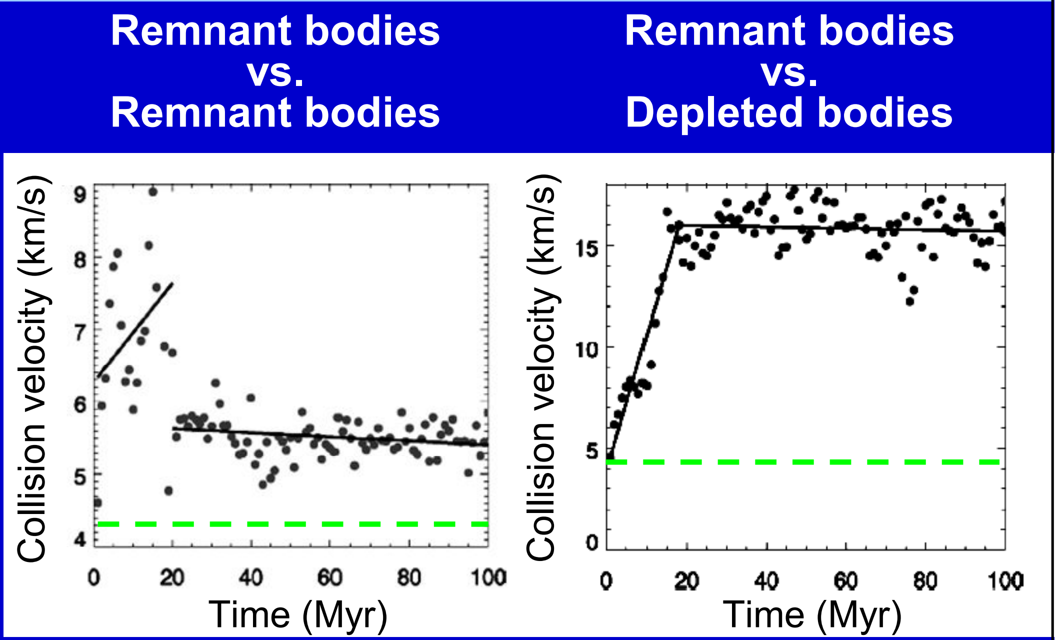
(Benz & Asphaug 1999)

# Collisional Evolution in the MB

**Post-accretion phase**

Planetesimal orbits are dynamically excited by Jupiter and protoplanets

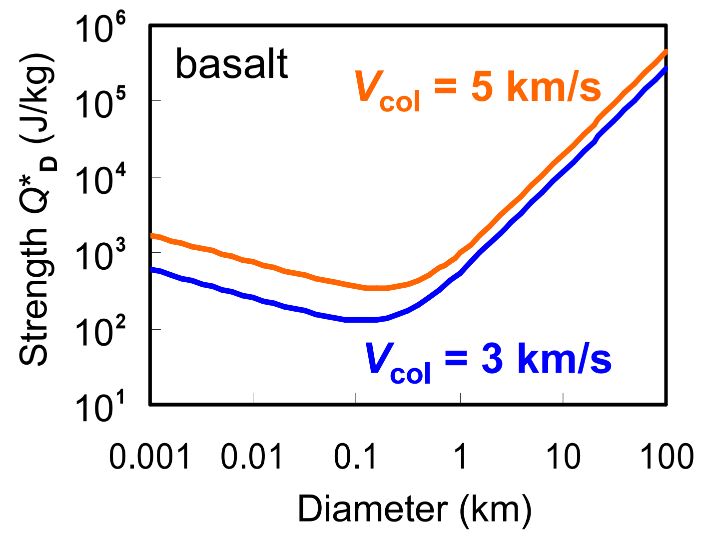
Collisional evolution under hypervelocity impacts



(Bottke et al. 2005)

- The impact strength law depends on collision velocity $V_{col}$ (Benz & Asphaug 1999)

- $Q^*_D$ function in the high collision velocity is unknown



(Benz & Asphaug 1999)

# Target

We are focusing high-inclination MBAs

→ High mean collision velocity (~10km/s)

SFD of high-inclination MBAs

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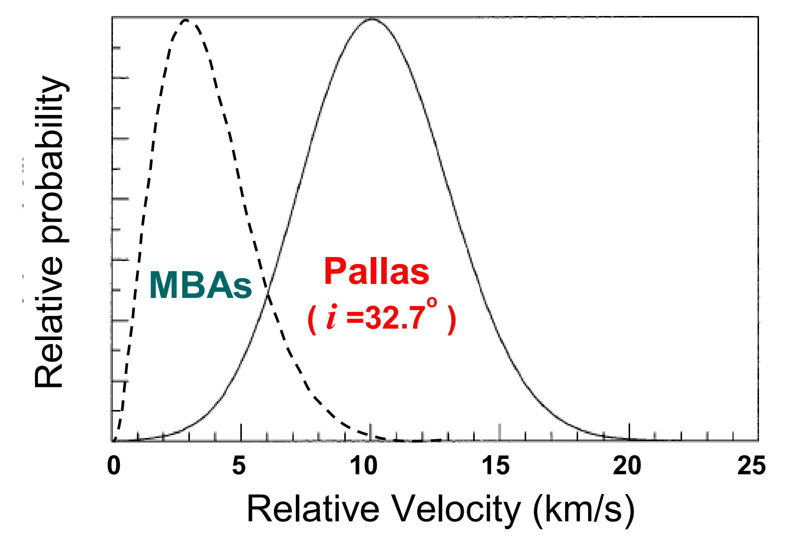
Understanding for hypervelocity impacts



(Vedder 1998)

