The 31st Virtual UNISEC-Global Meeting

Near-Earth Object Research and Planetary Defense Activities - Past, Present, and Future

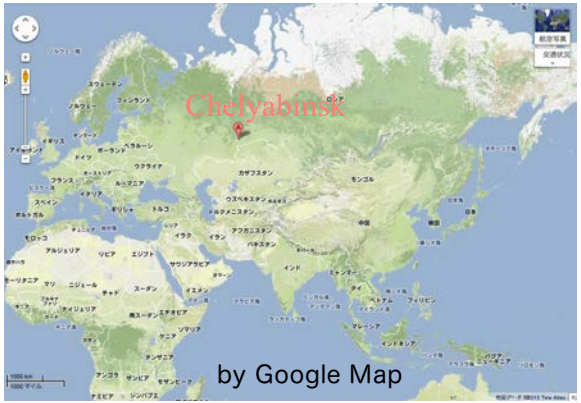
March 18, 2023@Online

Makoto Yoshikawa (JAXA)

Chelyabinsk Meteorite in 2013

Feb. 15, 2013, 09:20 AM (local time)

- A meteorite fell to Chelyabinsk in Russia.
- A lot of buildings were damaged and more than 1500 people were injured.
- The size of the colliding asteroid was about 17m.



Surveillance cameras in a university in Chelyabinsk

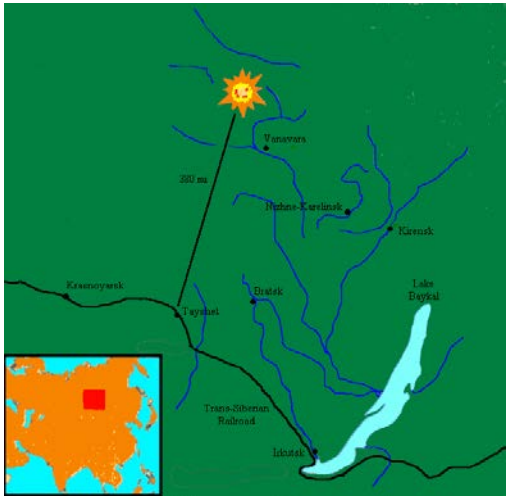
Video taken by in-vehicle camera

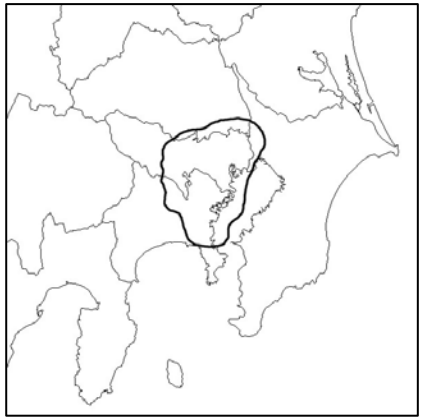
(from Web)

Tunguska Event in 1908

June 30, 1908

- A large explosion was occurred and about 2000 km^2 of the forest was damaged.
- This was caused by a impact of 60 m size asteroid (or comet).
- The energy was 2,000 times greater than that of the atomic bomb dropped on Hiroshima.



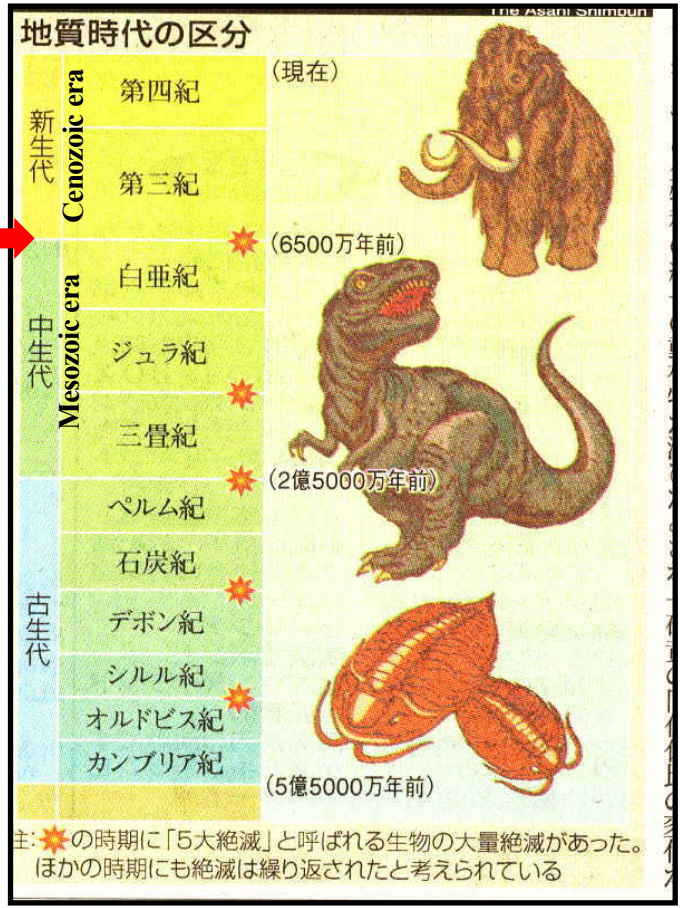


Damaged area
compared to Tokyo area in Japan

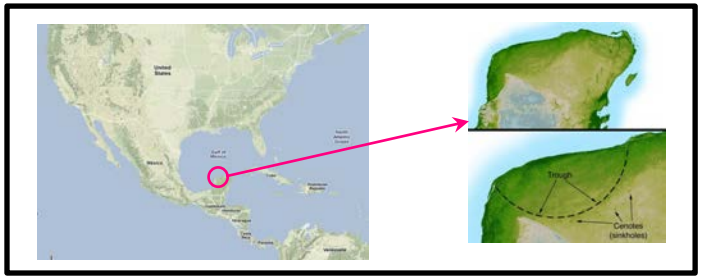
Now

Mass Extinction 66 Million Yeas Ago

- About 66 million years ago, dinosaurs and many other species became extinct.
- The geological age changed from the Mesozoic（中生代） to the Cenozoic（新生代）.
- This may have caused by an impact of an asteroid with a size of 10 km.
- The impact place was Yucatan Peninsula.



（Asahi Shimbun 2001.10.31）



Chicxulub craterin in Yucatan Peninsula (diameter 180km, 66 million years ago)

（from Wikipedia）

Impact of celestial bodies to the Earth

If a celestial body such as an asteroid or a comet collides with the Earth, a large natural disaster will occur.

■15 Feb. 2013 : Cheryabinsk meteorite in Russia

■30 June 1908 : Tsunguska event in Russia

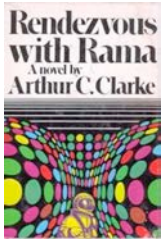
■ about 66 million years ago : Mass extinction

We want to prevent such disasters in advance.

⇒ Planetary defense (Spaceguard)

What is the planetary defense?

- Activities dealing with the problem of asteroids and comets colliding with the Earth.
- At first it was called **"Spaceguard"**.
- It is not good to be sensational, but scientific and technological approach is necessary to this “ultimate natural disaster”.
- Many activities were started from 1990's.
- In Japan, Japan Spaceguard Association (JSGA) was established in 1996 by the late Prof. Syuzo Isobe in National Astronomical Observatory.
- Bisei Spaceguard Center (BSGC) was constructed in Okayama prefecture in Japan in 2000, and observations of space debris and asteroids were started.
- From around 2000, discussions began at the United Nations, and the international activity called **"Planetary Defense"** was started.



The term "Spaceguard" was first used in Arthur C. Clarke's "Rendezvous with Rama".

JSGA
BATTeRS
The Bisei Asteroid Tracking Telescopes for Rapid Survey
日本スペースガード協会

The logo of the observation team of the Japan Spaceguard Association

What we should do for planetary defense

Step 1

Discover NEOs

⇩

Follow-up observations for precise orbit determination

⇩

Check of Earth collision by orbit calculations

Investigate the physical characteristics of NEOs

NEO : Near Earth Object → see next page
地球接近天体

Step 2

Avoid collision or Minimize damage

Evacuate from the region where NEO collides

keep people from panicking

Make international law / international coordination

What is NEO?

