

Virtual Observatory and Citizen Science as ingredients for asteroid data mining and surface characterization.

Enrique Solano, Benoit Carry



CENTRO DE ASTROBIOLOGÍA
ASOCIADO AL NASA ASTROBIOLOGY INSTITUTE



GOBIERNO
DE ESPAÑA



CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS



Instituto Nacional de
Técnica Aeroespacial



A few words about the VO...

- **Goal:** Easy and efficient access and analysis of the information hosted in astronomical archives.



... and also about the SVO

<http://svo.cab.inta-csic.es>

 Spanish Virtual Observatory

Home SVO-LAEFF Help Desk User Menu



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The SVO



The Spanish Virtual Observatory (SVO) officially started in June 2004. Its purpose is to coordinate the VO activities at national level and act as a contact point for the other VO initiatives. The SVO core team is hosted at Centro de Astrobiología (INTA-CSIC).

- SVO participants
- VO FAQs

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The CAB Scientific Data Centre

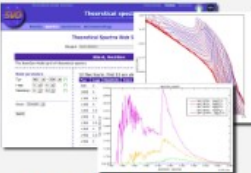


- Calar Alto
- DUNES
- GASPS
- GTC
- OMC
- X-exoplanets
- CMC-15
- Mark-I
- Census of astronomical Data Centres in Spain
- COROT
- DSS-63
- GAUDI
- INES
- Protostars
- ALHAMBRA
- Joan Oró
- Publishing data in the VO

[Edit](#)

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Theoretical Data Server

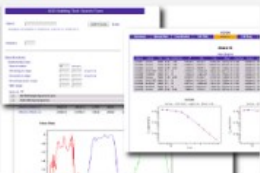


- Stellar Spectra theoretical models
- Evolutionary Synthesis Models
- Observational templates
- Synthetic Photometry
- Asteroseismology

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Services



- VOSA
- VOSED
- TESELA
- Filter Profile Service

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VO Science

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Data Mining

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Education & Outreach

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Miscellanea

Outreach... Fine, but what to do?



NEAs: Near-Earth Asteroids.

NEAs and the general public



NEAs and the general public



NATIONAL AERONAUTICS
AND SPACE ADMINISTRATION

+ View the NASA Portal



Near Earth Object Program

Object	Close-Approach (CA) Date ▾ (TDB)	CA Distance Nominal (LD/AU)
	YYYY-mm-DD HH:MM ± D_HH:MM	
(2016 EV27)	2016-Apr-06 19:20 ± < 00:01	14.99/0.03851
(2016 EF85)	2016-Apr-08 22:41 ± < 00:01	33.28/0.08552
(2016 FV6)	2016-Apr-10 09:05 ± 00:50	19.56/0.05026
(2016 ED158)	2016-Apr-10 12:40 ± < 00:01	28.82/0.07405
(2016 EH157)	2016-Apr-10 16:00 ± < 00:01	26.61/0.06837
406952 (2009 KJ)	2016-Apr-10 18:46 ± < 00:01	37.69/0.09684
363599 (2004 FG11)	2016-Apr-11 16:39 ± < 00:01	19.29/0.04956
(2009 BC11)	2016-Apr-11 19:04 ± 00:01	31.52/0.08098
(2005 GR33)	2016-Apr-13 03:28 ± < 00:01	7.73/0.01985
(2016 EK27)	2016-Apr-13 23:01 ± < 00:01	22.05/0.05667
(2008 HU4)	2016-Apr-16 10:00 ± 06:36	4.93/0.01267

NEAs and the general public

A Near-Earth Asteroid Census

Each image represents 100 objects

Known Asteroids ●
New Predicted Total (WISE) ○
Old Predicted Total (pre-WISE) ○



NEAs and the data centre

Search by Target:

Object List:

Examples (coordinates in J2000):

64.99061 52.98401

4 19 57.75 +52 59 02.436

4:19:57.75 +52:59:02.436

ULAS J135058.86+081506.8

Choose file No file chosen

Search radius:

arcmin

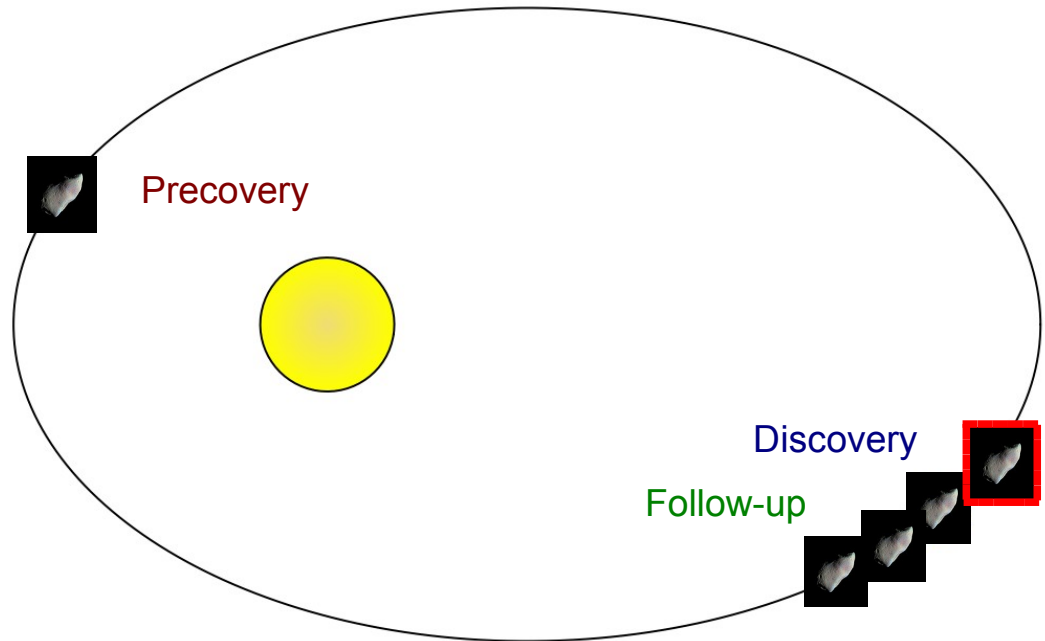
Search by Date:

Between:

March

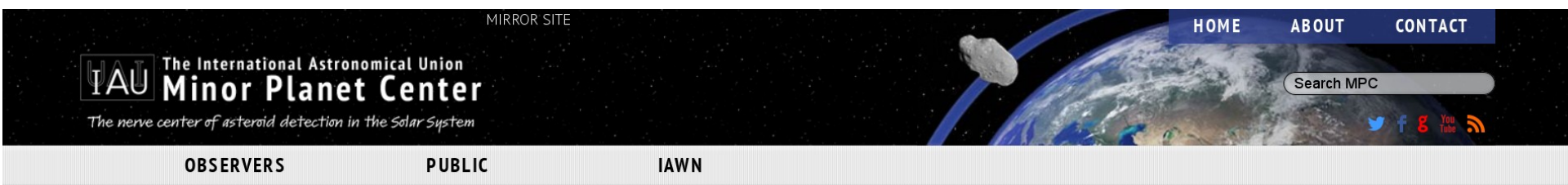
And:

January



Project's components

I. The list of NEAs



- [Processing \(Info\)](#)

List Of Apollo Minor Planets (by designation)

Information on [converting absolute magnitudes to diameters](#) is available, as is an [explanation of the quantities given in the listings below](#).

