Survey Observations of Small Solar System Bodies by Suprime-Cam (SC)

Fumi Yoshida (NAOJ)

1. Some results from the surveys using the Suprime-Cam.
2. Proposed observation using the Hyper Suprime-Cam

Surveys using Suprime-Cam

① Main belt asteroids survey (SMBAS)

② Jovian Trojans survey (SMBAS)

③ Irregular satellites survey (Univ. of Hawaii)

④ Kuiper belt objects survey

◆ ①,②,④ were done by Japanese research groups.

◆ They look different surveys, but they shared the same data from the same 3 nights.

◆ Let me introduce mainly ① and ②.

① Main belt asteroids survey

- Subaru Main Belt Asteroids Survey (SMBAS)

  Aim : investigate the size distribution of small MBAs. (D<1km)

  - SMBAS-I Feb. 22 and 25, 2001 (UT)
  - SMBAS-II Oct. 21, 2001 (UT)

	Searched area (deg^2)	Single exp. Time (min)	Used filters	Limiting magnitude for MBAs
SMBAS-I	3(14 fields*)	7	R	24.4
SMBAS-II	4(16 fields)	2	B, R	24.2

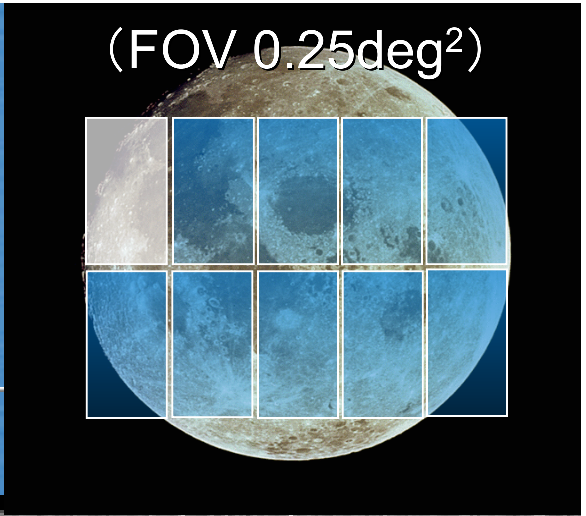
* FOV 0.23 deg^2 (nominal:0.255 deg^2)

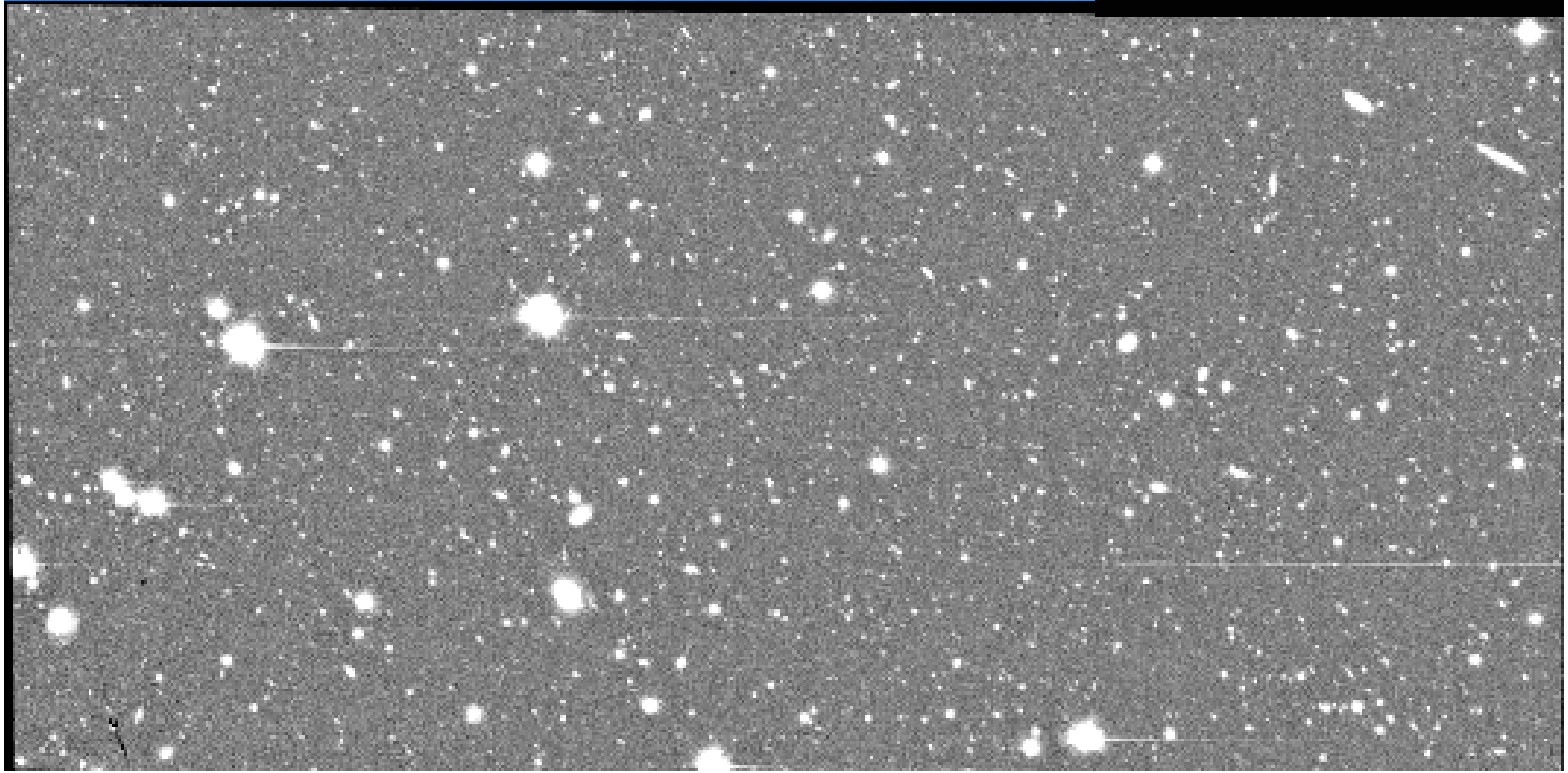
The deepest surveys for MBAs.