NEO = Near Earth Object

Definition :

Asteroids and comets whose perihelion distance is less than 1.3 au

||

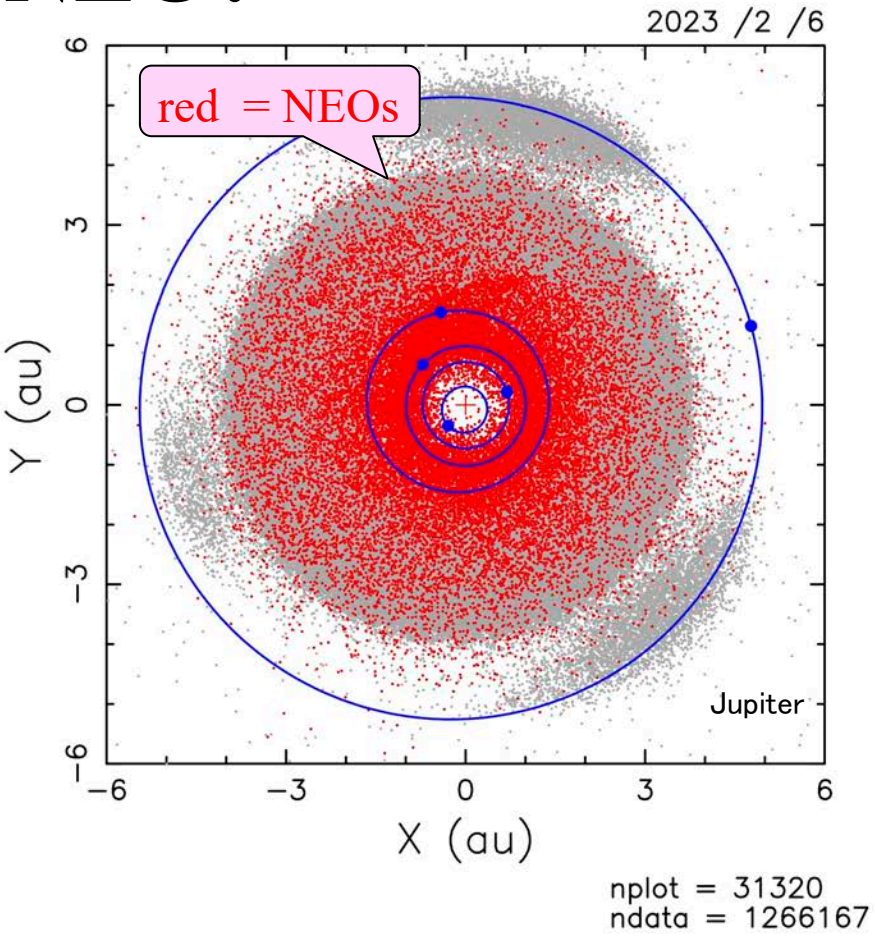
Such objects have the probability to collide with the Earth

PHO = Potentially Hazardous Object

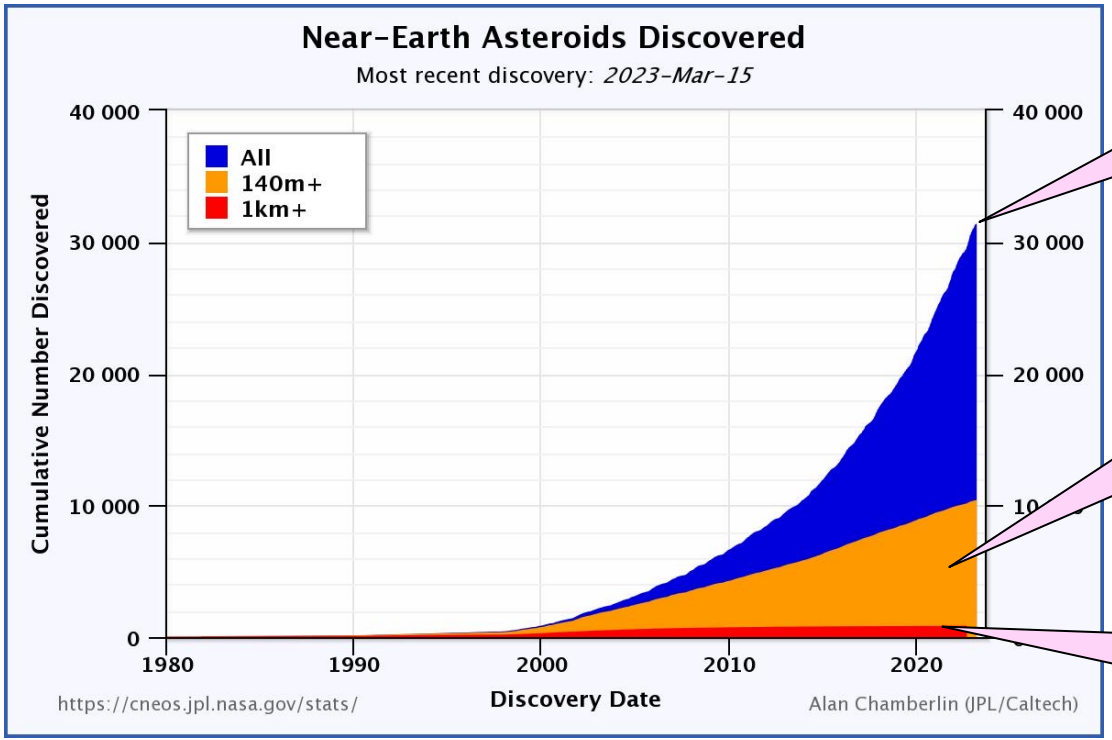
Definition :

Asteroids and comets whose
MOID is less than 0.05 au
absolute magnitude is 22 or brighter

※MOID = minimum orbit intersection distance



Current status of near-Earth asteroid discovery



Total number of NEO ～ 30,000

NEO lager than 140 m :
About 40% were discovered.

NEO lager than 1 km :
About 90% were discovered.

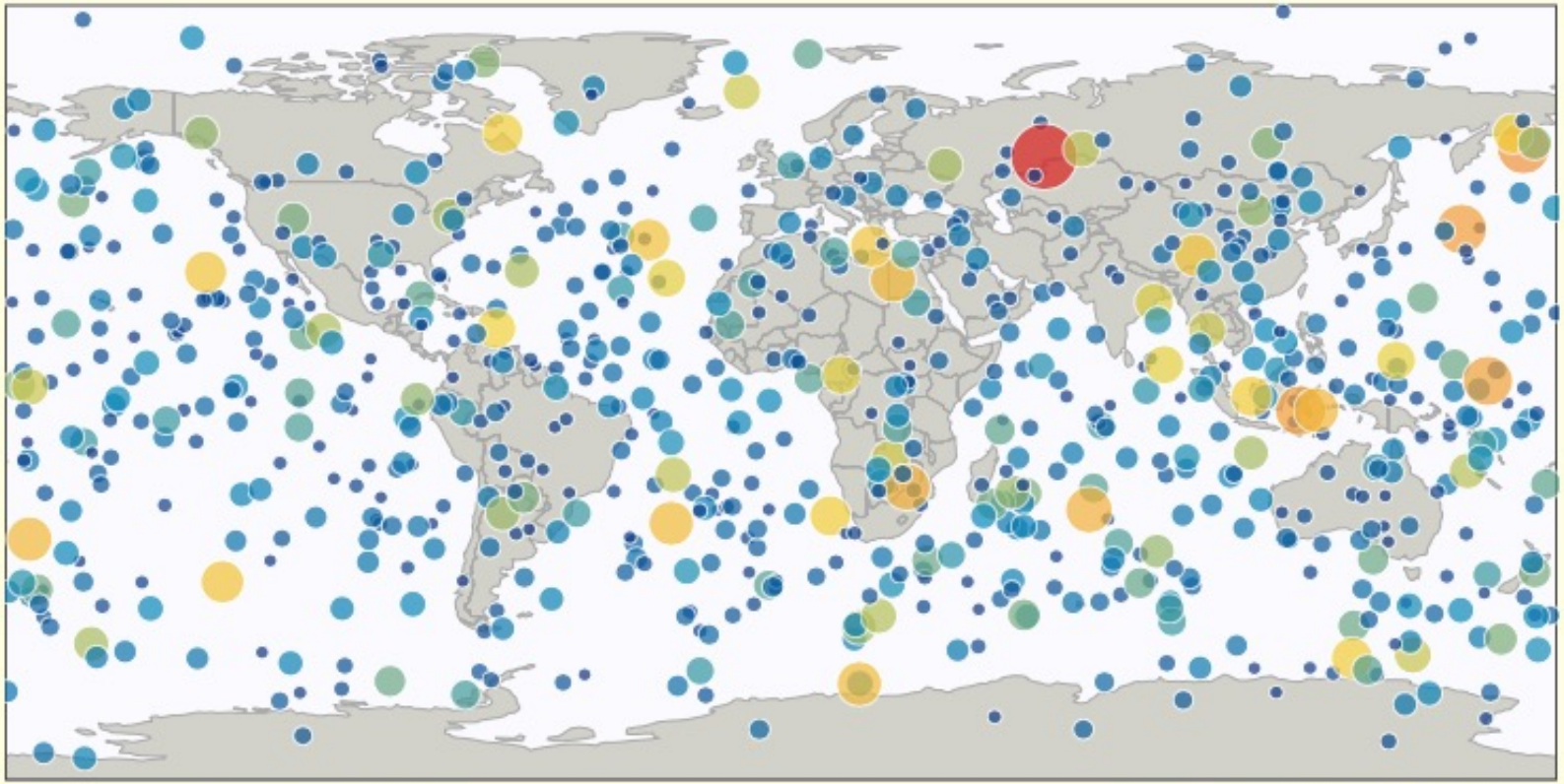
JPL : The Center for Near-Earth Object Studies (CNEOS)
https://cneos.jpl.nasa.gov/stats/totals.html