A list of [close approaches to the earth in the next 33 years](#) is available.

See a plot of the [innermost solar system](#) (or [the inner solar system](#))

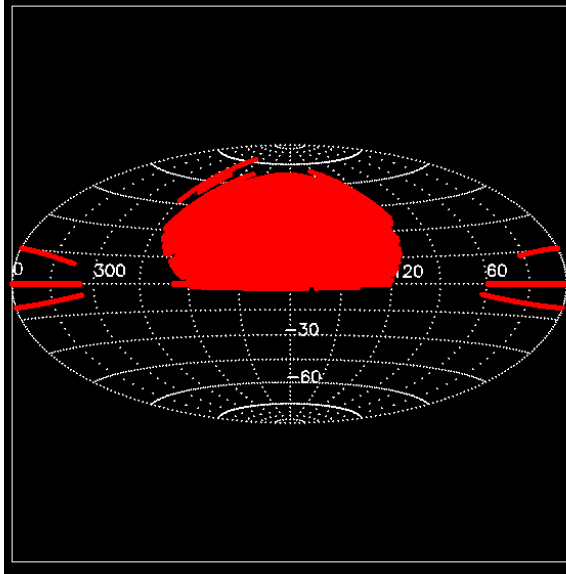
This list is updated daily and is also updated as and when new objects are discovered.

[Download a text version of the data.](#)

Designation (and name)	Prov. Des.	q	Q	EMoid	H	Epoch	M	Peri. Node	Incl.	e	a	Opps.	Ref.	Designation (and name)	Discovery date, site and discover
2016 FF13		0.990	3.853	0.04922	23.4	20160113	328.4	89.9 150.7	3.0	0.591	2.422	(2d)	E2016-G05	2016 FF13	2016 03 30 F51 Pan-STARRS 1
2016 FC13		0.988	1.528	0.03057	22.0	20160113	278.7	219.9 11.1	41.0	0.215	1.258	(2d)	E2016-G05	2016 FC13	2016 03 31 703 Catalina Sky St
2016 FB13		0.745	4.117	0.00218	26.4	20160113	328.0	10.3 251.3	0.1	0.694	2.431	(2d)	E2016-G05	2016 FB13	2016 03 30 W84 DECam
2016 FZ12		0.795	1.473	0.00545	26.7	20160113	356.4	106.6 349.3	1.9	0.299	1.134	(3d)	E2016-G05	2016 FZ12	2016 03 28 W84 DECam
2016 FV12		0.895	3.567	0.00406	26.3	20160113	321.6	47.2 207.6	6.4	0.599	2.231	(2d)	E2016-G05	2016 FV12	2016 03 29 W84 DECam
2016 FV12		0.643	2.614	0.01534	25.4	20160113	356.1	101.0 344.8	7.0	0.605	1.628	(3d)	E2016-G05	2016 FV12	2016 03 28 W84 DECam
2016 FU12		0.837	1.170	0.03964	26.9	20160113	34.6	193.9 228.7	2.1	0.166	1.003	(3d)	E2016-G05	2016 FU12	2016 03 28 W84 DECam
2016 FS12		0.905	3.067	0.06183	24.2	20160113	313.8	66.7 188.9	10.5	0.544	1.986	(3d)	E2016-G05	2016 FS12	2016 03 28 G96 Mt. Lemmon Surv

Project's components

II. The survey (SDSS DR8)







- Almost 10^6 images
- Coverage $> 14500 \text{ deg}^2$
- Multiwavelength info. (u,g,ri,z)
- Large FoV: 1.5 sq. deg.
- Deep limiting mag.: 22.0, 22.2, 22.2, 21.3 and 20.5.
- Observing sequence: 5.7m (five filters)

- Image Id.
- Mid-exposure time.
- RA,DEC of the image center.
- Image size.




Project's components

III. The ephemerides

NEODyS-2  Sponsored by   

Near Earth Objects - Dynamic Site

Home **Objects** Observatories Search Risk page NEA elements Related sites Info & Credits

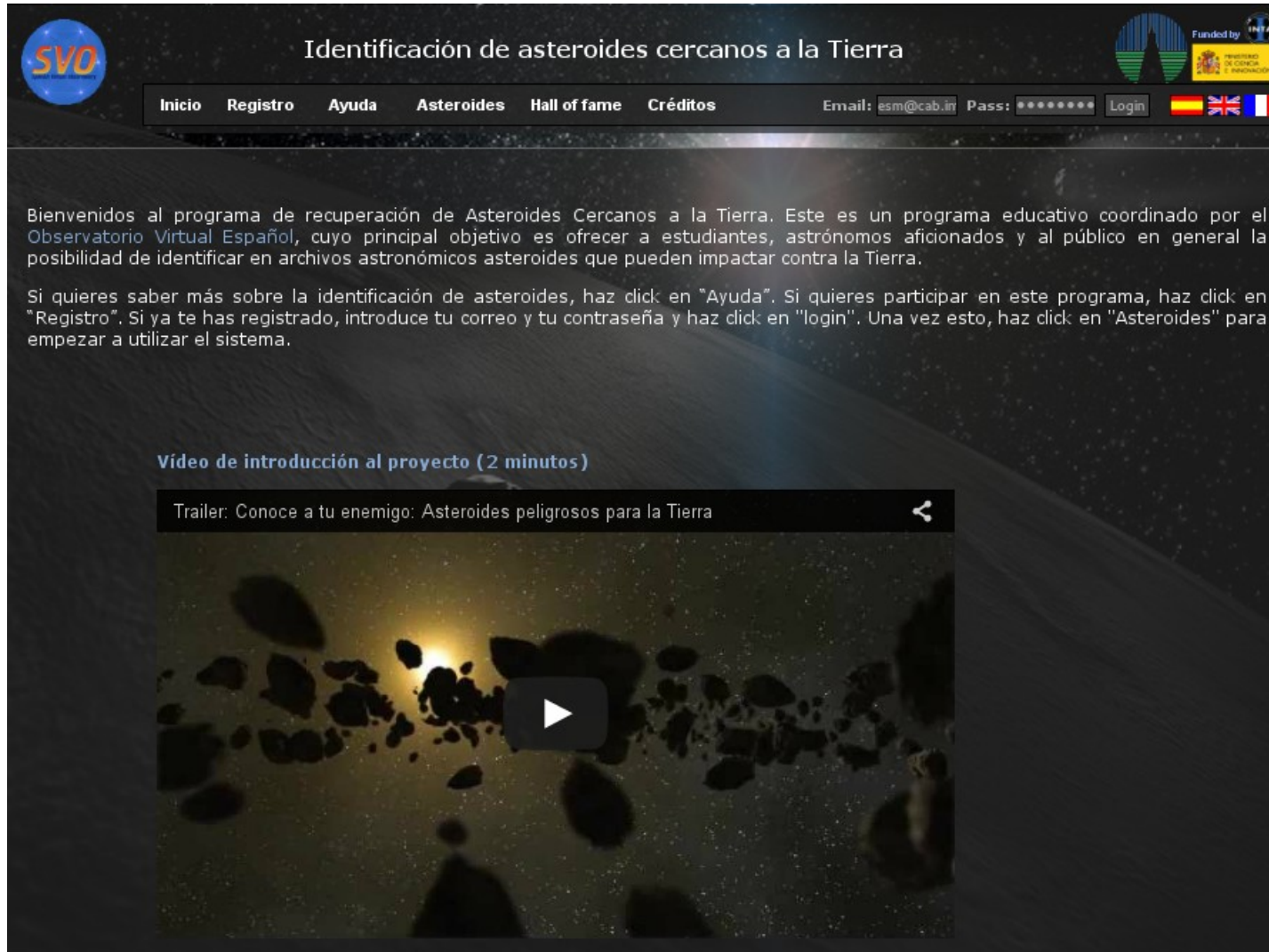
(433) Eros [EPHEMERIDES](#) [\[Help\]](#) 