- Searched sky regions; oppositions, near the ecliptic (< ±3 deg).

Moving objects on one CCD chip

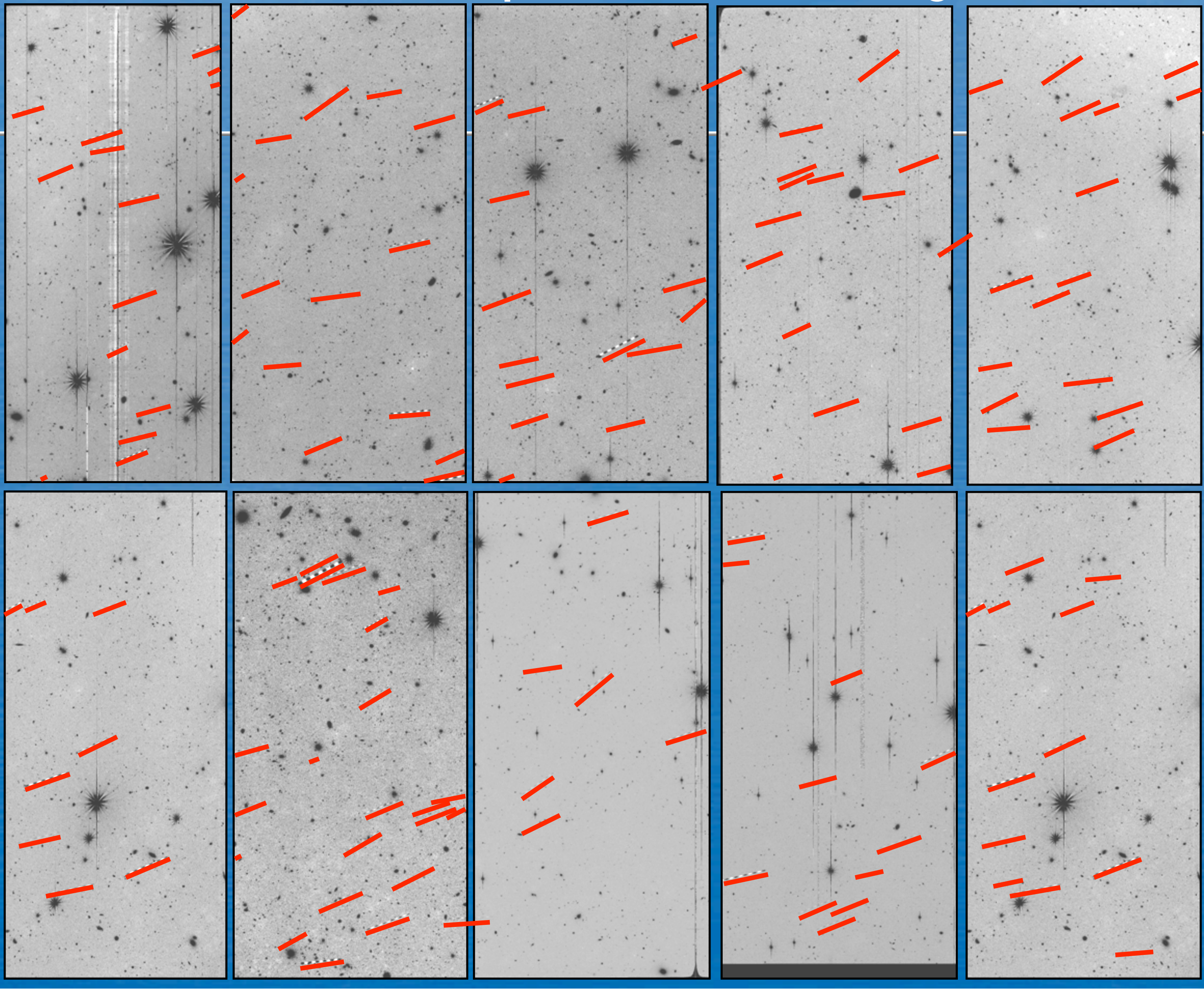
Animation of moving objects images taken with 2 min - exp. for one night