Asteroids discovered before colliding with the Earth

Case	Object	Size (m)	entry speed (km/s)	Discovery time Collision time	time from discovery to collision (h)	Impact place	discoverer
1	2008 TC3	～4	12.8	6 Oct. 2008, 06:39 UTC 7 Oct. 2008, 02:46 UTC	～20	northern Sudan	Catalina Sky Survey
2	2014 AA	2～4	11.7	1 Jan. 2014, 06:18 UTC 2 Jan. 2014, 01～04?	～21?	Atlantic Ocean	Catalina Sky Survey
3	2018 LA	2～4	17	2 June 2018, 08:22 UTC 2 June 2018, 16:44 UTC	～8	the border of Botswana and South Africa	Catalina Sky Survey
4	2019 MO	～3	16.1	22 June 2019 22 June 2019, 21:25 UTC	～12	the south coast of Puerto Rico	ATLAS
5	2022 EB5	～2	18	11 Mar. 2022 11 Mar. 2022, 21:22 UTC	～2	the Arctic Ocean southwest of the Norwegian island Jan Mayen	Konkoly Observatory's Piszkéstető Station
6	2022 WJ1	～1		19 Nov. 2022, 04:53 UTC 19 Nov. 2022, 08:27 UTC	～3.5	Brantford, Ontario, Canada	Arizona, USA Mt. Lemmon Survey

Fireballs Reported by US Government Sensors

(1988-Apr-15 to 2023-Feb-19)

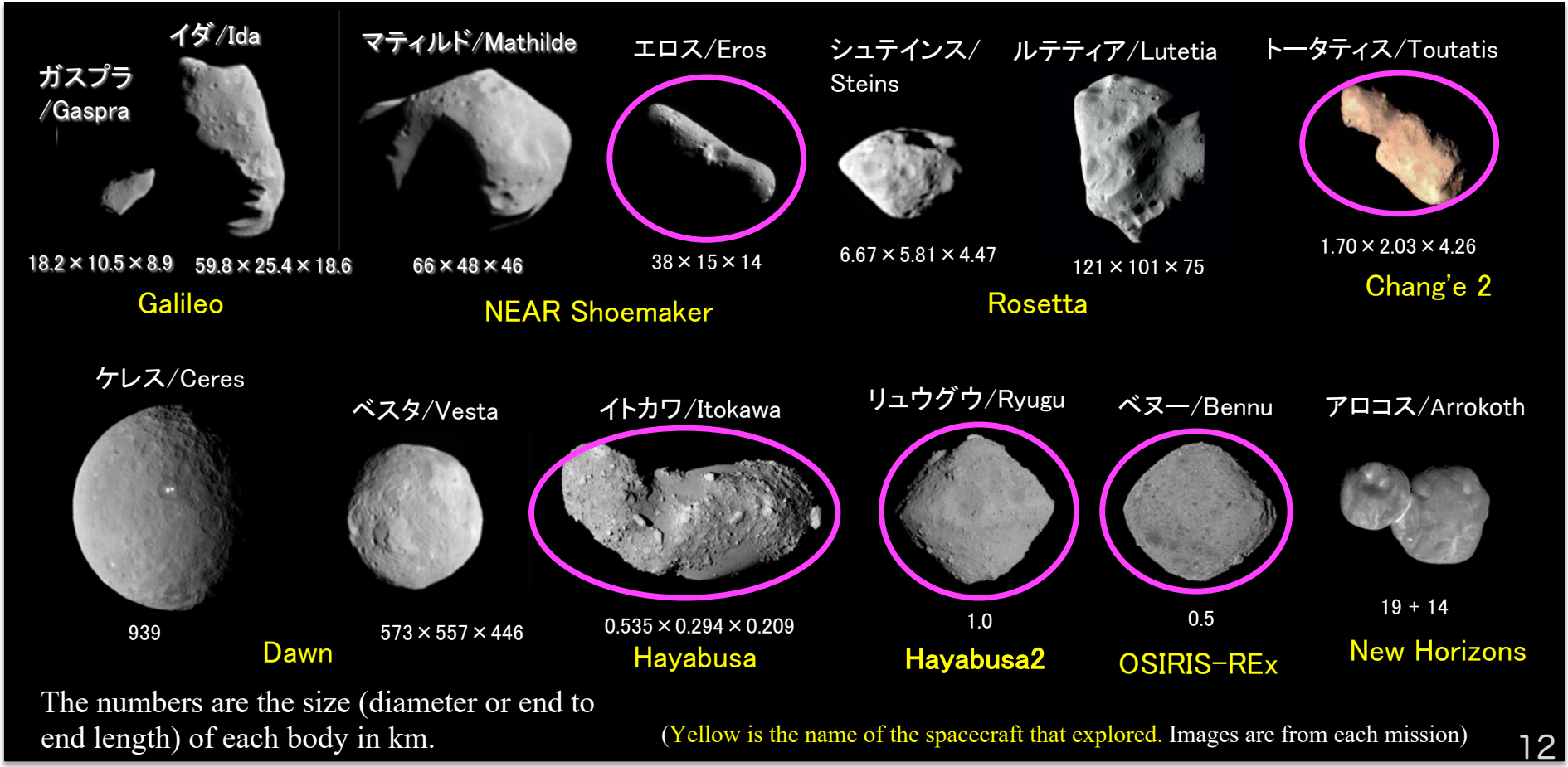


https://cneos.jpl.nasa.gov/fireballs/

Alan B. Chamberlin (JPL/Caltech)

Asteroids observed by spacecraft

NEO



The numbers are the size (diameter or end to end length) of each body in km.

(Yellow is the name of the spacecraft that explored. Images are from each mission)

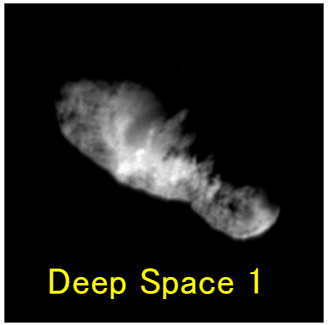
Comets observed by spacecraft

NEO

ハレー(ハリー)彗星/Halley

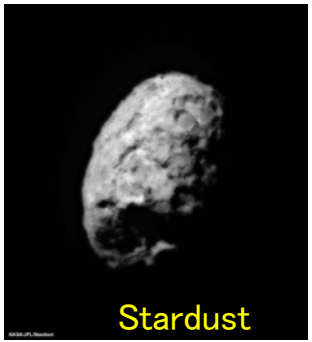
14.4 × 7.4 × 7.4

ボレリー彗星/Borrelly



4.0 × 1.58

ビルト第2彗星/Wild 2

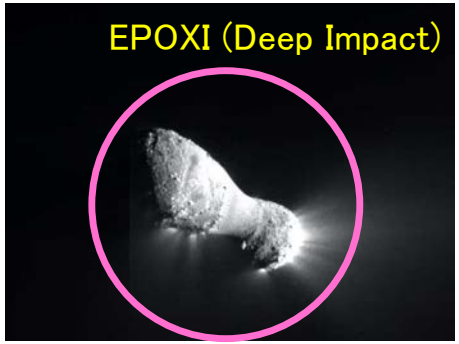


5.4 × 3.8 × 3.0

テンペル第1彗星/Tempel 1

7.6 × 4.9

ハートレー第2彗星/Hartley 2



0.69 × 2.33

チュリュモフ・ゲラシメンコ彗星
/Churyumov-Gerasimenko

4.1 × 3.3 × 1.8 + 2.6 × 2.3 × 1.8

The numbers are the size of each body in km.

(Yellow is the name of the spacecraft that explored. Images are from each mission)

How to avoid collisions?

Destroying asteroids is not a good idea.

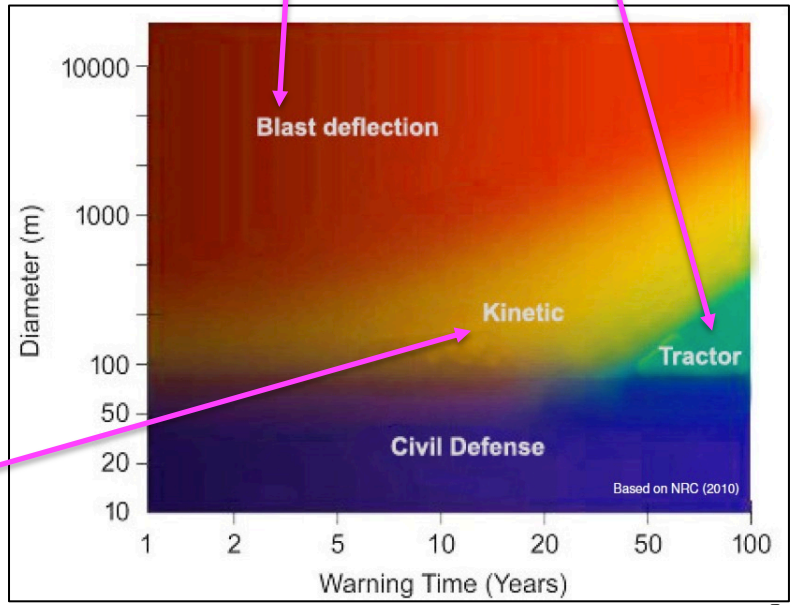
When an asteroid that will collide with the Earth is discovered, it is better to deflect the orbit.