[Download ASCII file](#)

		Equatorial coordinates													
Date	Hour	RA	DEC	Mag	Alt	Airmass	Sun	SoLEl	LunEl	Phase	Glat				
	(UTC)	h m s	d ' "		(deg)		elev.	(deg)	(deg)	(deg)	(deg)				
=====	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====				
6 Jul 2013	9.533	4 11 53.152	+28 34 13.76	13.8	0.0	INF	NaN	38.6	20.2	27.8	-16.4				
7 Jul 2013	9.533	4 15 29.441	+28 42 51.56	13.8	0.0	INF	NaN	38.8	30.4	28.0	-15.8				
8 Jul 2013	9.533	4 19 6.855	+28 51 10.78	13.8	0.0	INF	NaN	38.9	41.0	28.2	-15.1				
9 Jul 2013	9.533	4 22 45.379	+28 59 11.05	13.8	0.0	INF	NaN	39.0	51.8	28.3	-14.4				
10 Jul 2013	9.533	4 26 24.998	+29 6 52.00	13.8	0.0	INF	NaN	39.2	62.8	28.5	-13.8				
11 Jul 2013	9.533	4 30 5.698	+29 14 13.29	13.7	0.0	INF	NaN	39.3	73.9	28.7	-13.1				



Summary
Ephemerides
Obs prediction
Orbital info
MOID
Proper elements
Observational info
Close approaches




The citizen-science project



SVO

Identificación de asteroides cercanos a la Tierra


Funded by  

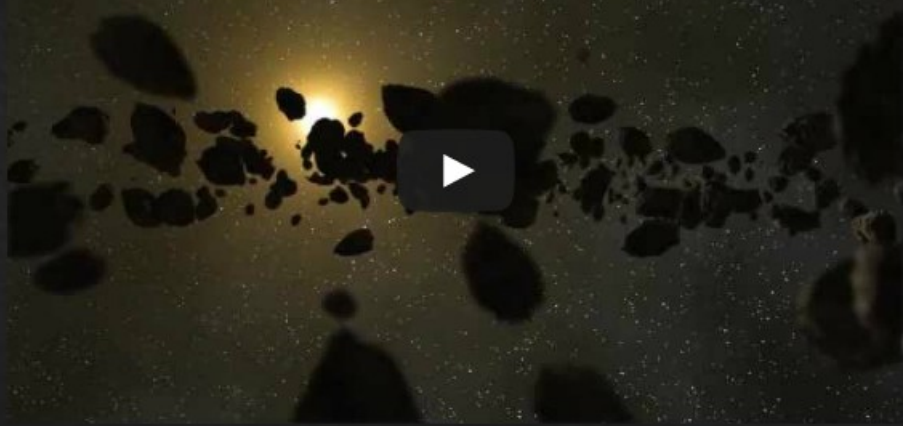
[Inicio](#) [Registro](#) [Ayuda](#) [Asteroides](#) [Hall of fame](#) [Créditos](#) Email: Pass: [Login](#)   

Bienvenidos al programa de recuperación de Asteroides Cercanos a la Tierra. Este es un programa educativo coordinado por el Observatorio Virtual Español, cuyo principal objetivo es ofrecer a estudiantes, astrónomos aficionados y al público en general la posibilidad de identificar en archivos astronómicos asteroides que pueden impactar contra la Tierra.

Si quieres saber más sobre la identificación de asteroides, haz click en "Ayuda". Si quieres participar en este programa, haz click en "Registro". Si ya te has registrado, introduce tu correo y tu contraseña y haz click en "login". Una vez esto, haz click en "Asteroides" para empezar a utilizar el sistema.

Vídeo de introducción al proyecto (2 minutos)

Trailer: Conoce a tu enemigo: Asteroides peligrosos para la Tierra 



<http://www.laeff.cab.inta-csic.es/projects/near>

The citizen-science project





Identificación de asteroides cercanos a la Tierra



Inicio Registro Resumen Ayuda Asteroides Astero-Dance Hall of fame Créditos SVO

Usuario

Enrique Solano  

Asteroides disponibles

(Mostrar Ayuda)

Hay 27 asteroides con detecciones potenciales

Por favor, elije uno para ver los detalles.

13 asteroides de tipo Amor (?)

142040 2006KL21	162196 2006QS	189973 2006QW89	1995SD1 2007HZ	1999EE5 2012MP	1999EE5	2000JA3	2006KF89
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12 asteroides de tipo Apolo (?)

143992 2003DN4	152964 2003WL25	153311 2004TB18	153814 2012LT7	154715	164184	177614	2002XC91
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2 asteroides de tipo Atón (?)

2007EP88	2008EE
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The citizen-science project





Identificación de asteroides cercanos a la Tierra



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Usuario

Enrique Solano  

2012MP

(Mostrar Ayuda)

Hay 1 conjunto de observaciones con detecciones potenciales de 2012MP

Banda	Posición esperada				Comprobación visual		
	MJD	RA	DEC	mag	RA/DEC	Estatus	Com
sdss_r	55153.15539669	355.61941	30.41233	21.75		-----	+
sdss_i	55153.15622596	355.61971	30.41202	21.75		-----	+
sdss_u	55153.15705522	355.62031	30.41139	21.75		-----	+
sdss_z	55153.157884901	355.62061	30.41108	21.75		-----	+
sdss_g	55153.15871375	355.62091	30.41077	21.75		-----	+

[Ver en Aladin](#)

(script)

[Guardar Datos](#)

The citizen-science project

The image displays a software interface for a citizen-science project, showing four panels of astronomical data in different SDSS filters: **sdss_r** (top-left), **sdss_i** (top-right), **sdss_z** (bottom-left), and **sdss_g** (bottom-right). Each panel shows a grayscale image of a star field with a central crosshair and a red crosshair. A scale bar in the bottom-left of each panel indicates $15''$ and a $1.406' \times 1.241'$ field of view. Orientation is indicated by 'E' (East) and 'N' (North) arrows.