Detected moving objects

about 100 objects are in the single shot images

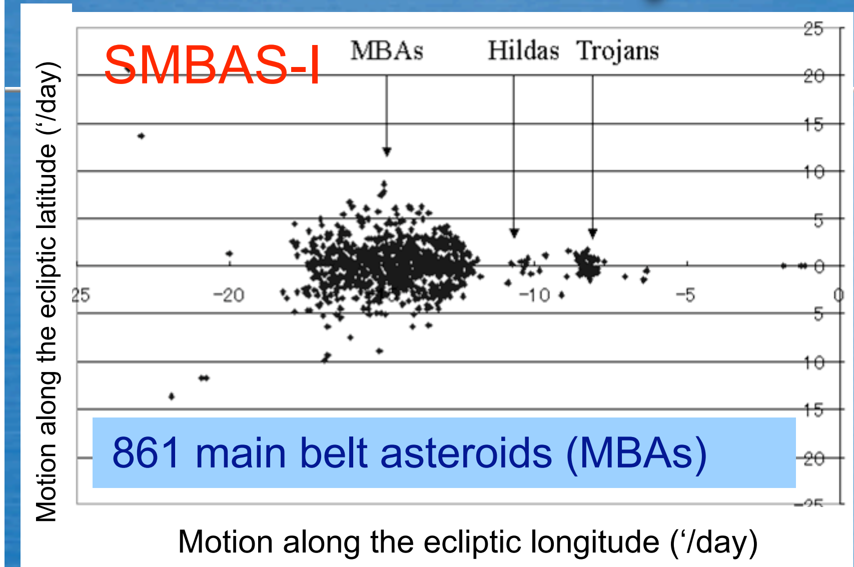


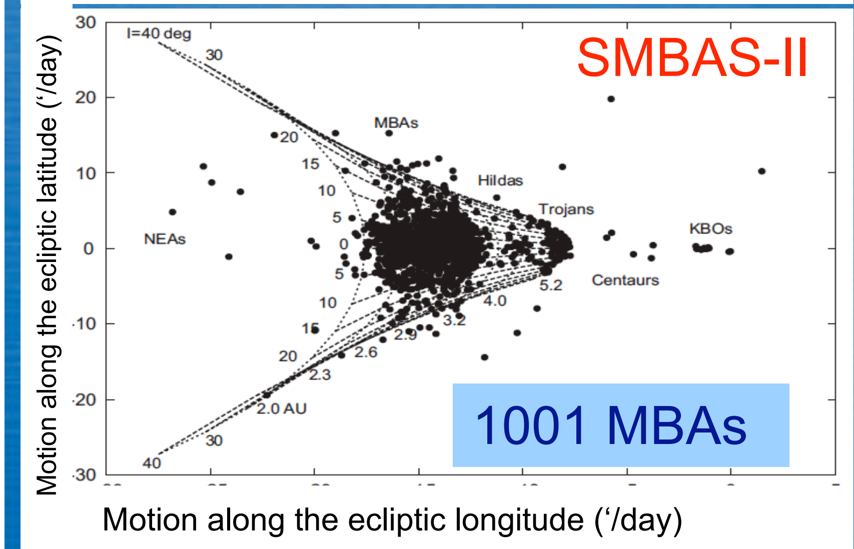
If the objects is close to the Earth, it moves quickly.

While if the objects is far from the Earth, it moves slowly.

We can distinguish the objects by their motions.