How?

- Kinetic impactor
- Gravity tractor
- Blast deflection

DART & Hera

- Laser beam, Sun light
- Solar radiation pressure, thermal effect
- Mass driver, Rocket propulsion
- Asteroid capture, Asteroid eaters?
- ・・・

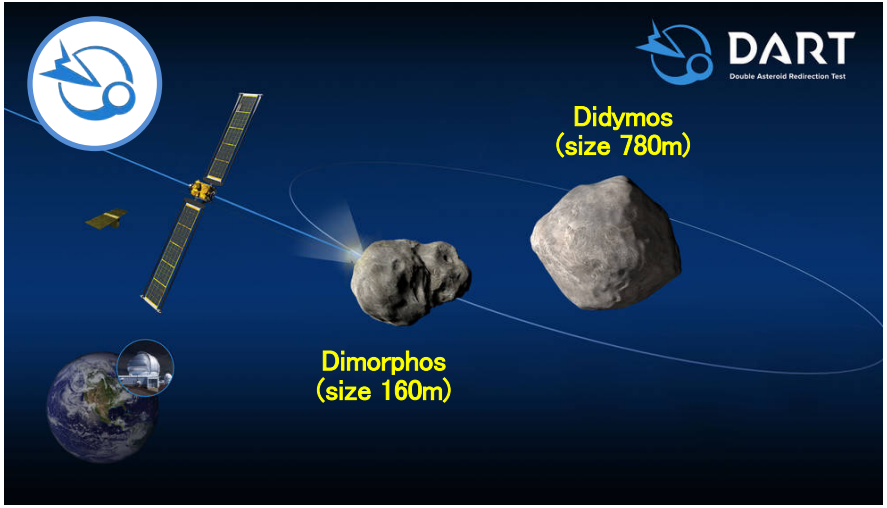


AIDA : DART＋ Hera

AIDA（Asteroid Impact ＆ Deflection Assessment)
DART: An experiment to change the orbit of an asteroid by colliding spacecraft to the asteroid
Hera ：Investigate the result of the impact by DART

★DART (Double-Asteroid Redirection Test) by NASA

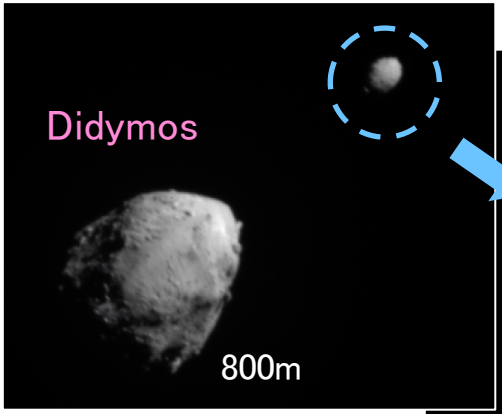
- Lunch : 24 Nov. 2021
- Impact : 26 Sept. 2022
- A DART spacecraft (about 600 kg) collides with Dimorphos at a speed of about 6 km/s to investigate orbital changes.

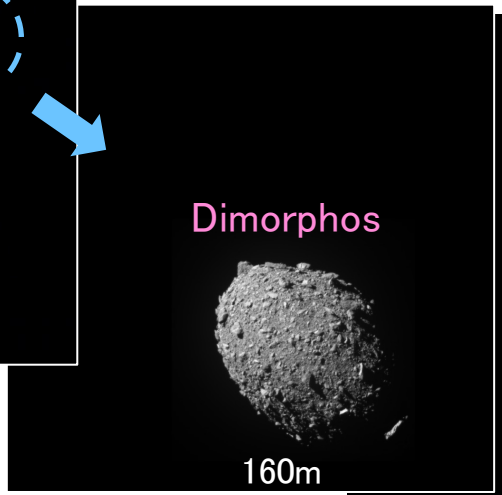


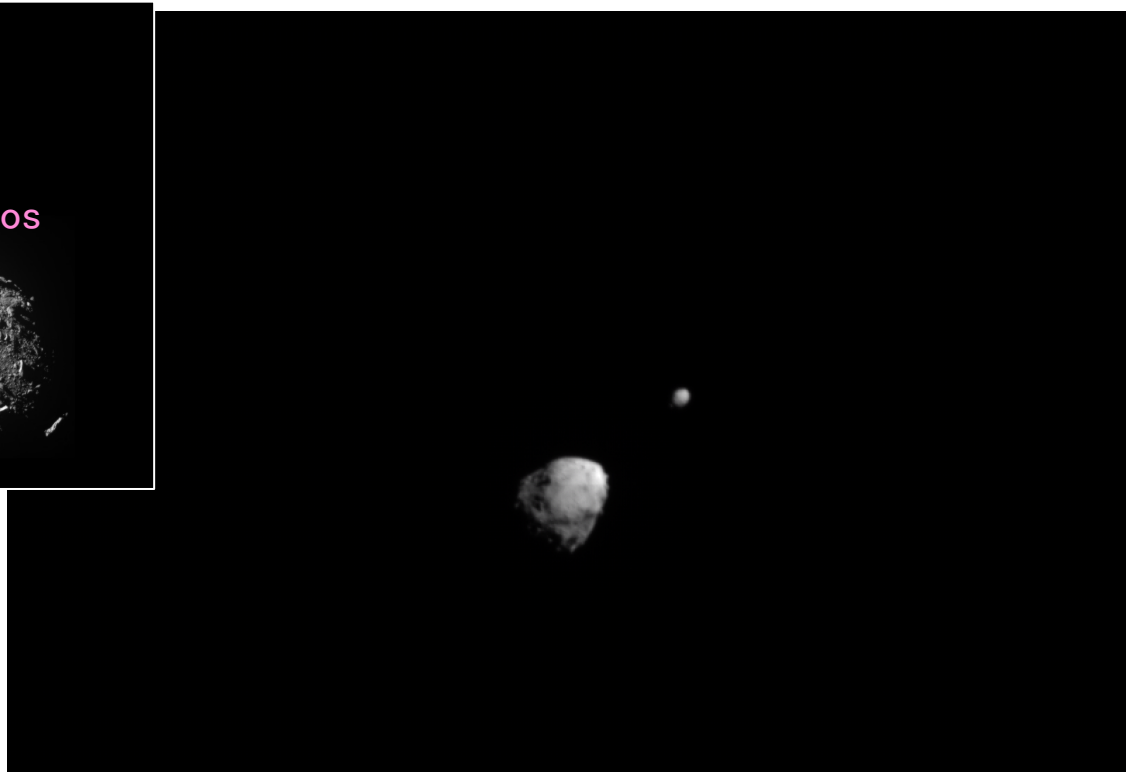
★AIM (Asteroid Impact Mission) → Hera by ESA

- Lunch : Oct. 2024
- Arrival : Jan. 2027
- A detailed exploration will be done for Didymos and Dimorphos.

The Results of DART







The orbital period of Dimorphos around Didymos was changed by the impact of the spacecraft.