The right side of the interface features a control panel with the following elements:

- Navigation Tools:** select, pan, zoom, dist, phot, draw, tag, filter, cross, xy, rgb, assoc.
- Drawing Layer:** A list of layers with checkboxes: **sdss_g**, **sdss_z**, **sdss_i**, and **sdss_r**. The **sdss_z** layer is currently selected.
- Adjustments:** sliders for size, opac, and zoom.
- Other Tools:** crop, cont, pixel, prop, del.

At the bottom right, a small thumbnail shows the entire field of view with a blue square indicating the current zoomed-in area, with dimensions $13.52' \times 9.827'$.

The citizen-science project

Potentially Hazardous Asteroids Precovery

Inicio Registro Ayuda Asteroides Hall of fame SVO Usuario Carlos Rodrigo

2005FE3
(Mostrar Ayuda)

Hay 1 conjunto de observaciones con detecciones potenciales de 2005FE3

Banda	Posición esperada				Comprobación visual	
	MJD	RA	DEC	mag	RA/DEC	Estatus
sdss_r	53389.52256453	175.43906	24.54815	20.96	175.43764 +24.54747	Confirmado
sdss_i	53389.5233938	175.43935	24.54833	20.96	175.43801 +24.54771	Confirmado
sdss_u	53389.52422306	175.43964	24.54852	20.96		Demasiado débil
sdss_g	53389.5258815901	175.4405	24.54908	20.96	175.43896 +24.54838	Confirmado

Ver en Aladin

Guardar Datos

©Spanish Virtual Observatory(Credits)

The citizen-science project

[SAO/NASA ADS](#) [Astronomy Abstract Service](#)

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- [Also-Read Articles \(Reads History\)](#)
- [Translate This Page](#)

Title: Minor Planet Observations [645 Apache Point--Sloan Digital Sky Survey]

Authors: [Ivezic, Z.](#); [Survey, S.](#); [Galvez Ranera, E.](#); [de Madrid, P.](#); [Solano, E.](#); [Bustabad Alonso, L.](#); [Car Cuadrado Garcia, J.](#); [de La Osa Lopez, J. M.](#); [Gil Rey, J.](#); [Gutierrez Bulnes, L.](#); [Izarra Cala, J.](#); [Pascual Gutierrez, J. I.](#); [Rodriguez Perez, D.](#); [Rodriguez Pumarada, C.](#); [Vazquez, J.](#); [Antoranz Muñoz Barros, F. D.](#); [Rojas Garcia, C.](#); [Romero Dueñas, J. L.](#); [Serrano Guinot, J. P.](#); [Tapiole Gomez Sanchez-Tirado, M. A.](#); [Leal, G.](#); [Sixto Perez, A. J.](#); [Valenzuela, J.](#); [Sala Puig, C.](#); [Baar](#)




Publication: Minor Planet Circular 75600, 1 (2011)

Publication Date: 08/2011




Origin: MPC

Bibliographic Code: [2011MPC..75600...1I](#)

Results: Users

 **Identificación de asteroides cercanos a la Tierra**  

[Inicio](#) [Registro](#) [Resumen](#) [Ayuda](#) [Asteroides](#) [Astero-Dance](#) [Hall of fame](#) [Créditos](#) [SVO](#)

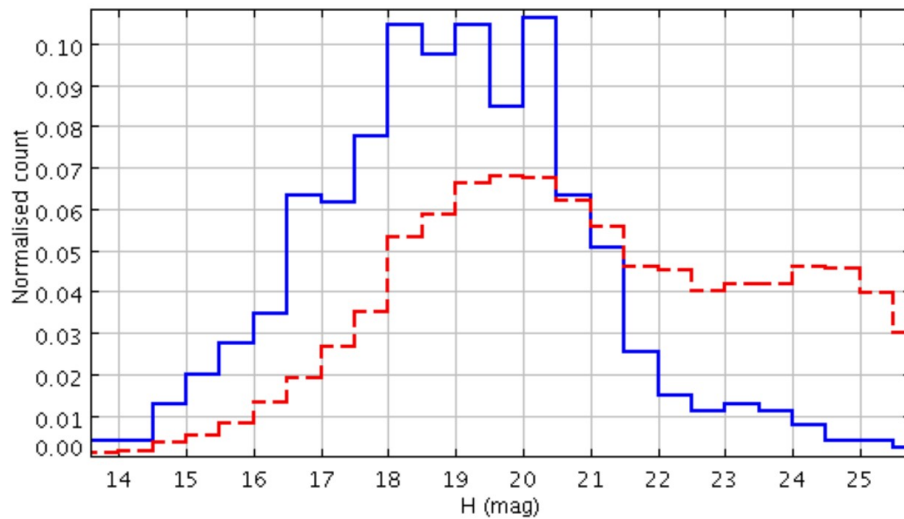
Usuario Enrique Solano   

Ver resumen hasta el - -

Número de usuarios registrados: **3788**

	all	mars	nea	sdss	vhs	vst	ukidss
Número de usuarios que han hecho medidas	560	260	529	528	67	59	129
Número de medidas realizadas	396155	184170	211971	377843	3749	1016	13533
Número de objetos comprobados	4107	2572	1534	3731	69	48	470
Número de parejas objeto/imagen distintas comprobadas	40518	26688	13829	38220	562	100	1635
Objetos para los que se han publicado medidas en el MPC	958	351	607	870	44	4	52
Número de medidas publicadas en el MPC	4417	1842	2575	3948	317	8	144

Results: Sizes & orbits



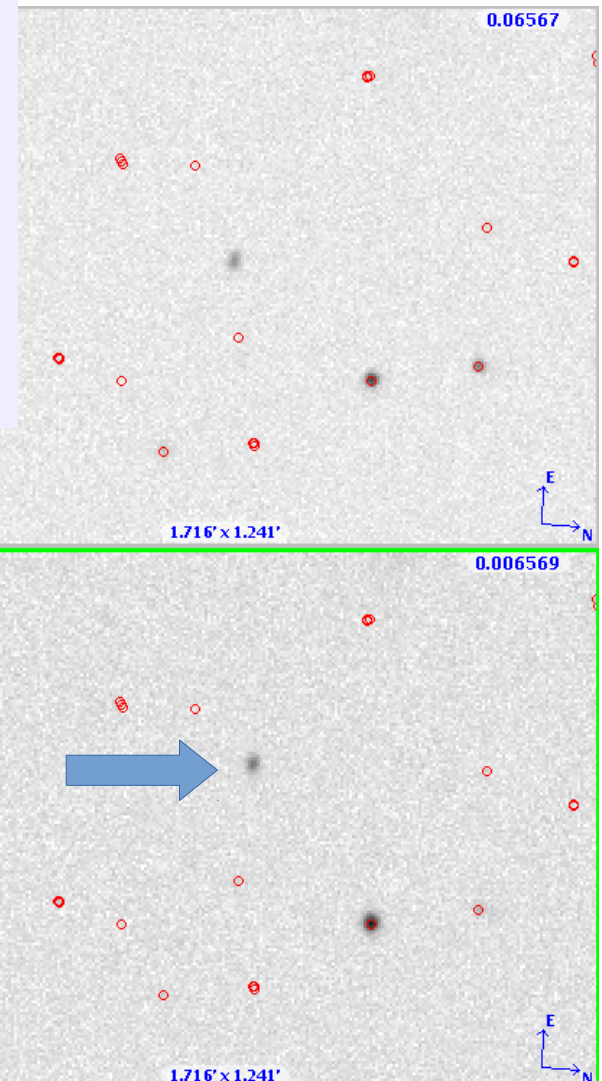
Size: > 300m

Table 1 Summary of the measurements reported to MPC.
(1): Extended arc beyond last observation reported by the MPC. (2): New intermediate positions. (3): New observations for single opposition asteroids.