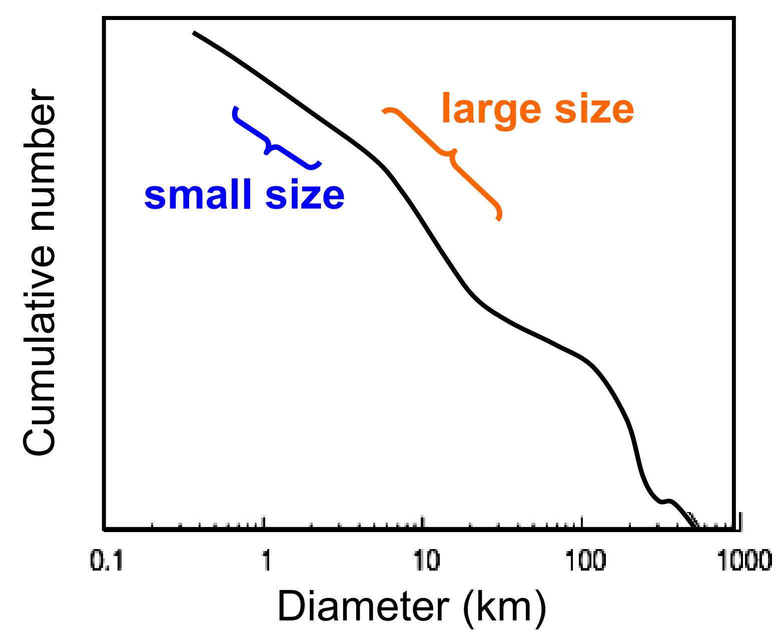
## Our survey

Small size (~1km) :

Observation with **Subaru telescope**

Large size (~10km) :

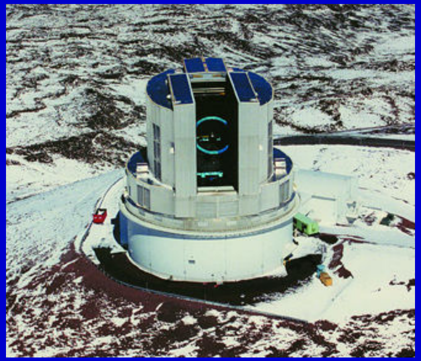
Using the data from **Sloan Digital Sky Survey (SDSS) Moving Object Catalog**



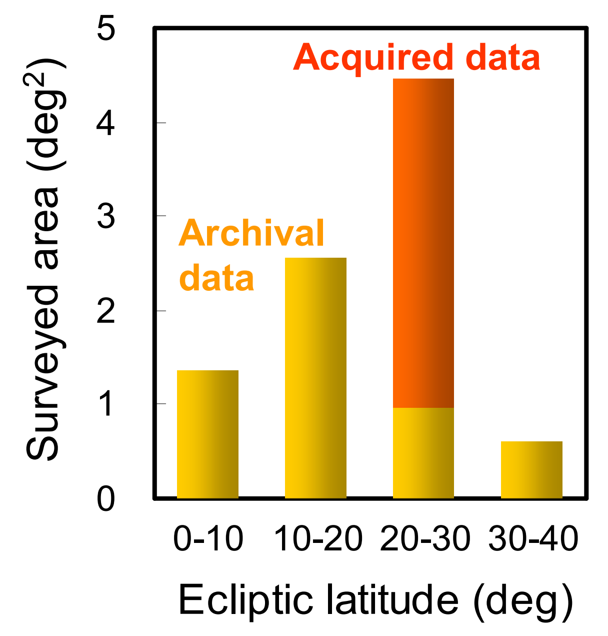
# Observation

Because high-$i$ MBAs are minor population,

- Wide-field survey using the **Subaru Prime-focus Camera** (Suprime-Cam ; field of view $34' \times 27'$ )
- Observation in high ecliptic latitude fields ( $\beta \sim +25^\circ$ )
- Each field is taken only two times for time-saving
  - Date : June 3, 2008
  - Ecliptic latitude ~25° at the opposition
  - Filter : $r'$-band (~0.63 um)
  - Seeing : ~ 0.6”
  - Detection limit : $r' = 24.0$ mag (240s exp)
- Also utilizing the archival data obtained by other observations with Suprime-Cam



**8.2m Subaru Telescope**
(NAOJ)



# Reduction

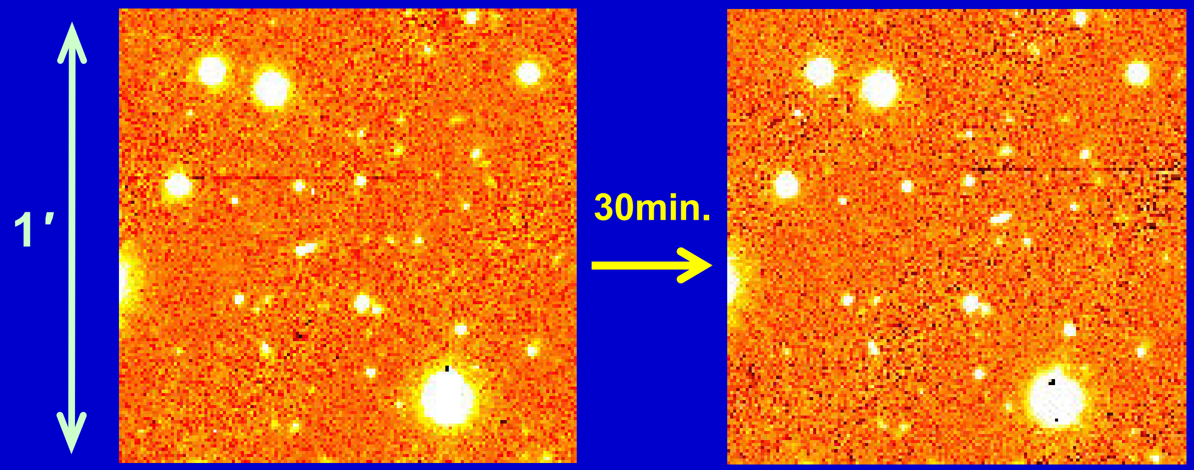
Efficient method for asteroid detection in two images (Terai et al. 2007)