Before : 11 hours 55 min
After : 11 hours 23 min → 32min shorter

https://dart.jhuapl.edu/Gallery/

JAXA's activities for planetary defense

Observations

- NEO observation at Bisei Spaceguard Center (BSGC)
- Discovery of high-speed moving objects by new NEO search technologies

Space Missions

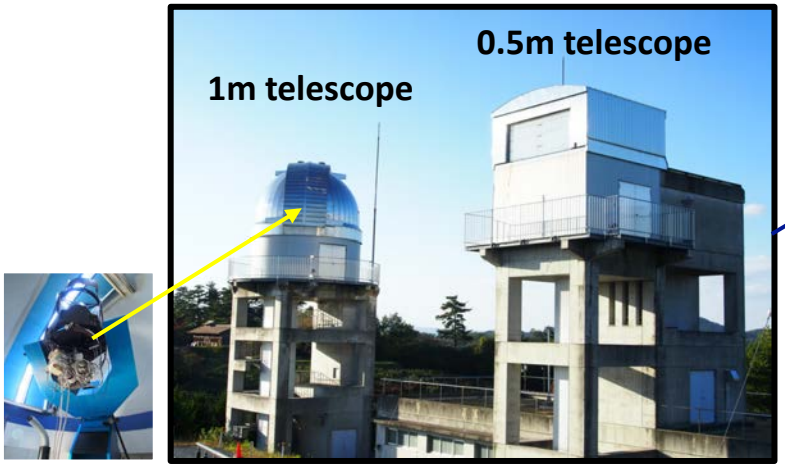
- Hayabusa, Hayabusa2, Hayabusa2 extended mission, DESTINY+
- Participation in ESA's Hera mission
- Initial study of Hayabusa2 : impactor mission → small impactor of Hayabusa2
- Study for NEO observation satellite

International activities

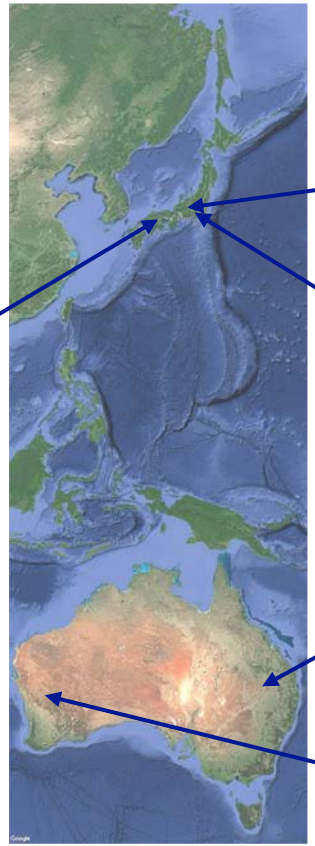
- SMPAG, IAWN, PDC, Asteroid Day

Asteroid observations in JAXA

Bisei Spacegurad Center (BSGC)
(Space Tracking and Communications Center)

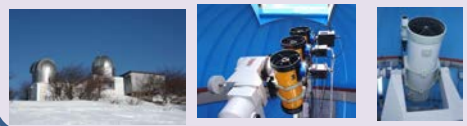


- Built in 2000 and owned by the Japan Space Forum, it was transferred to JAXA in April 2017.
- The observation work is carried out by the Japan Spaceguard Association (NPO).
- Observation targets: Space debris, NEO (asteroids)



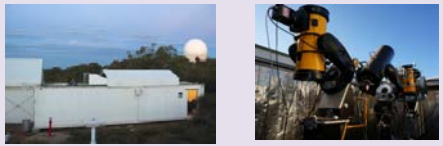
Observation facility of Research and Development Directorate

Mt.Nyukasa Observational facility



Chofu LEO Observational facility

Remote observation site at Siding Spring Observatory



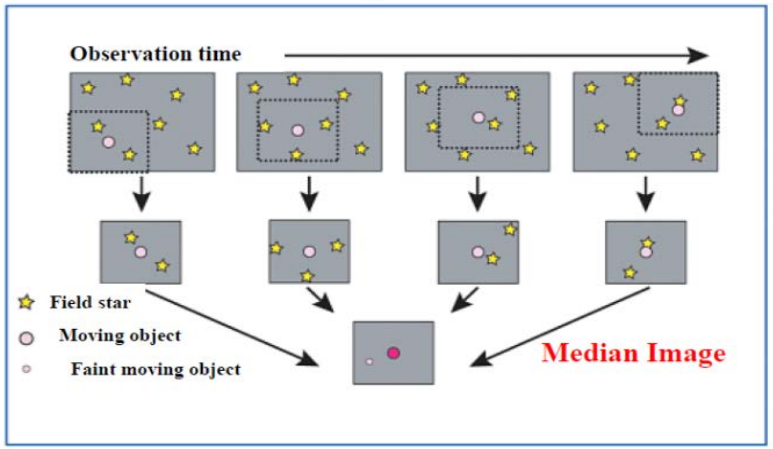
Remote observation site at Zadko Observatory

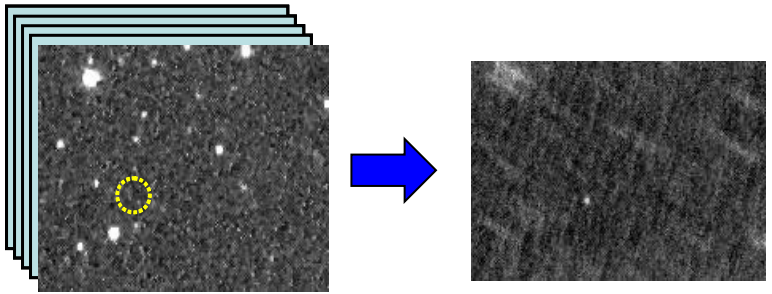
Discovery of high-speed moving objects by new NEO search technologies

To find faint fast moving objects, we use a stacking method.

The stacking method uses multiple CCD images to detect very faint NEOs that are undetectable on a single CCD image.

Concept of the stacking method





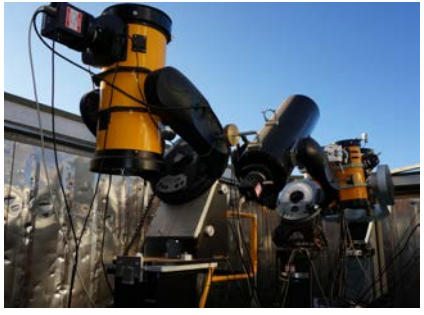
We assume various movements of the faint object and overlap the images to find faint objects.
The FPGA board was developed to reduce analysis time.

The FPGA board for the stacking method

(Image credit：JAXA)

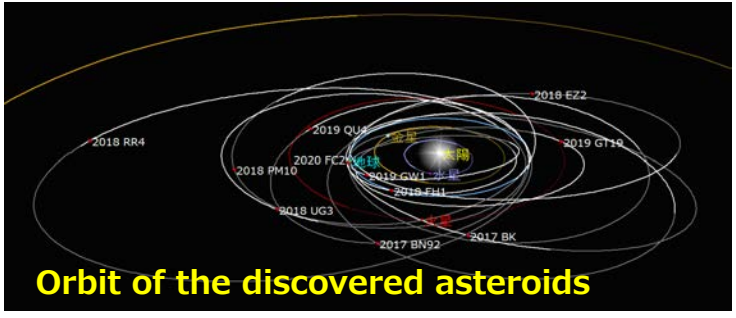
Discovered NEOs by the stacking method

Provisional designation	Discovery date & time (UTC)	Mag. at discovery	Orbit type	e	a (au)	i (deg)	Distance at discovery (au)	Abs. Mag.	Size(m)
2017 BK	2017.1.17 14:51	17.5	Apollo	0.489	1.909	6.6359	0.051	24.0	67
2017 BN92	2017.1.31 16:04	17.1	Apollo	0.483	1.921	1.0734	0.014	25.6	32
2018 EZ2	2018.3.12 10:06	18.2	Apollo	0.510	1.951	4.9718	0.01	26.6	20
2018 FH1	2018.3.18 12:36	18.7	Aten	0.177	0.938	3.5468	0.013	26.6	20
2018 PM10	2018.8.9 10:36	18.3	Amor	0.427	1.780	9.2065	0.001	27.0	17
2018 RR4	2018.9.11 12:21	18.0	Apollo	0.621	2.637	3.1793	0.015	27.1	16
2018 UG3	2018.10.31 12:51	19.4	Apollo	0.423	1.662	6.1673	0.03	24.5	53
2019 GW1	2019.4.4 11:36	17.5	Aten	0.114	0.934	13.2945	0.009	26.1	25
2019 GT19	2019.4.12 13:06	18.2	Apollo	0.370	1.273	7.7488	0.01	27.5	13
2019 QU4	2019.8.28 10:06	18.1	Apollo	0.332	1.426	10.1313	0.017	24.8	46
2020 FC2	2020.3.17 13:36	18.5	Apollo	0.398	1.644	6.8153	0.006	28.0	11



We used small telescopes like these. (18cm, 25cm)