Grouping of moving objects by their motion





- We can divide moving objects into several groups having the different heliocentric distance by their motions.
- Velocity of motion → heliocentric distance, i.e. approximate semi-major axis (a) (under assumption $e = 0$)
- Apparent mag.(m_R) + a → Absolute mag.(H) (under assumption $e = 0$)

$$H = m_R - 5\log(a\,(a - 1))$$

- H → diameter (D km)

$$\log D\,(\mathrm{km}) = 3.13 - 0.5\log A - 0.2H$$

A=0.09 --- SMBAS-I, A_S=0.21(S-type asteroid), A_C=0.04(C-type) --- SMBAS-II

Size distributions

Detection limit: R~24.4 mag

H_V~20 mag

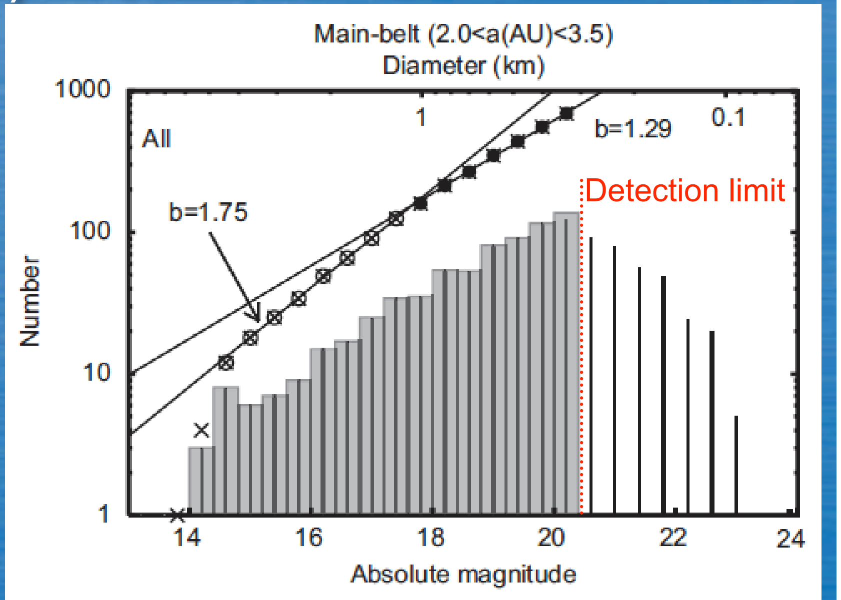
D~400m (all),
300m (for S), 600m (for C)

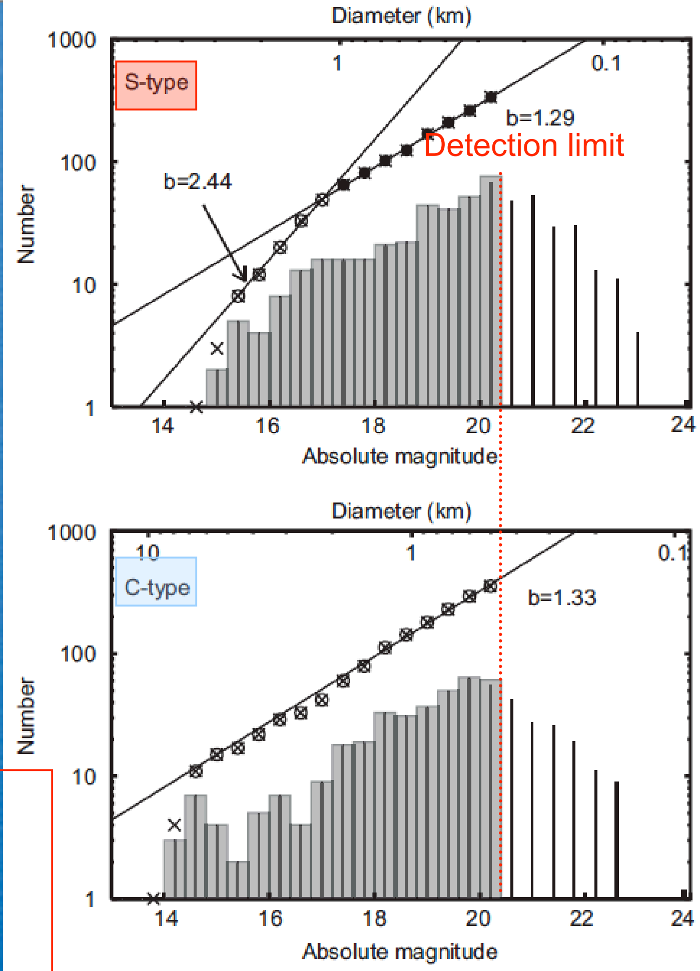
- Cumulative number
  $N(>D) = CD^{-b}$

For all MBAs
(S-type , C-type)

b~1.3
(0.5<D(km)<1)