Removal of fixed objects by image processing technique

Automatically detecting moving object candidates

Sieving operation to remove false detections

Visual identification



Original images

# Reduction

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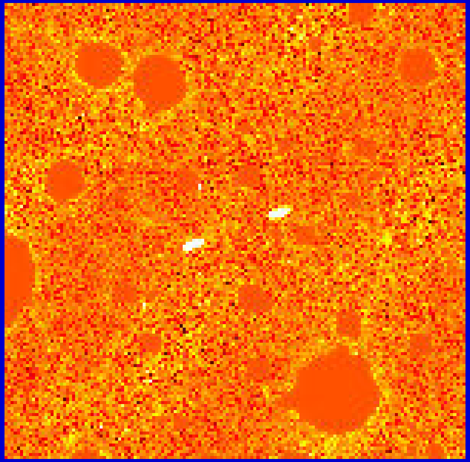
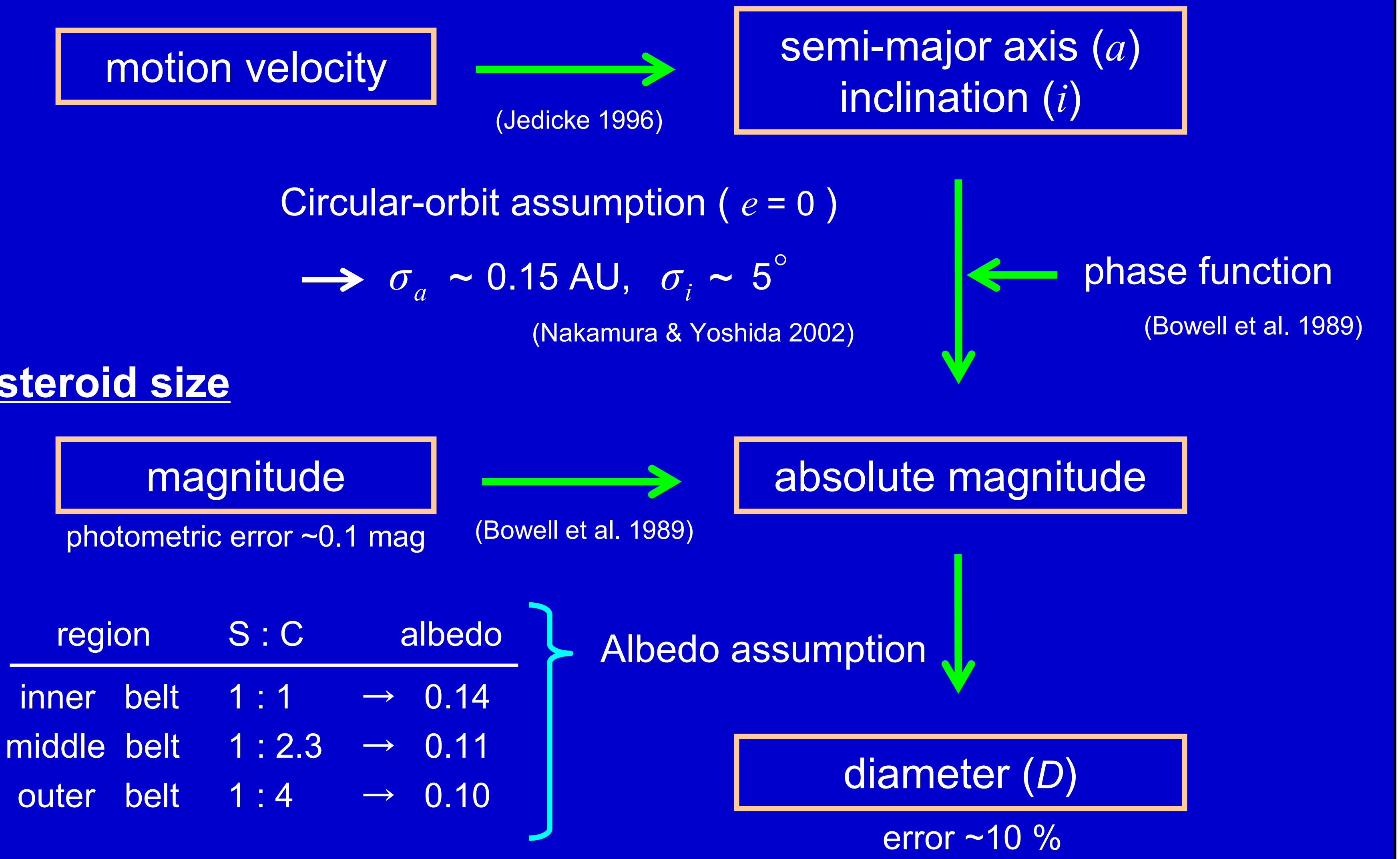


**Processed image**

# Estimation



## Orbital elements

motion velocity → semi-major axis ($a$) inclination ($i$)

(Jedicke 1996)

Circular-orbit assumption ( $e = 0$ )

→ $\sigma_a \sim 0.15$ AU, $\sigma_i \sim 5^\circ$

(Nakamura & Yoshida 2002)

phase function

(Bowell et al. 1989)

## Asteroid size

magnitude → absolute magnitude

photometric error ~0.1 mag

(Bowell et al. 1989)

| region | S : C | | albedo |
|---|---|---|---|
| inner belt | 1 : 1 | → | 0.14 |
| middle belt | 1 : 2.3 | → | 0.11 |
| outer belt | 1 : 4 | → | 0.10 |

(Yoshida & Nakamura 2007)