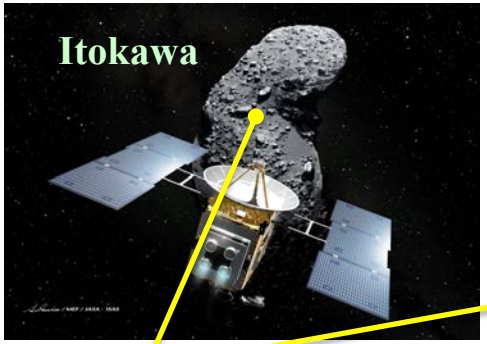
（Image credit：JAXA）



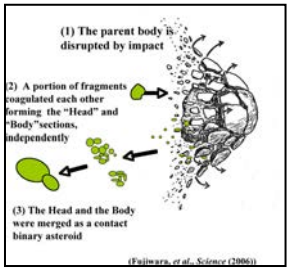
Orbit of the discovered asteroids

JAXA's Asteroid Missions

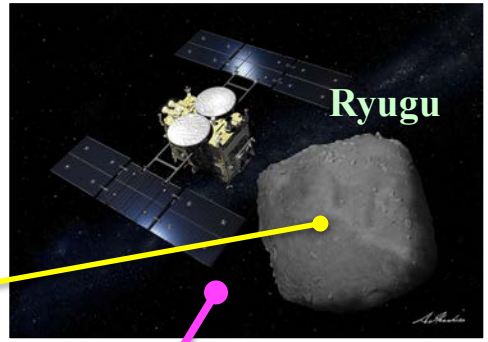
Hayabusa 2003-2010



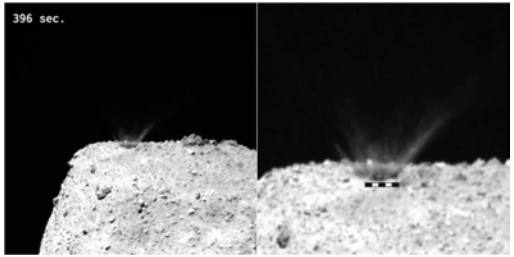
"Rubble Pile" structure



Hayabusa2 2014-2020



Impact crater



(Image credit：JAXA / A. Ikeshita)　©Arakawa et al., Science 2020

Hayabusa2 Extended mission
Hayabusa2#

Arrival in 2031

1998 KY26

30 m

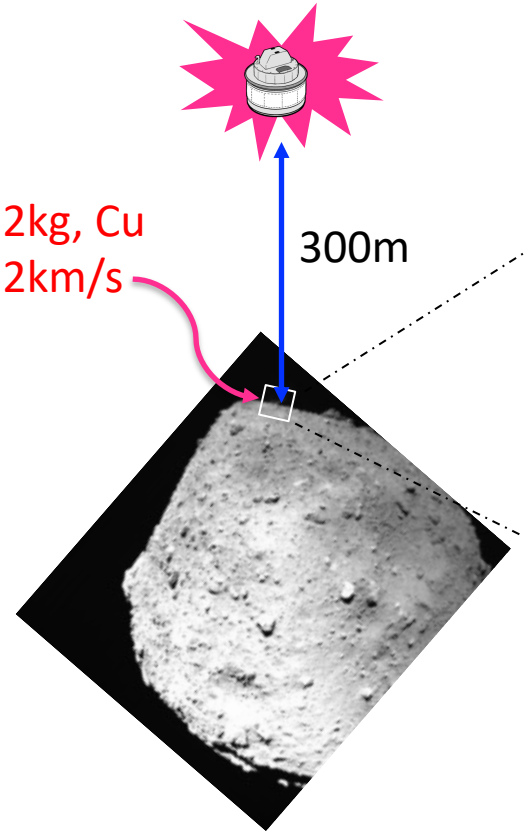
Future mission

DESTINY$^+$: Phaethon

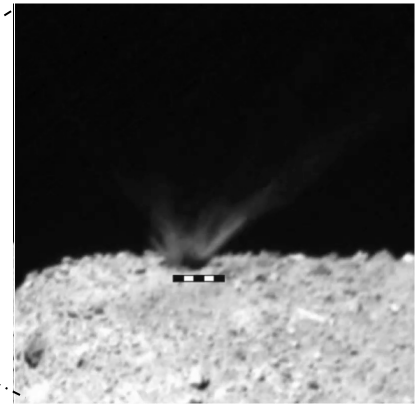
Launch 2024

Hayabusa3 ? ・・・

Impact experiment

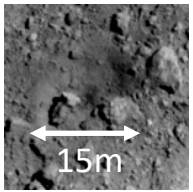


Ejecta from Ryugu

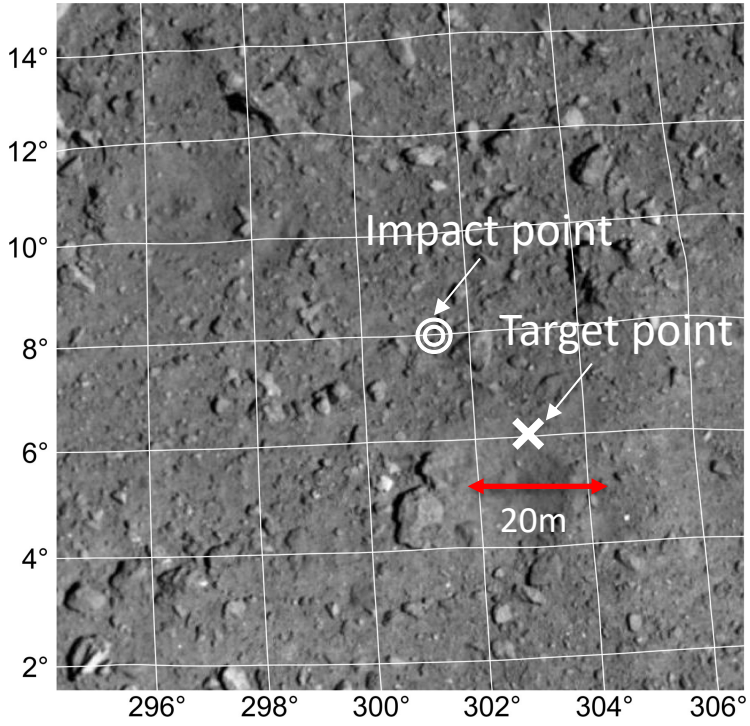


scale bar : 25m

©Arakawa et al., Science 2020



Impact point



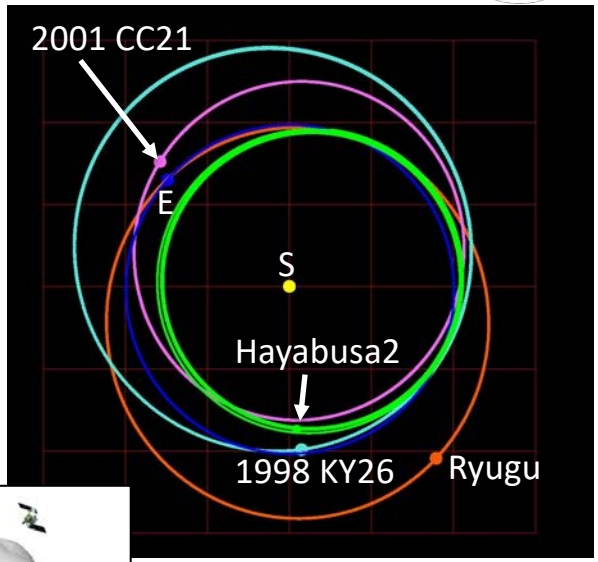
Error ~ 20m

(Image credit: JAXA, University of Tokyo, Kochi University, Rikkyo University, Nagoya University, Chiba Institute of Technology, Meiji University, University of Aizu, AIST)

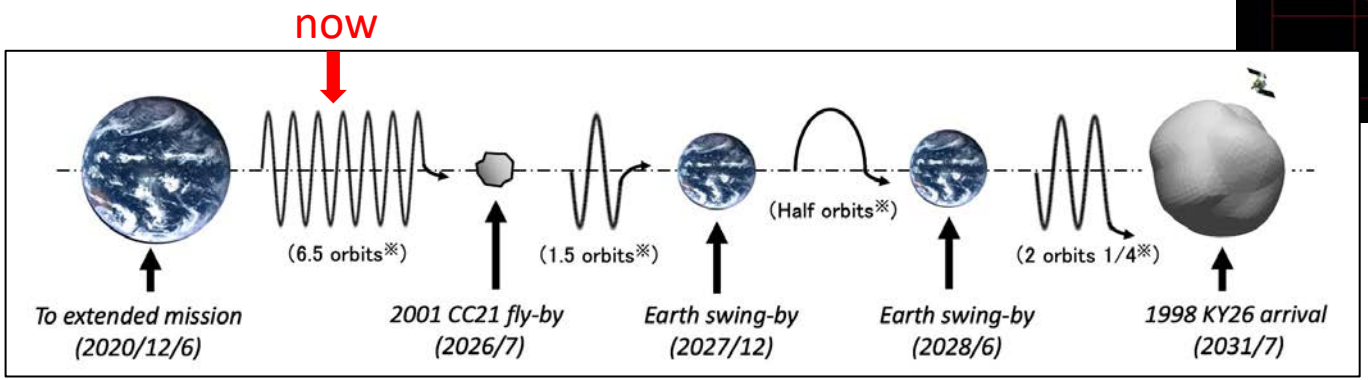
Hayabusa2 Extended mission : Hayabusa2#

 # (SHARP) : Small **H**azardous **A**steroid **R**econnaissance **P**robe

- After returning to the Earth in December 2020, we continue to operate Hayabusa2. (After the main mission, the spacecraft dose not have major problems.)
- The next target is the fly-by of 2001 CC21 in July 2026.
- The final target is the rendezvous of 1998 Ky26 in July 2031.



Object positions on 8 Feb. 2023



※ indicates the number of orbits around the Sun.