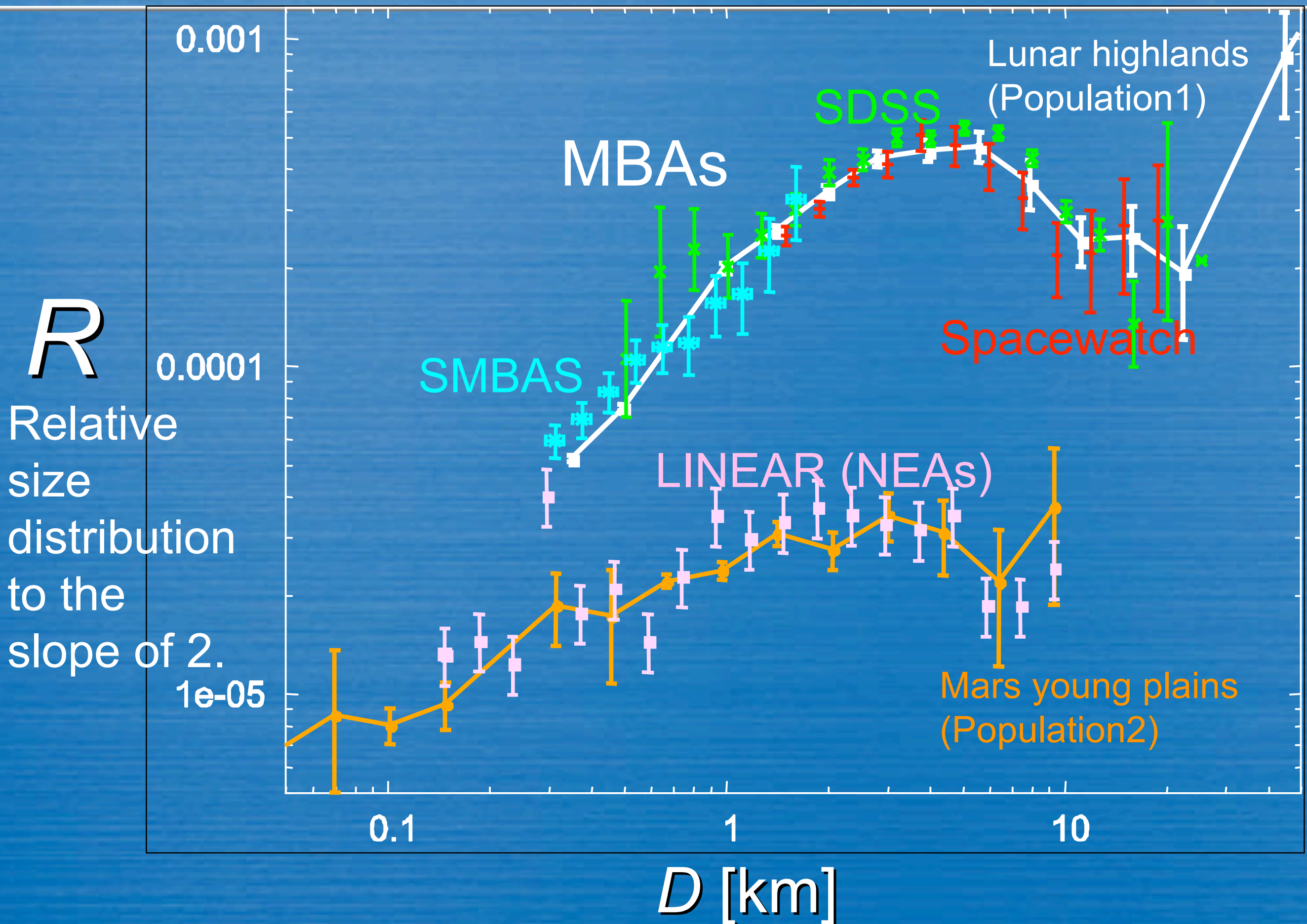
This is consistent with SDSS result
(Ivezic et al. (2001)





1. The index (b) is 1.3 for smaller MBAs. It's shallower than that of larger MBAs.
2. The slope is probably independent from asteroids types.

Comparison of the size distributions with MBAs, NEAs and planetary impactors



The MBA size distribution is virtually identical with Population 1 projectiles responsible for the old crater record (3.8 Gyr ago).