	PHA	Apollo	Aten	Amor	Total
Precovery	24	42	6	58	130
Extended ⁽¹⁾	4	13	—	12	29
Intermediate ⁽²⁾	3	6	—	15	24
Single ⁽³⁾	11	15	1	29	56
Total	42	76	7	114	239

Visual inspection. Is it worth it?

```
WHERE (  
  (objFlags & (OBJECT_SATUR | OBJECT_BRIGHT | OBJECT_BLENDED)) == 0  
  &&  
  (objFlags & OBJECT_DEBLENDED_AS_MOVING) > 0  
  &&  
  (objc_type == 6)  
  &&  
  (psfCounts[2] > 14.5) && (psfCounts[2] < 21.5)  
  &&  
  (rowv*rowv + colv*colv > 0.0025)  
  &&  
  (rowv*rowv + colv*colv < 0.25)  
)
```



New features

- **New surveys:** UKIDSS, VISTA/VHS, VST/ATLAS.
- **New classes of asteroids:** Mars crossers, binary asteroids.
- **Rapid response system**

Hypatia Control

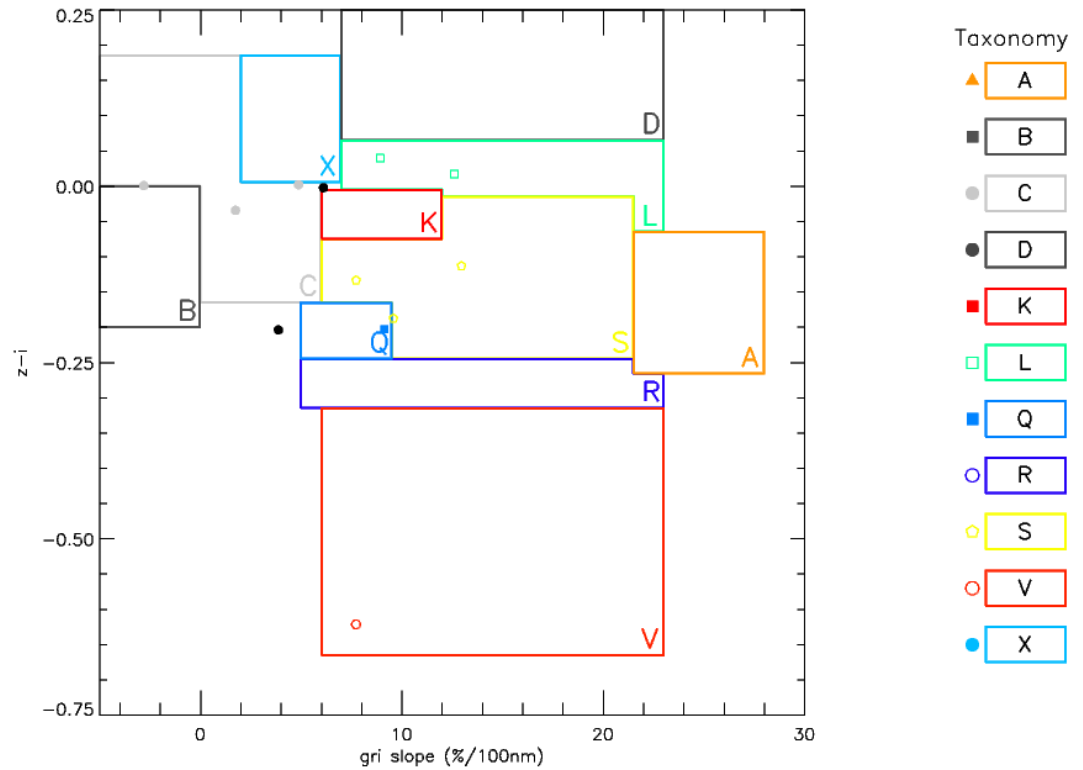
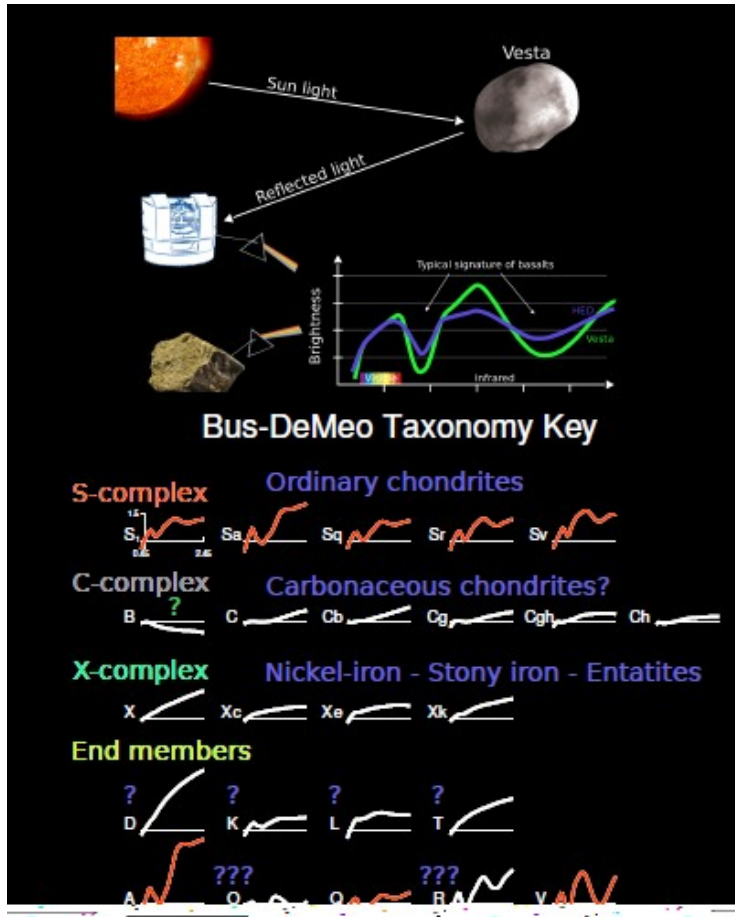
Status Objects Logs Surveys Risk CloseAp Highlight