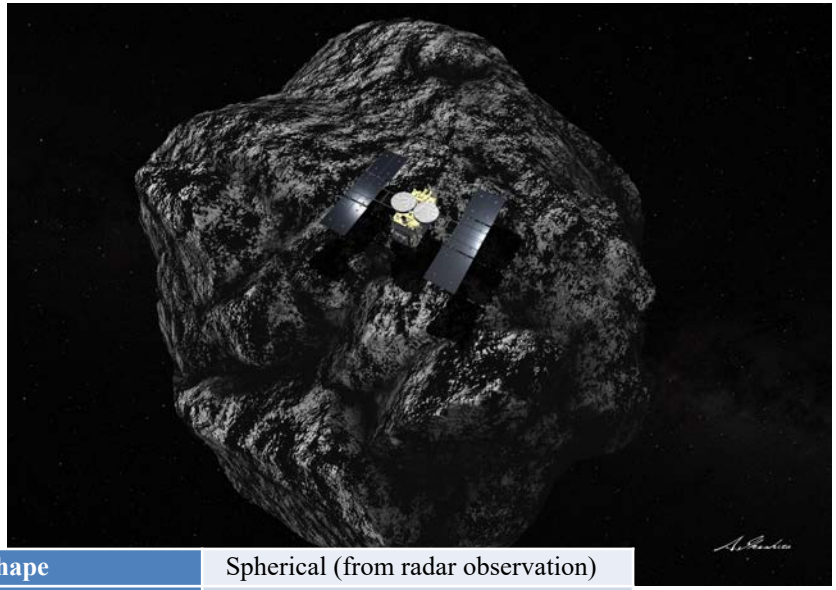
（Image credit：JAXA）

The target asteroids of Hayabusa2#

2001 CC21 artist's illustration

Shape	elongated?
diameter	700 m (albedo 0.15 assumed)
Spin period	5.017 hours
Spectral type	L type
Semimajor axis	1.03 au
Orbital period	1.05yr（383 day）

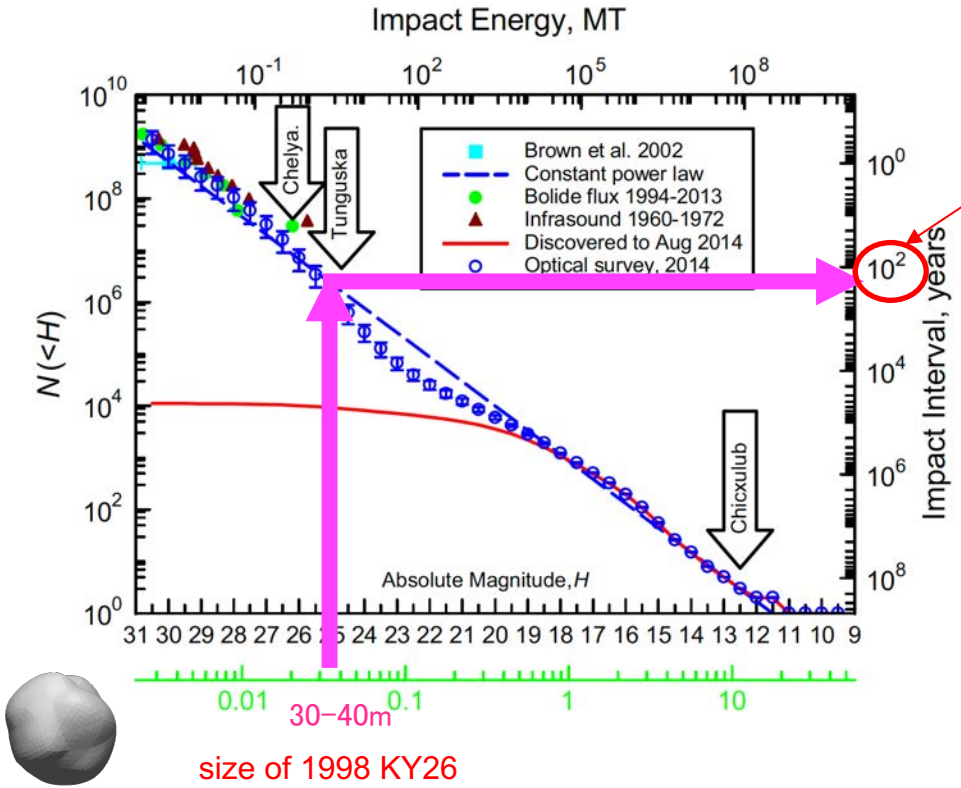
1998 KY26 artist's illustration



Shape	Spherical (from radar observation)
Av. diameter	About 30 m
Spin period	10.7 min (0.178 hr)
Tumbling motion	No short-term variability detected
Spectral type	Possible carbonaceous asteroid
Semimajor axis	1.23 au
Orbital period	1.37yr（500 day）

（Image credit：A. Ikeshita）

Prediction of asteroid collision frequency



A disaster once every 100 to 200 years!

1998 KY26 is exactly the type of asteroid that should be realistically consider the Earth collision.

(Modified from Harris and D'Abramo, Icarus 257 (2015) 302–312)

Initial study for Hayabusa2 : dual spacecraft mission

Launch

July 2014

Main spacecraft arrival

June 2018

This proposal was not accepted.

Sample analysis

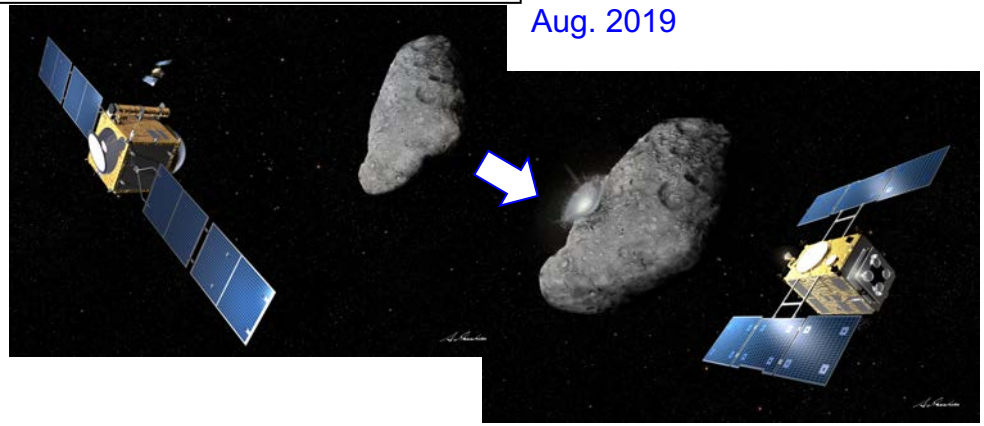
Earth return

Dec 2020

Dec. 2019

Impact spacecraft arrival

Aug. 2019



Study for NEO observation satellite

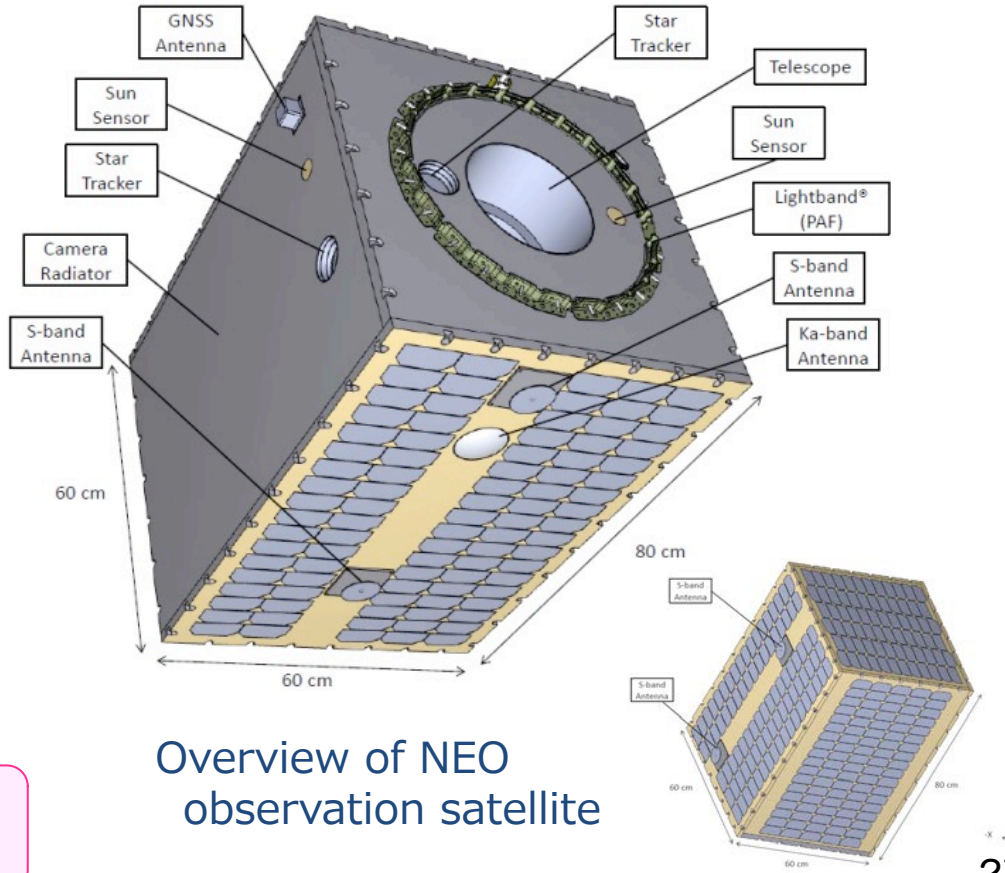
Satellite
Size : 60×60×80㎝
Mass : 65kg

Orbit:
Sun synchronous orbit (650km Alt.)