Albedo assumption

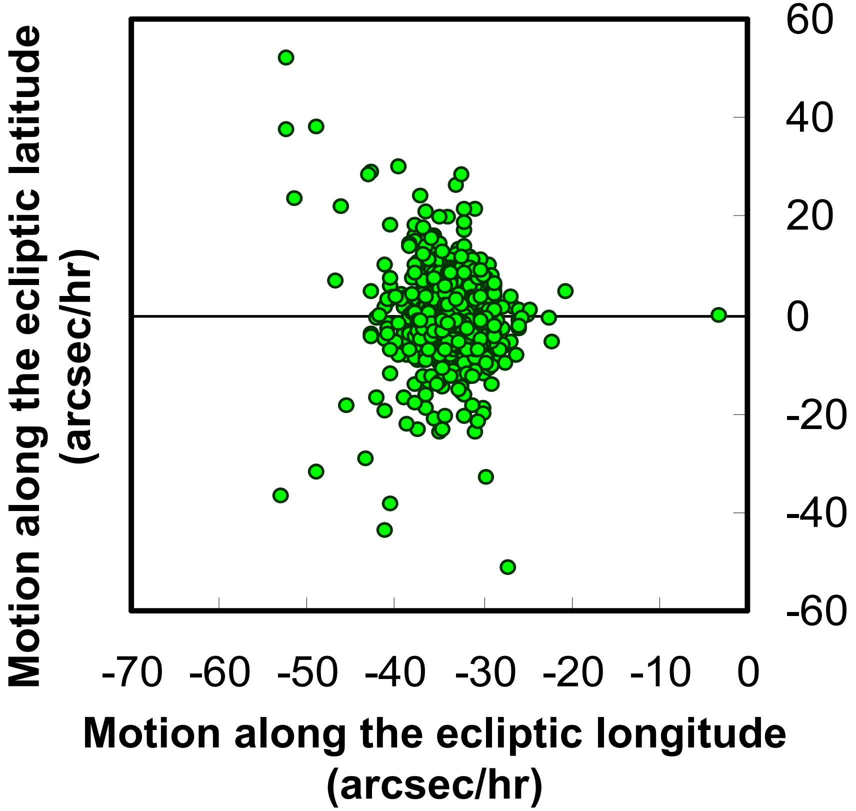
diameter ($D$)

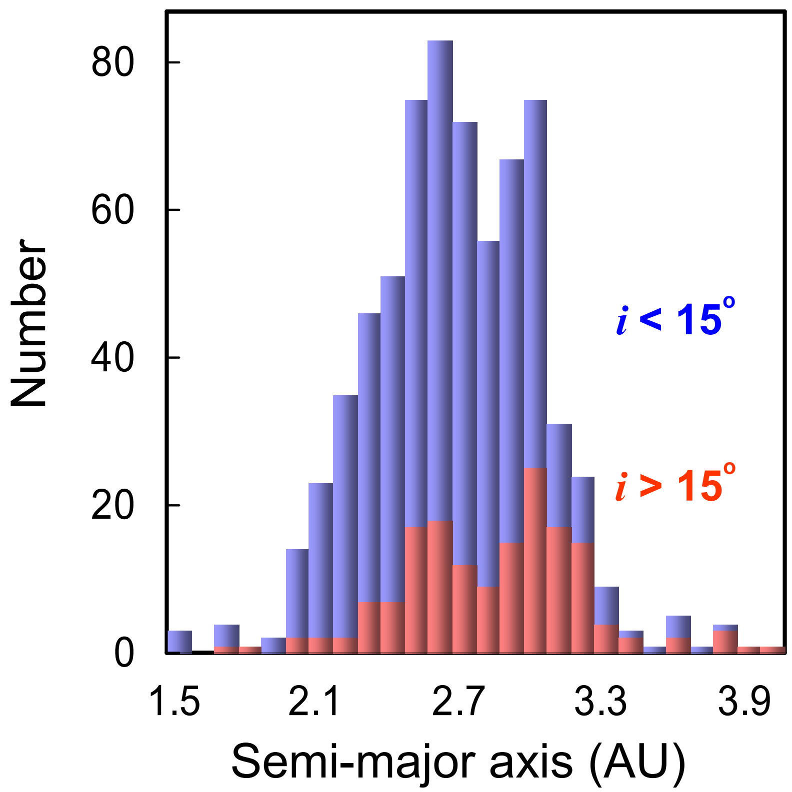
error ~10 %

# Detection

In the area of 9.0 deg$^2$, 656 moving objects were detected.