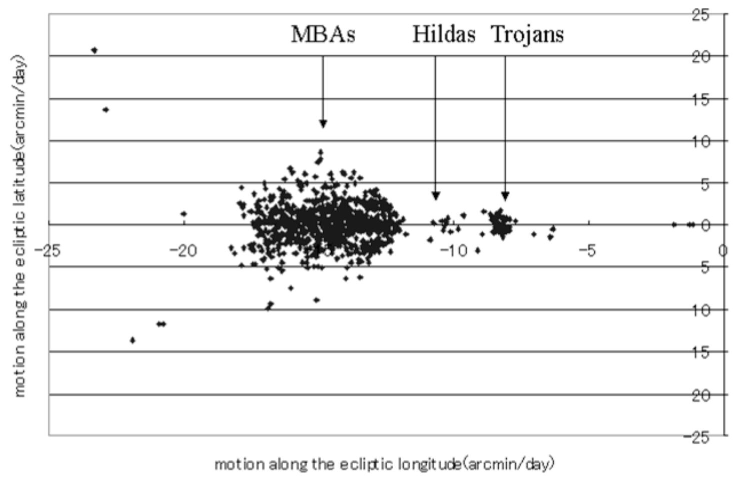
The NEA size distribution is the same as Population 2 projectiles responsible for the younger crater record.

We can say the origin of the Lunar highlands craters is related to the main belt asteroids.

Strom, R. G., Malhotra, R., Ito, T., Yoshida, F., and Kring, D. A., 2005, Science, 309, 1847-1850. The origin of planetary impactors in the inner solar system.

② Jovian Trojans (JTs) survey

Aim : The investigation of size distribution and total population of L4 and L5 Trojans

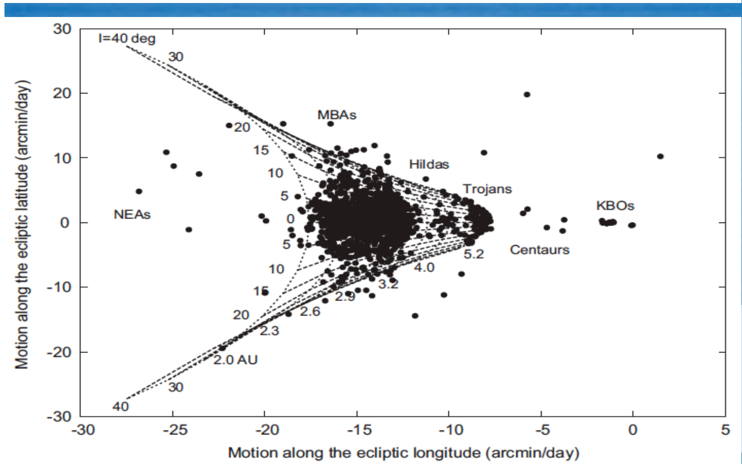


SMBAS-I

2001.Feb.22, 25

32° ahead of L4, 3deg²

SMBAS-I found 51 L4 JTs.

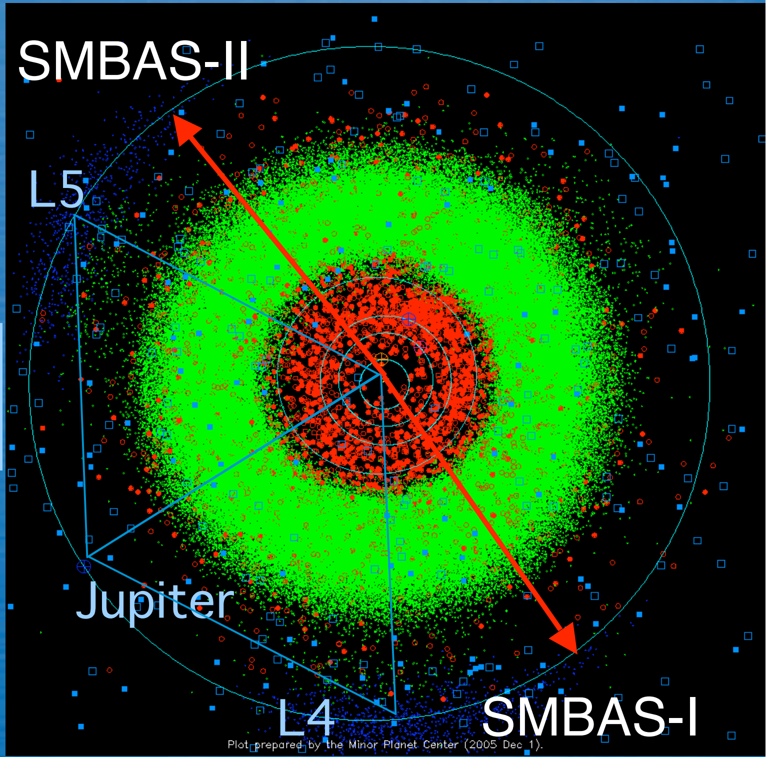


SMBAS-II

2001.Oct.21

22° behind of L5, 4deg²

SMBAS-II found 62 L5 JTs.