340 objects

name	imp	sdss	vhs	vst	ukidssdr9	uncertainty	opp_nused	risk	close	see
2014MR67	2	X				9	1	X		go
2015RN35	2	X				4	1	X		go
2015YK	2	X				6	1		X	go
2016EK56	2	X				7	1		X	go
2011SH16	1	X				7	1			go
2008OX8	1	X				4	1			go
2007VO84	1	X				9	1			go

And still more!: Science

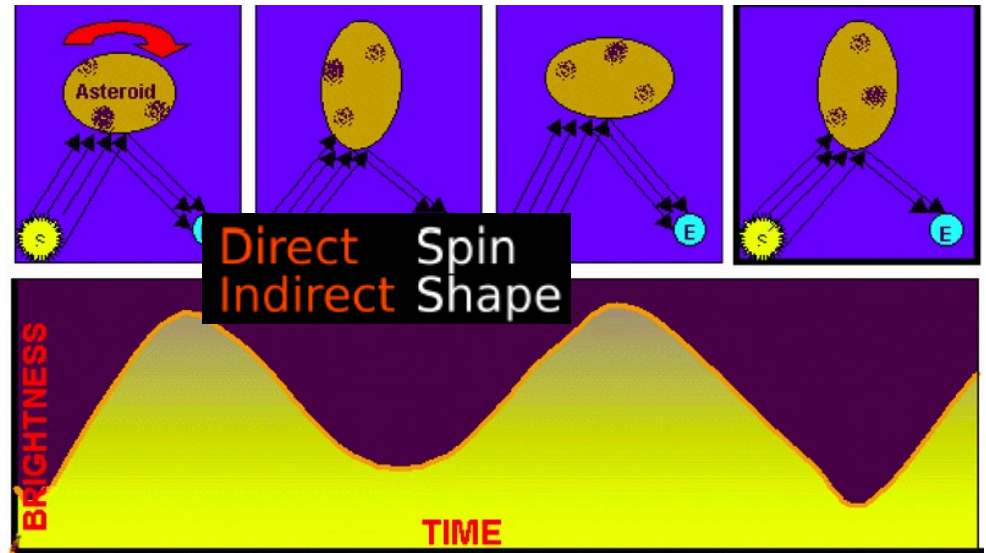
- Asteroid taxonomy



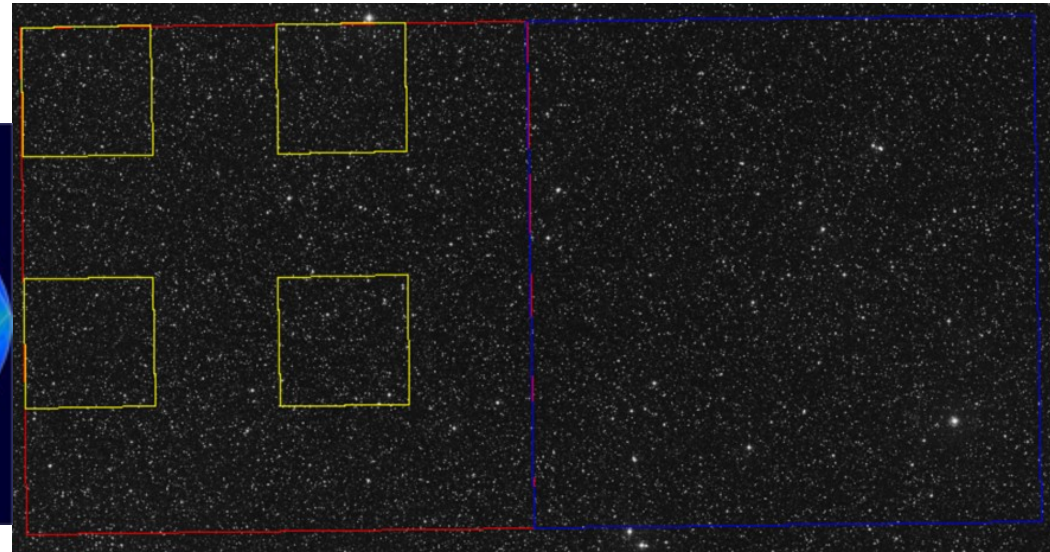
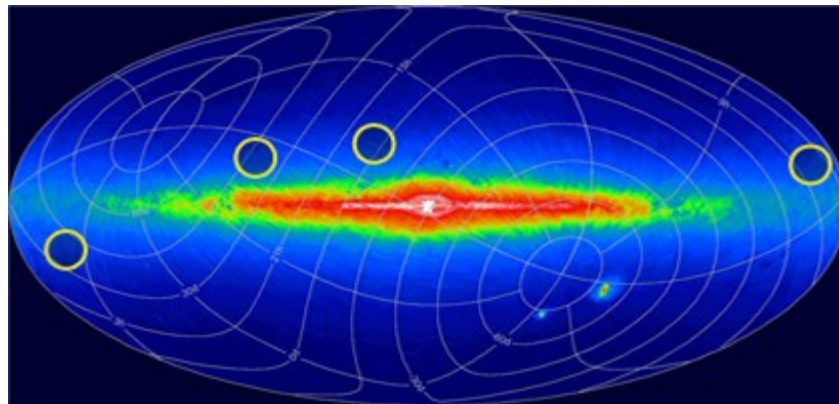
- 206 NEAs and 776 MCs classified.
- Increase of 40% and 663%.

And still more!: Science

- Light curves



The WFCAM Transit Survey



Surface rejuvenation by planetary encounters?

B. Carry^{1,2}

E. Solano^{3,4}

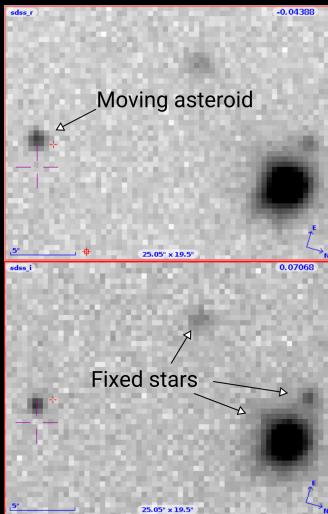
¹Lagrange, Observatoire de la Côte d'Azur

²IMCCE, Observatoire de Paris

³Centro de Astrobiología (INTA-CSIC)

⁴Spanish Virtual Observatory

Sloan Digital Sky Survey



1. SDSS is amazing for asteroids

- Colors over visible
- But: miss slow

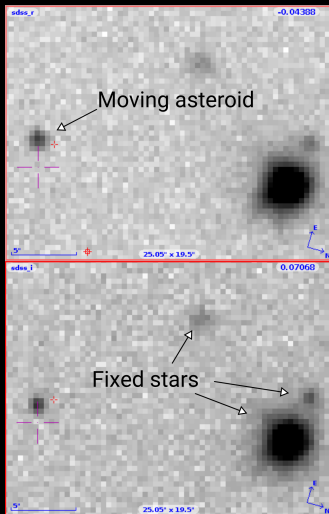
2. Citizen science program

3. Built large sample

4. Classify objects

Solano et al. 2014

Sloan Digital Sky Survey



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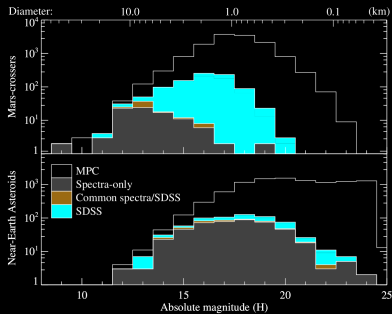
- Ephemeris \leftrightarrow FOV
- Thousands of clicks
- ▶ **Could be avoided!**