→ We regarded 616 objects located 2.0 – 3.3 AU as MBAs





# Samples

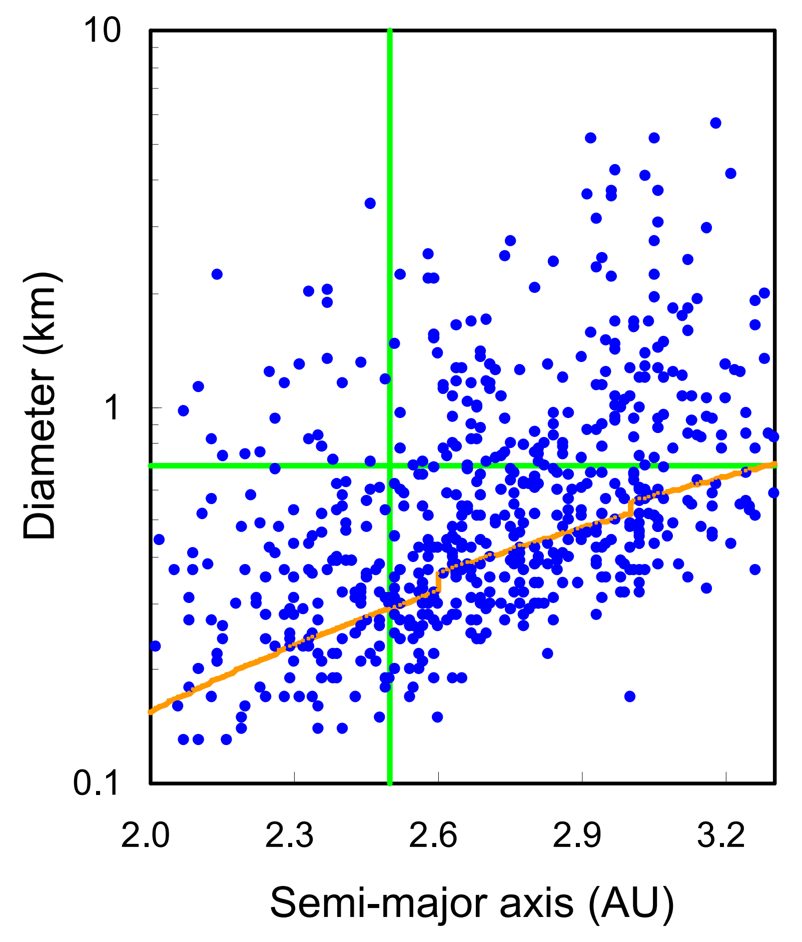
**Sample selection :**

(i) Diameter > 0.7 km

(detection limit at 3.3 AU)

(ii) Semi-major axis > 2.5 AU

- high-$i$ asteroid population
- orbital estimation accuracy



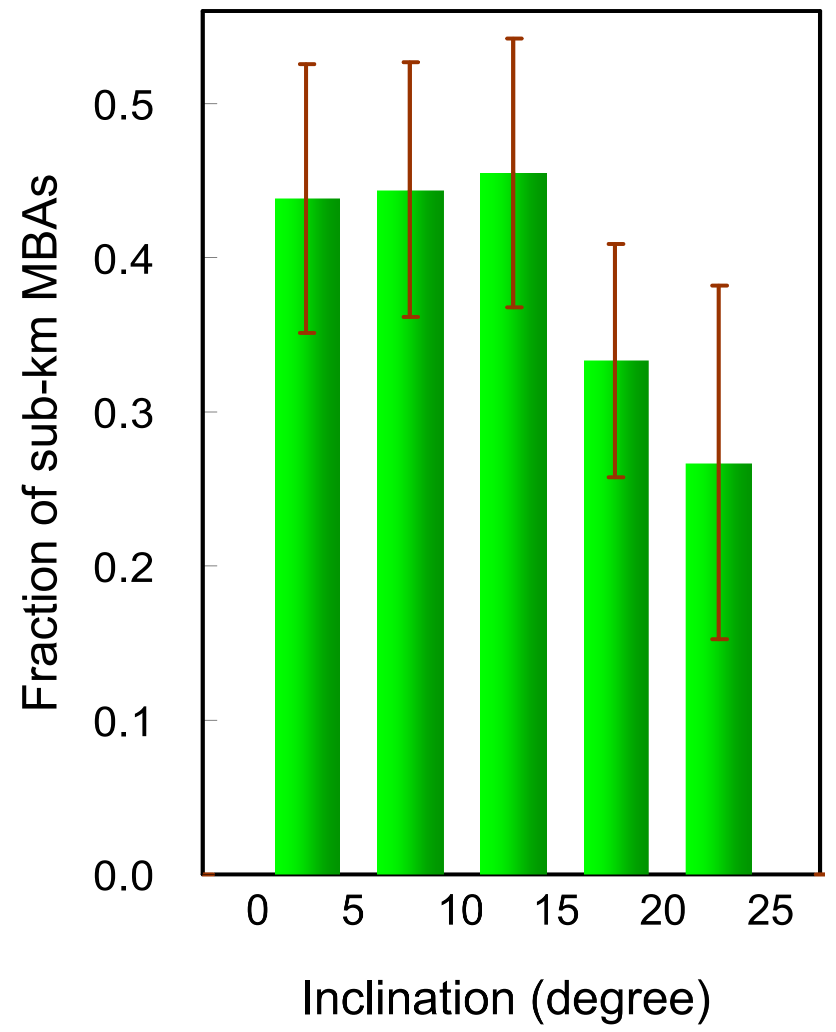
The unbiased samples consist of 178 MBAs

# Results

**Fractions of sub-km MBAs** (0.7–1 km)

The fractions are almost constant from $i = 0^{\circ}$ to $15^{\circ}$, while they significantly decrease beyond $15^{\circ}$

The SFD of MBAs depends on inclination.



# Results

## Cumulative size distribution (CSD)

Power-law fitting :