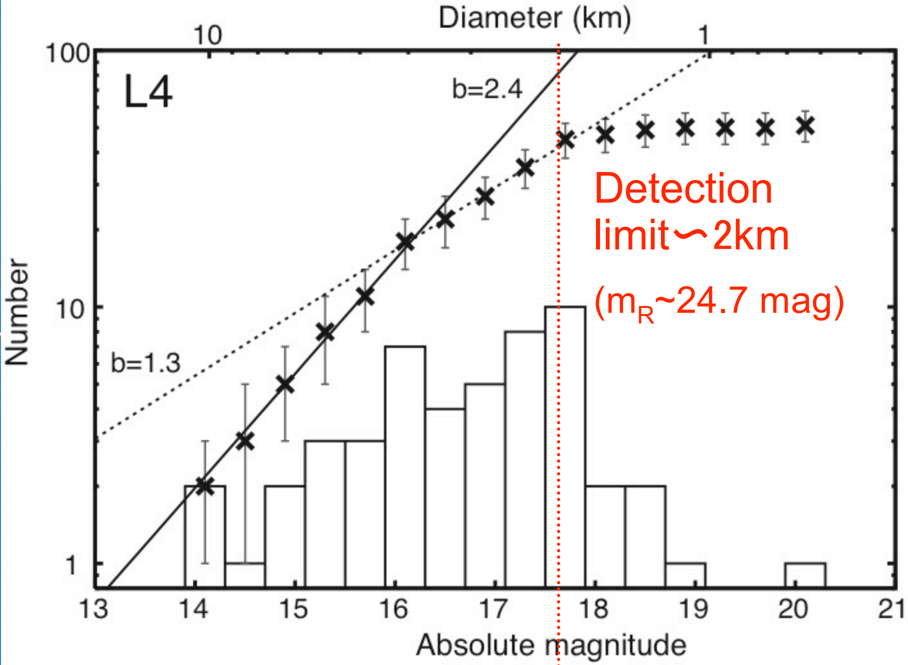
Size distributions for L4、L5 Jovian Trojans

- Cumulative size distribution

  N(>D)∝D^{-b}　D : diameter

L4 Trojans b=1.3 (2<D(km)<5)

L5 Trojans b=2.1 (2<D(km)<5)



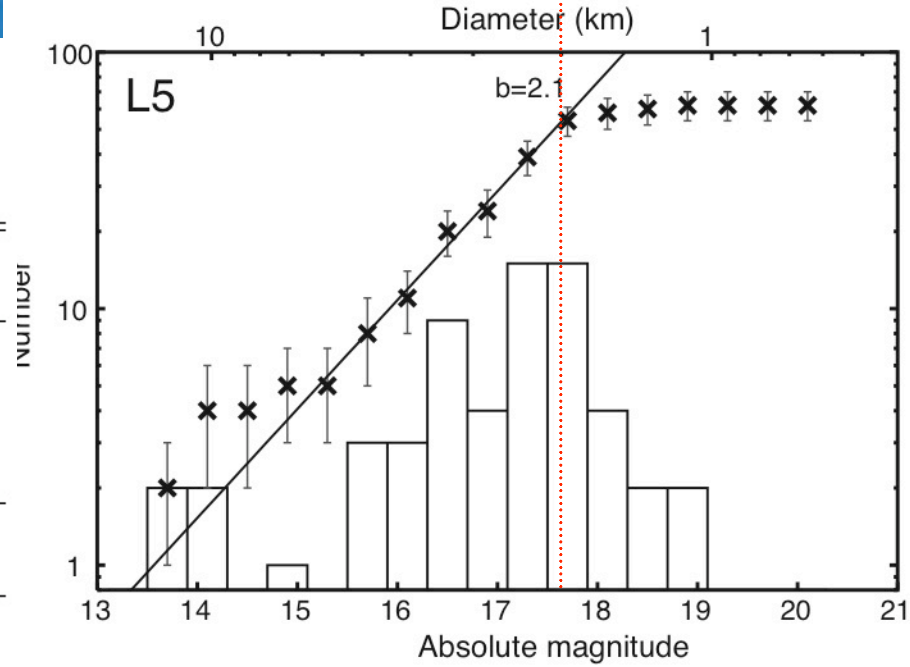


Table 1. Slopes of cumulative size distributions for L4 and L5 Trojans with different size ranges.

Depletion?