Sensor : CMOS (-80℃)
Telescope : 20cm
Communication : Ka
Data : 30Gbyte/day

Cost : 1.3 × 10^9 yen ～ $ 10 × 10^6

Not approved in the internal review



Overview of NEO observation satellite

International activities

United Nations

COPUOS/UNOOSA

IAWN ：International Asteroid Warning Network

SMPAG：Space Mission Planning Advisory Group

JAXA was participated as an observer.

JAXA is one of the members.

International conference

PDC：Planetary Defense Conference

JAXA hosted PDC in Tokyo 2017.

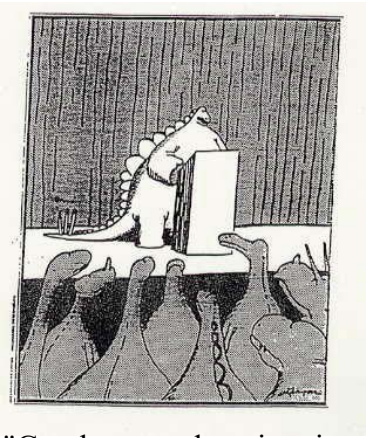
International outreach

JAXA is cooperating with the events both in Japan and abroad.

Summary up to now

about 20 yeas ago

Crisis management as humanity



"Gentlemen, the situation is critical...the climate has changed, mammals are pressing us, and we have a too little brain for these big problems" (1993)

The SGF - ACM'96 - July 8, 1996

Asahi Shimbun editorial Nov. 24, 1999

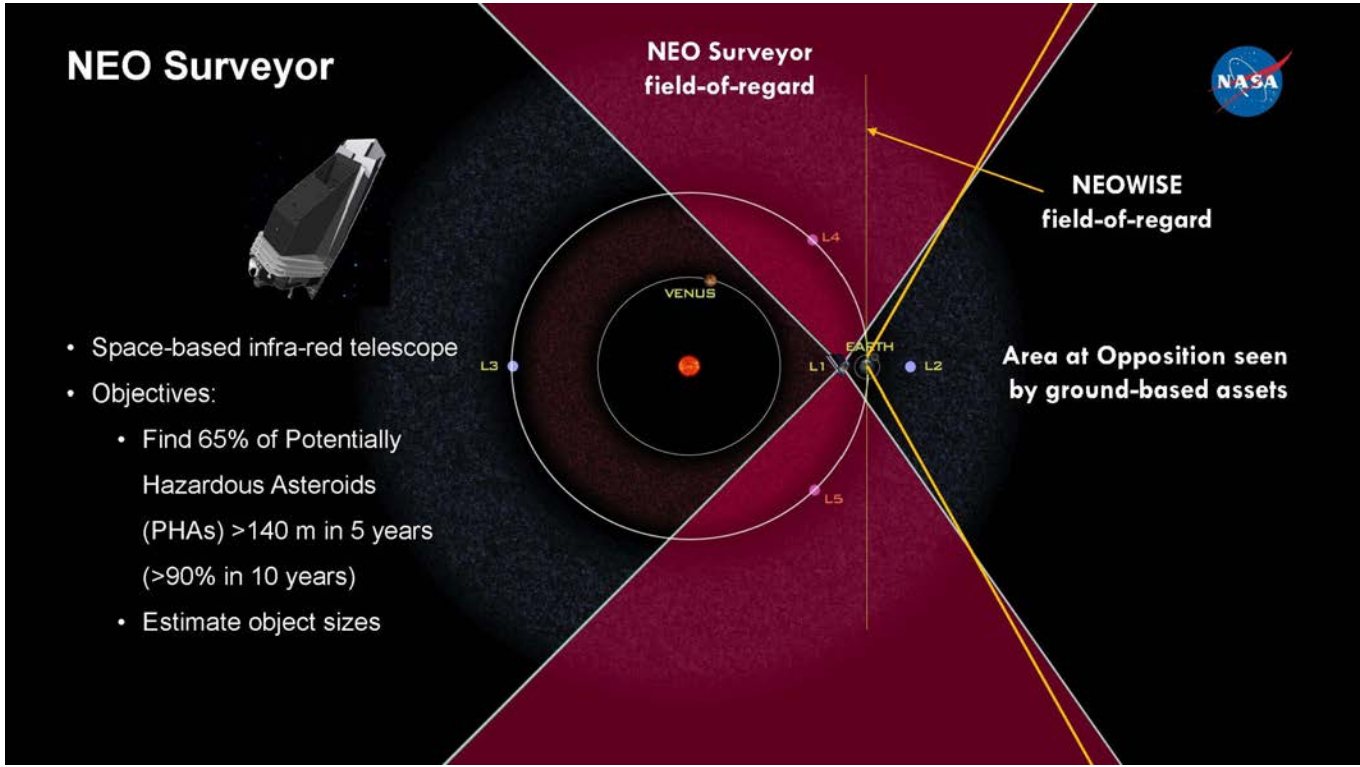
Now(2023)

- ■Increase in the number of NEOs discovered:
  a few hundred → about 30,000
- ■Progress in NEO exploration : 10 NEOs
- ■Progress in scientific research
- ■Impact experiment to change the orbit of asteroids
- ■Increasing awareness of planetary defense

What next?

NASA : NEO Surveyor

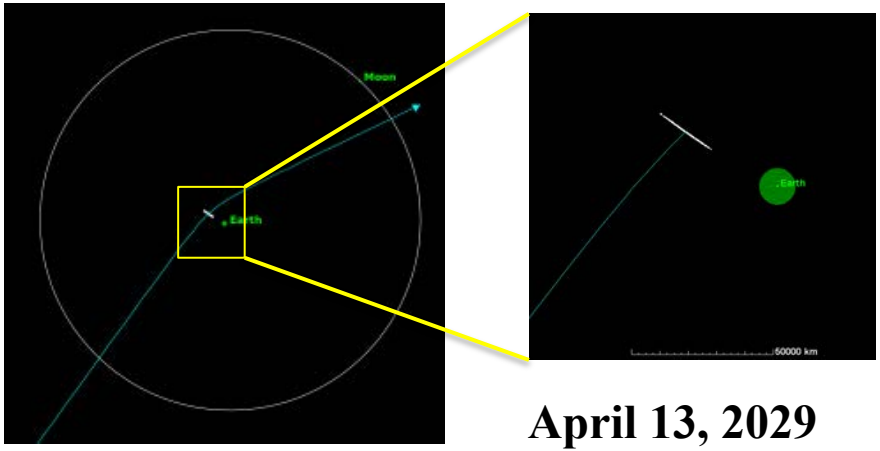
- Observe NEOs from space
- 50cm infrared telescope
- Discover 2/3 NEOs larger than 140m in 5 years
- Discover 90% NEOs in 10-12 years



by Lindley Johnson (NASA)

(99942) Apophis

- Apophis will pass about 30,000 km above the surface of the Earth on April 13, 2029.
- The size is about 350m.



April 13, 2029

Explorations of Apophis

- OSIRIS-REx (Asteroid sample return mission of NASA)
  - return to the Earth on 24 Sept. 2023
  - then extend the mission and rendezvous with Apophis (after the approach to the Earth)

- Some other missions are under discussions

2023 DW, 2023 DZ2 ・・・

2023 DW

- Discovery : 26 Feb. 2023
- On 28 Feb. 2023 : The collision probability on 14 Feb. 2046 was calculated as about 0.1%.
- The size is about 50m.
- On 16 March 2023 : The estimated collision probability has decreased to 0.03%.

2023 DZ2

- Discovery : 27 Feb. 2023
- It will pass about 174,000 km from the Earth on 25 March 2023.
- The size is about 50～110m.

Importance of Small Solar System Bodies

Science

To study the origin and evolution of the solar system and life

Planetary defense

To protect the Earth from collisions of the small solar system bodies

Resource

To utilize the mineral, metal, water, and etc.

Manned mission

To be the target of manned mission before manned mission to Mars

Engineering

To develop new technology for the exploration of the solar system

Culture

To create new culture and educate new generation