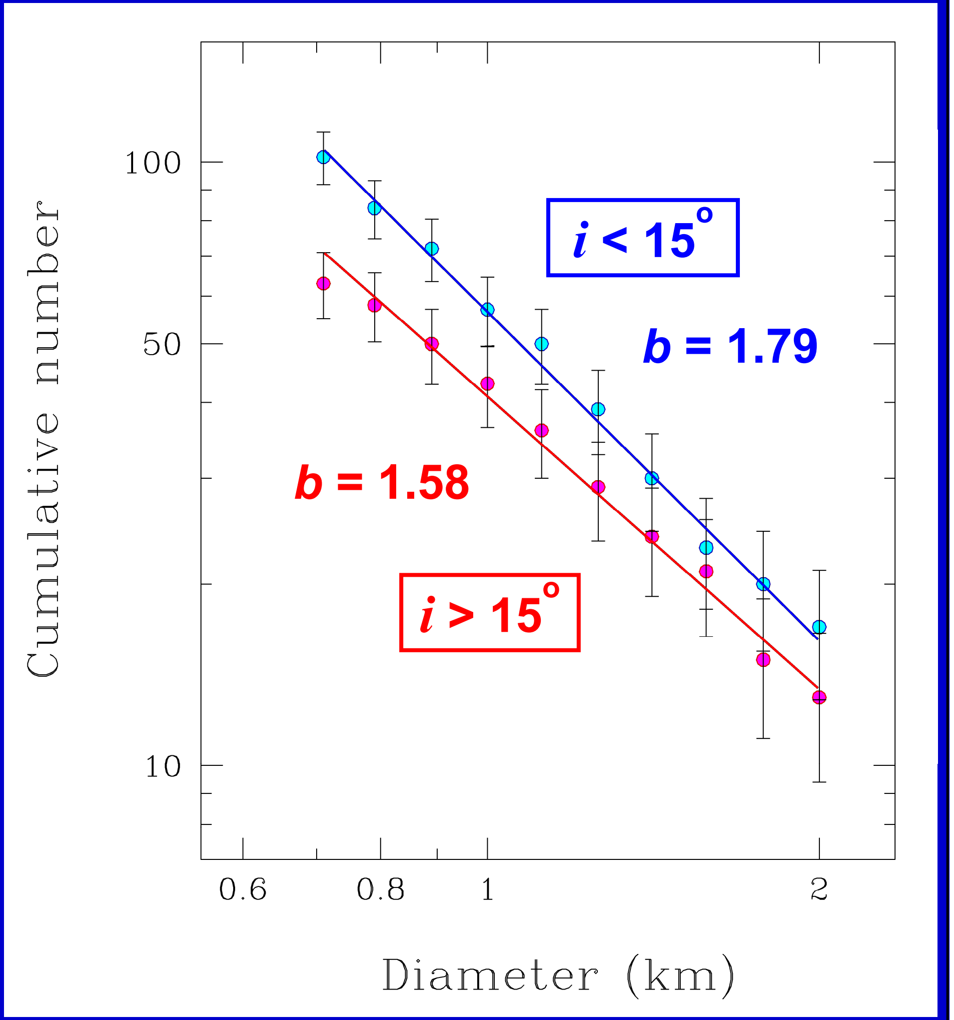
$$N(>D) \propto D^{-b}$$

$N$ ($>D$) : cumulative number, $b$ : CSD slope

| **low-$i$ ( $i < 15^\circ$ )** | **high-$i$ ( $i > 15^\circ$ )** |
|---|---|
| $b$ = 1.79 +/- 0.05 | $b$ = 1.58 +/- 0.06 |

( 0.7 km < $D$ < 2 km )

High-$i$ CSD is shallower



# Results

**SDSS Moving Object Catalog**

| low-$i$ ( $i < 15^{\circ}$ ) | high-$i$ ( $i > 15^{\circ}$ ) |
|---|---|
| $b$ = 2.44 +/- 0.02 | $b$ = 2.56 +/- 0.01 |

( 12 km < $D$ < 30 km )

⇩

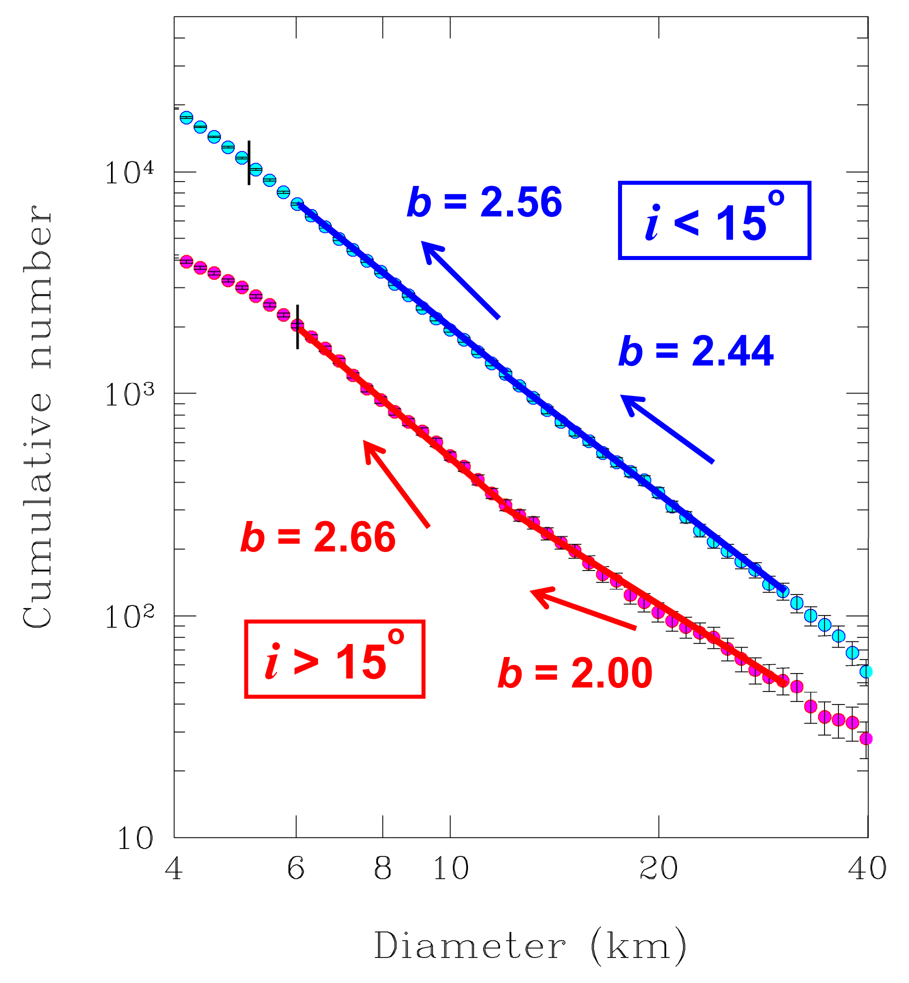
High-$i$ CSD is shallower

| low-$i$ ( $i < 15^{\circ}$ ) | high-$i$ ( $i > 15^{\circ}$ ) |
|---|---|
| $b$ = 2.00 +/- 0.03 | $b$ = 2.66 +/- 0.03 |

( 6 km < $D$ < 12 km )