Group	Slope (b)	Size range D (km)	Reference
L4	1.3 ± 0.1	$2 < D < 5$	SMBAS-I YN2005
L4	2.4 ± 0.1	$5 < D < 10$	SMBAS-I YN2005
L4	2.0 ± 0.3	$4 < D < 40$	Jewitt *et al.* (2000)
L4	2.0 ± 0.1	$20 < D < 93$	Known Trojan catalog*
L5	2.1 ± 0.3	$2 < D < 5$	SMBAS-II (This work)
L5	2.1 ± 0.1	$20 < D < 93$	Known Trojan catalog*

* http://cfa-www.harvard.edu/iau/lists/JupiterTrojans.html

Population asymmetry between L4 and L5 swarms

- Sky number density

L4 JT (D>2km) 14.7±2.3/deg^2 at 32° ahead of L4 point

L5 JT (D>2km) 13.8±1.9/deg^2 at 22° behind of L5 point

Table 1. Model dependence of Trojan total populations.

Model	$N_{\rm Gauss}(>2\rm km)$	$N_{\rm Max\text{-}Gauss}(>2\rm km)$
L4	$\sim 1.6\times10^{5}_{\star a}$	
L4	$2.4\pm0.38\times10^{5}_{\star b}$	$6.3\pm1.0\times10^{4}_{\star c}$
L5		$3.4\pm0.54\times10^{4}_{\star c}$

$\star$a) JW2000, $\star$ b) YN2005, $\star$ c) this work

- Total population

L4 JT (D>2km)
(6.3±1.0)x10^4

L5 JT (D>2km)
(3.4±0.54)x10^4

Estimated through a model

More Trojans in L4 swarm

SDSS also found the population asymmetry. L4/L5=1.6 (D>10km)
（Szabo et al. 2007）

What is the meaning of the depletion of small L4 and the population asymmetry between L4 and L5 ?

- Three-body dynamics tells us that there is no asymmetry in the orbital stability between L4 and L5 swarms.

- Theorists suggests that

1. Gas drag (proto-planetary nebula) makes much survivors in L5 for small JT.（Peale 1993, Murray 1994, Marzari & Scholl 1998）
2. Planetary migrations makes the orbit of L5 objects unstable.（Gomes 1998）

③ Irregular satellites survey

The Hawaii Irregular Satellites Survey (HISS)

Aim : The exploration and characterization of the irregular satellites of the planets

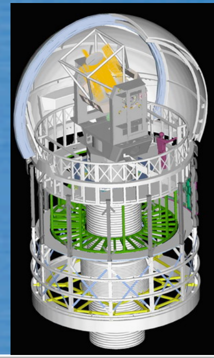
HISS has discovered 63 irregular satellites.

④ Kuiper belt objects survey

A deep sky survey of EKBOs with an improved shift-and-add method. Yamamoto, N., Kinoshita, D., Fuse, T., Watanabe, J. and Kawabata, K. accepted to PASJ.

- 14 KBOs were detected with m_R~26 mag.
- The surveyed area was 0.4 deg^2.

Pan-STARRS



- Pan-STARRS is a survey system which consists of four individual telescopes, each with a 1.8 meter diameter mirror, they observe the same region of sky simultaneously.
- Its main purpose is searching for potential killer asteroids.
- Pan-STARRS will cover 6,000 deg^2 per night. The whole available sky as seen from Hawaii will be observed 3 times during the dark time in each lunar cycle.
- Pan-STARRS reaches a limiting magnitude of 24.
- Pan-STARRS will detect moving objects and then determine their orbits almost automatically.

PS1 Haleakala in Hawaii

What can Hyper SuprimeCam do?

➢FOV: 1.77 deg^2

➢Sensitivity not different from SC

Based on Yamamoto et al.(2008),

- Detection limit of TNOs ~26 mag
- Expected number : 62 TNOs per shot
- Detectable size of TNOs (at 40 AU) : D~67km

  (cf.Pan-STARRS can detect TNOs down to D~170km)
- New detection method Yanagisawa et al. (2004)

  We can reach 2 mag deeper → ~ 28 mag

  Detectable size : 27km

Since smaller objects are important for studying collisional evolutions, it is worth obtaining the size distribution of TNOs with different size range from Pan-STARRS.

My proposal for HSC

- Do TNOs survey and get the size distribution of smaller TNOs.

- Because smaller objects are an important key for studying collisional evolutions as I showed you examples of MBAs and JTs.
- Only larger telescope can reach such size range.
- This will be the only way for the Hyper Suprime-Cam to be scientifically significant during the era of Pan-STARRS for studies of the small solar system bodies.
- If the New Horizon take images of Pluto, we will be able to compare the size distributions between Pluto's crater and TNOs. It will reveal the unexplored TNOs world.