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Solano et al. 2014

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Carry et al. 2016

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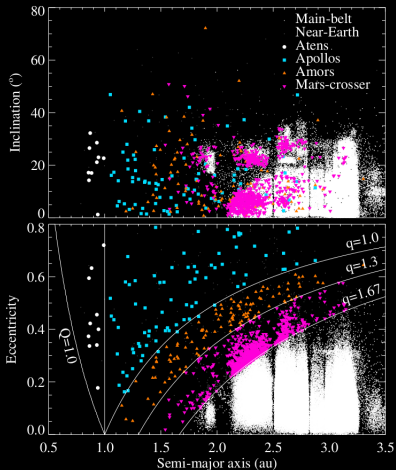
3. Built large sample

- NEAs: 35 → 210
- MCs: 310 → 620
- 40% and 660% vs spectra

4. Classify objects

- ▶ Classes in NEAs
- ▶ NEA source regions
- ▶ Surface processes

Sloan Digital Sky Survey



Carry et al. 2016

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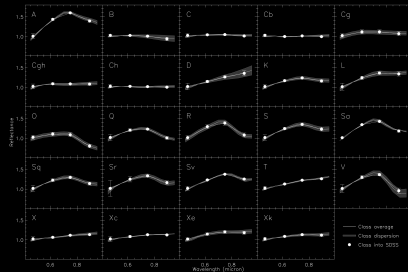
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Sloan Digital Sky Survey



DeMeo & Carry, 2013

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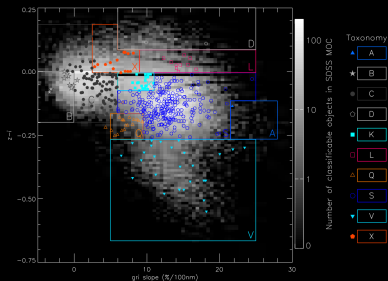
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- MCs: 310 → 620
- 40% and 660% vs spectra

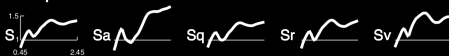
4. Classify objects

- ▶ Classes in NEAs
- ▶ NEA source regions
- ▶ Surface processes

Asteroid taxonomy

Bus-DeMeo Taxonomy Key

S-complex



C-complex



X-complex



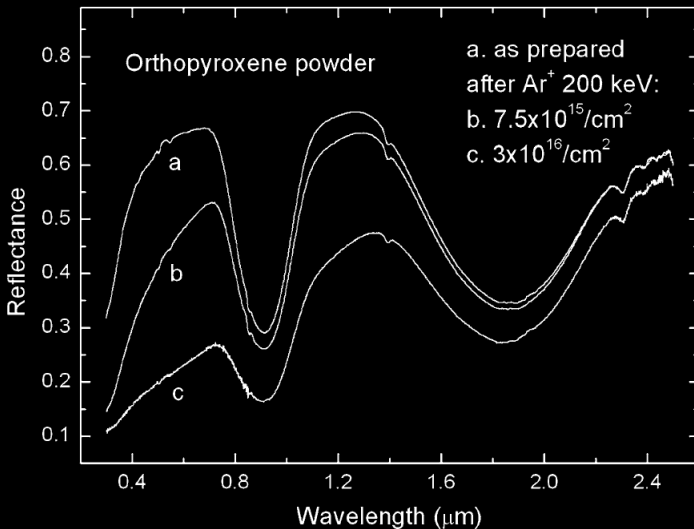
End Members



<http://smass.mit.edu/busdemeoclass.html>

F. E. DeMeo, R. P. Binzel, S. M. Slivan, and S. J. Bus. *Icarus* 202 (2009) 160-180

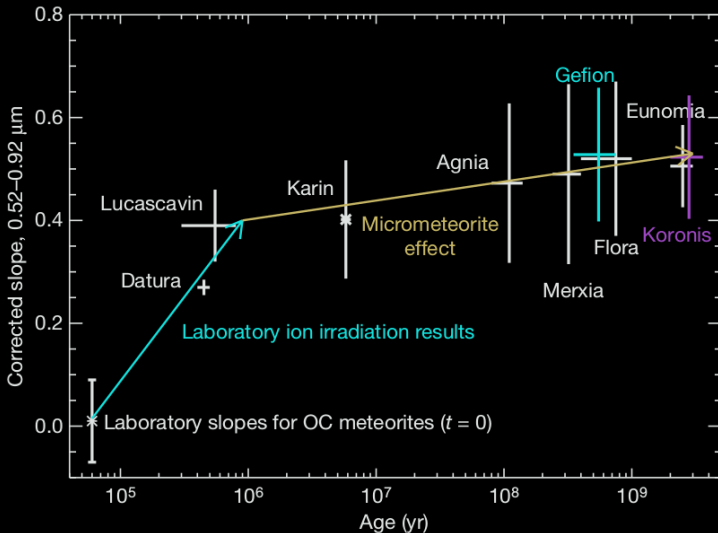
Space weathering effect



Brunetto et al. 2006

→Reddening and darkening

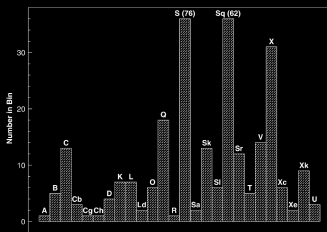
Space weathering timescale



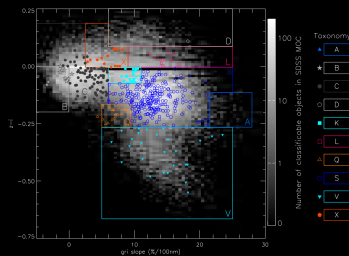
Vernazza et al. 2009

→ 10^5 – 10^6 years

Existence of fresh NEAs



Binzel et al. 2004, 2010

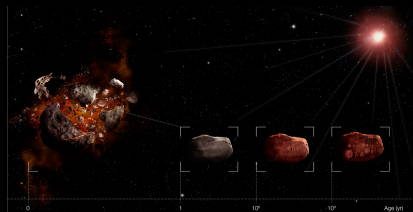


Carry et al. 2016

Rejuvenating processes?

- Collisions
 - ▶ Not enough collisions
 - ▶ One Q in the MB

- Planetary encounters



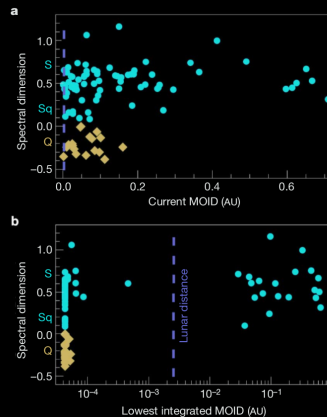
ESO

- YORP spin-up

Rejuvenating processes?