⇩

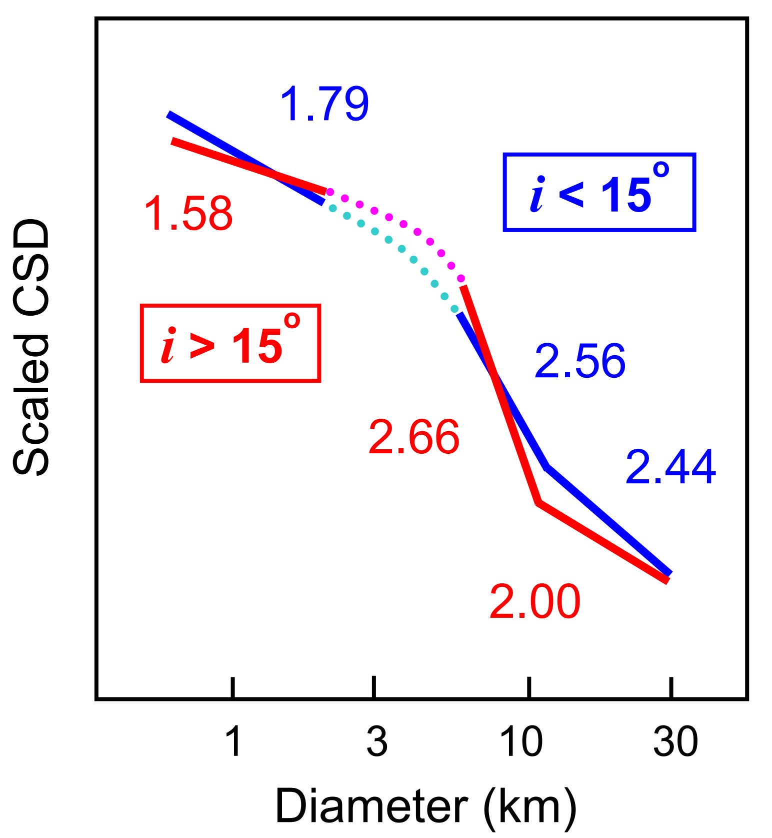
High-$i$ CSD is steeper



# Discussion

## CSD slopes

| low-$i$ ( $i < 15^\circ$ ) | high-$i$ ( $i > 15^\circ$ ) |
|---|---|
| $b = 2.44$ | $b = 2.00$ |
| ( 12 km < $D$ < 30 km ) | |
| $b = 2.56$ | $b = 2.66$ |
| ( 6 km < $D$ < 12 km ) | |
| $b = 1.79$ | $b = 1.58$ |
| ( 0.7 km < $D$ < 6 km ) | |



High-$i$ CSD has larger amplitude of the wave structure

# Discussion

**Numerical collisional model**

(Durda et al. 1998)

Larger slope variation $Q^*_D$ -law

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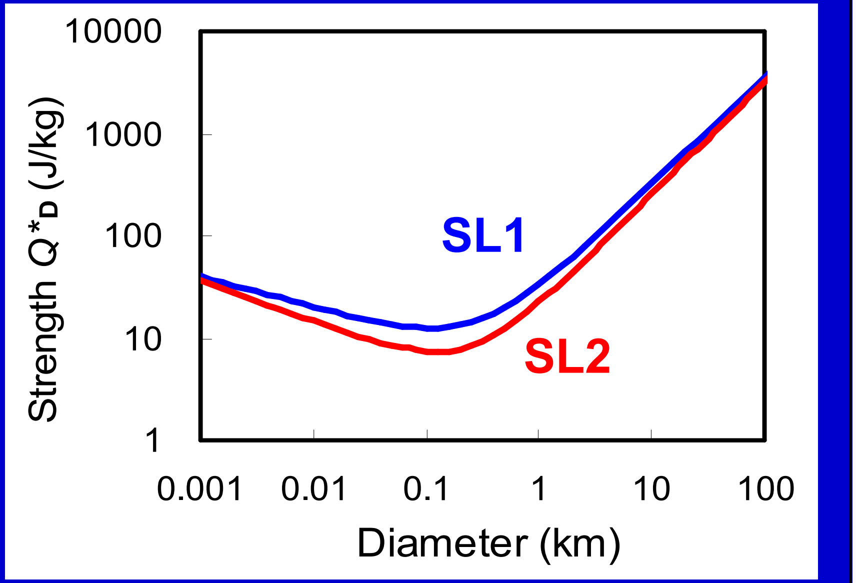
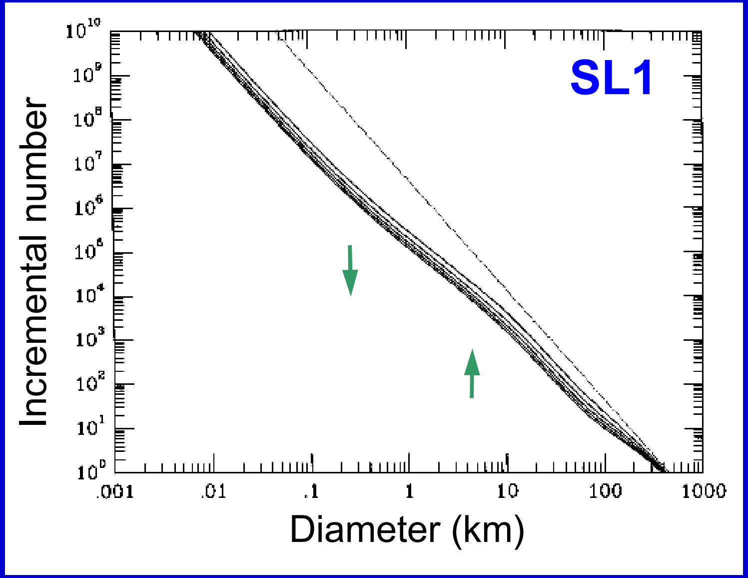
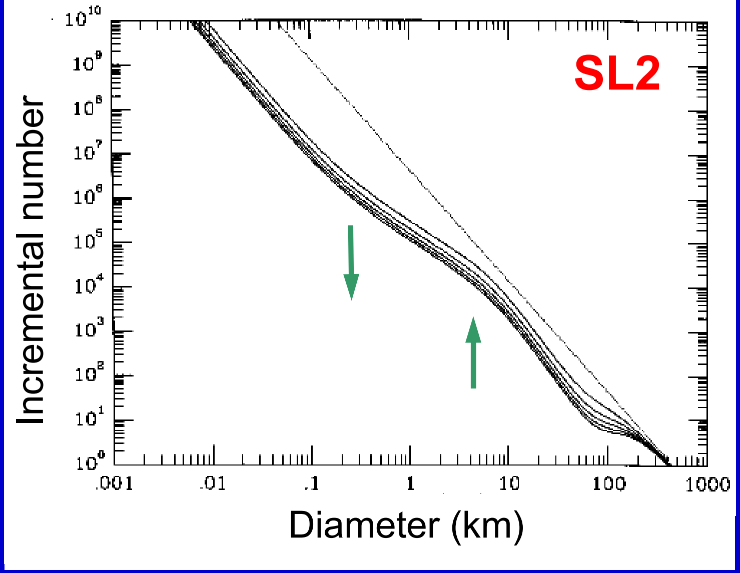
Larger amplitude wave in CSD







(Durda et al. 1998)

# Discussion

**SPH simulation** (Benz & Asphaug 1999)

Variation of $Q^*_D$ slopes between gravity and strength regimes

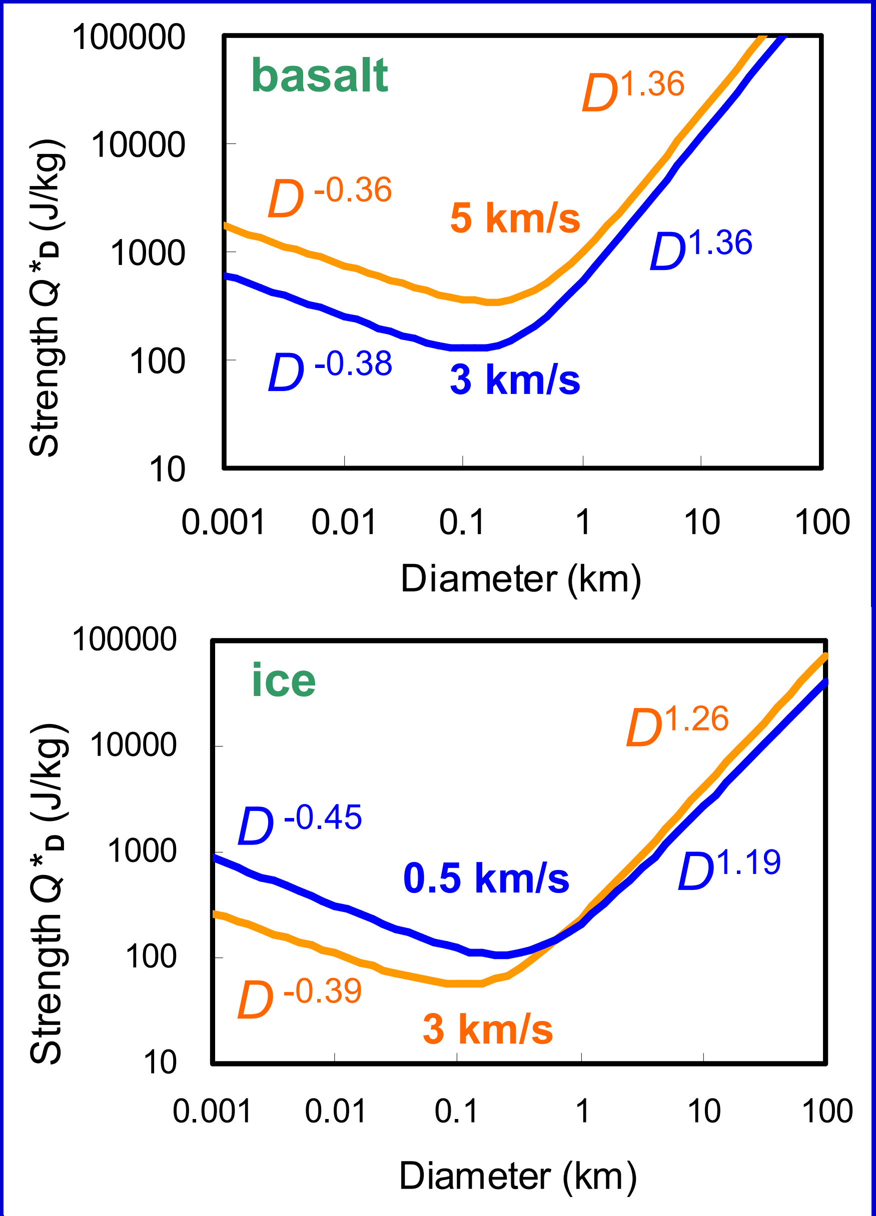
**basalt**
- 1.74 in $V_{col}$ = 3 km/s
- 1.72 in $V_{col}$ = 5 km/s

larger $V_{col}$ , smaller slope variation

**ice**
- 1.64 in $V_{col}$ = 0.5 km/s
- 1.65 in $V_{col}$ = 3 km/s

larger $V_{col}$ , larger slope variation

MBAs have ice-like strength-law rather than basalt ?



（Benz & Asphaug 1999）

# Summary

- We carried a survey for investigating the size distribution of high-inclination MBAs using the observation data obtained by Subaru telescope and the public data using SDSS Moving Object Catalog
- We found that the cumulative size distribution of high-inclination MBAs has larger amplitude of the wave structure than that of low-inclination MBAs
- Our result indicates that the strength law against collisional disruption has large slope variation between gravity regime and strength regime under hypervelocity impacts