- Collisions
 - ▶ Not enough collisions
 - ▶ One Q in the MB
- Planetary encounters
 - ▶ Q-types in NEA only
 - ▶ Tides during encounter

● YORP spin-up



Binzel et al. 2010

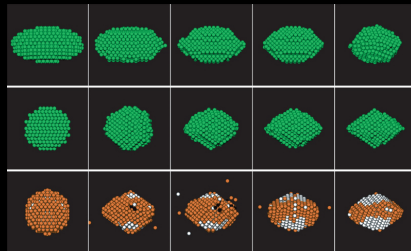
Rejuvenating processes?

- Collisions

- ▶ Not enough collisions
- ▶ One Q in the MB

- Planetary encounters

- ▶ Q-types in NEA only
- ▶ Tides during encounter

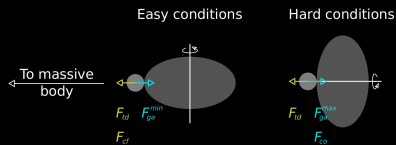


Walsh et al. 2008

- YORP spin-up

- ▶ YORP creates binaries
- ▶ Not studied until recently

Planetary encounters



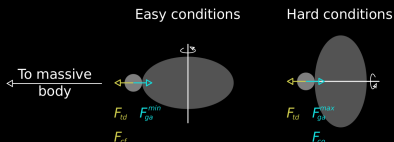
1. Simple force model on grains

- Tides, centrifugal forces
- Gravity, cohesion

2. Set limit cases

3. Compare with Q/S history

Planetary encounters



1. Simple force model on grains

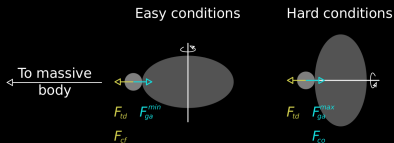
- Tides, centrifugal forces
- Gravity, cohesion

2. Set limit cases

- easy:** Fast spinner & obliquity=90°
hard: Obliquity=0°

3. Compare with Q/S history

Planetary encounters



1. Simple force model on grains

- Tides, centrifugal forces
- Gravity, cohesion

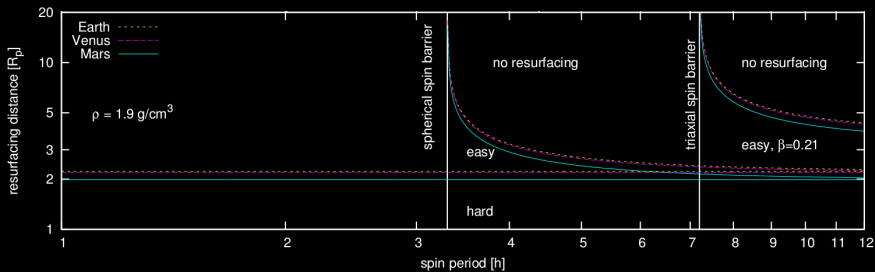
2. Set limit cases

- easy:** Fast spinner & obliquity= 90°
hard: Obliquity= 0°

3. Compare with Q/S history

- 100 clones per asteroid
- 500 ky integration
- Track encounters

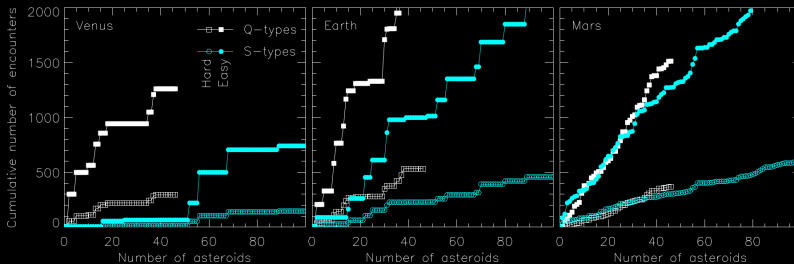
Planetary encounters?



Carry et al. 2016

→ $5 R_p$

Planetary encounters?



Carry et al. 2016

→ Mars?

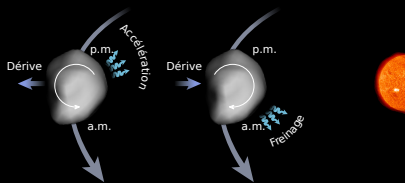
→ Another process?

YORP fission

1. YORP spins up asteroids

2. Recent YORP study

- NEAs dyn. integration
- Simple YORP model
- Spin threshold



3. Key predictions

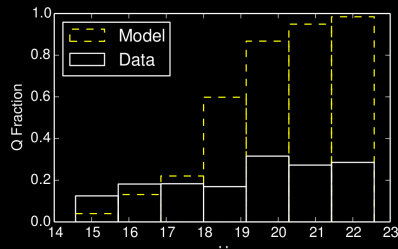
- Q-types in any population
- Q/S ratio vs diameter

YORP fission

1. YORP spins up asteroids

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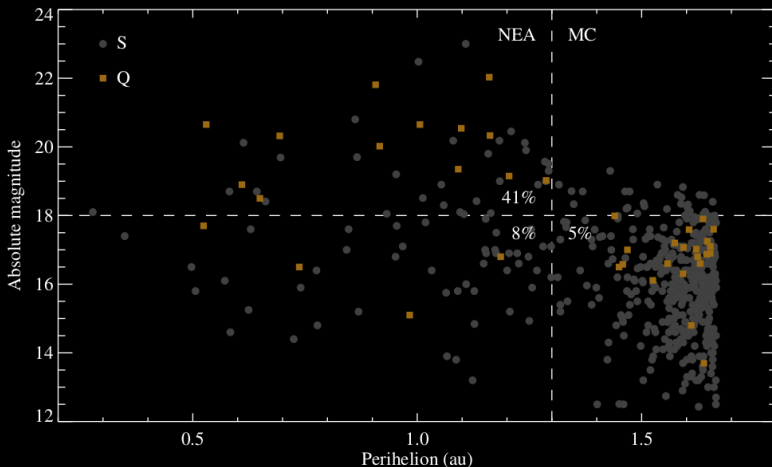


Graves et al. 2016

3. Key predictions

- Q-types in any population
- Q/S ratio vs diameter

Fraction of Q-types



⇒ Apparent lack of Q-types in MC/MB related to size effect

Next steps?

- Spectral follow-up
 - SDSS Q may not all be *genuine* Q-types
 - Near-infrared spectrum required
- Search for Q-types in the main belt
 - Time consuming for VNIR spectroscopy
 - Broad-band photometry
- Spin statistics of Q-types?
 - Expected spin states after resurfacing?

Data mining

- Tremendous amount of data in archives
 - Ground: ESO, big surveys, national telescopes
 - Space: ESA, NASA, JAXA, ...
- Research projects and publications from pure archives
 - 50% of articles from HST!
 - 15% of articles from ESO!
 - ▶ And from ESA?
- Archives are generally **not** solar-system friendly
 - Queries by RA/Dec
 - ▶ Solar system requires special developments
 - ▶ Great rewards!