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

Enrique Solano, Benoit Carry

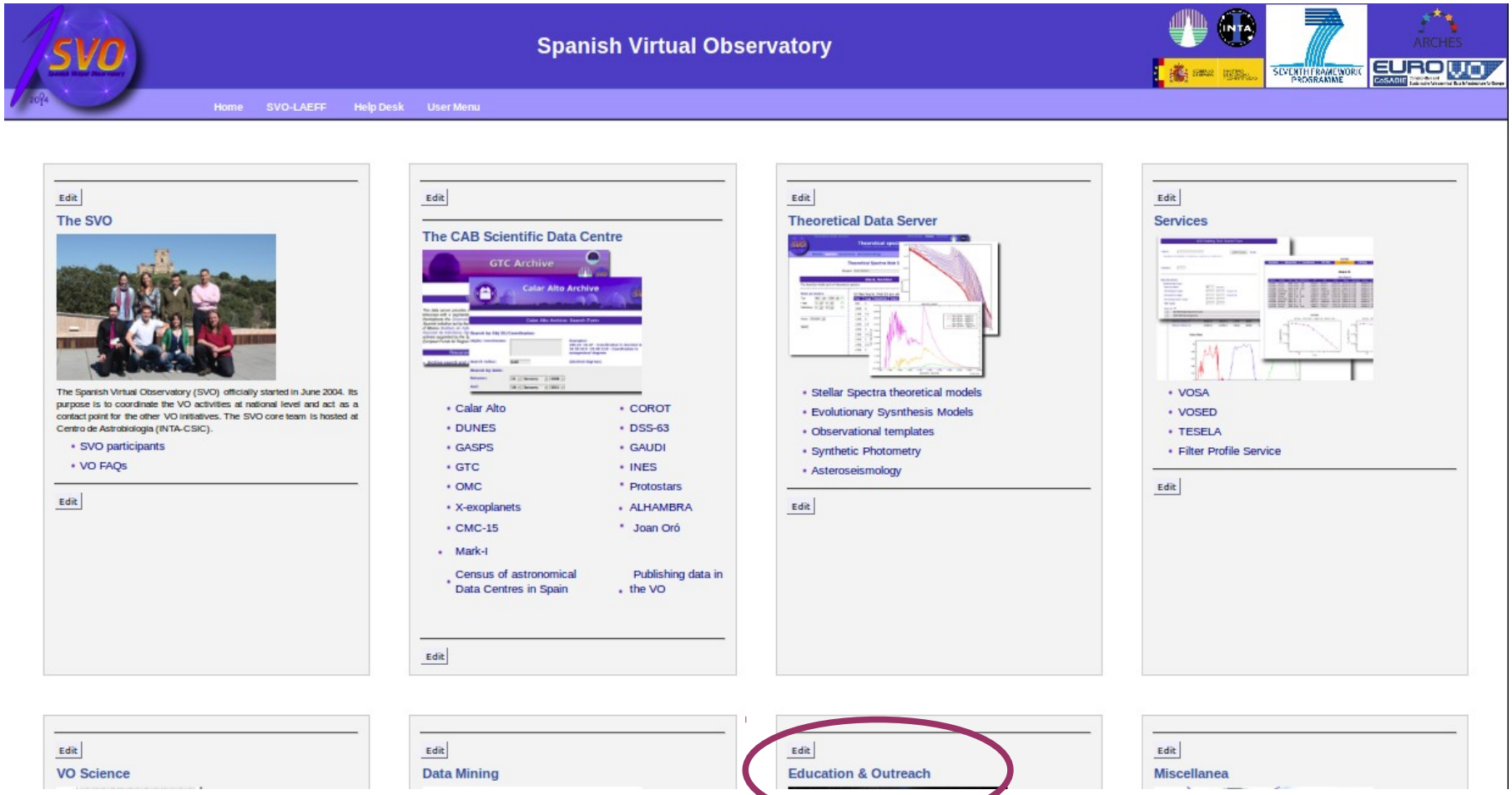
ESAC Seminar. April 2016

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



Outreach… Fine, but what to do?

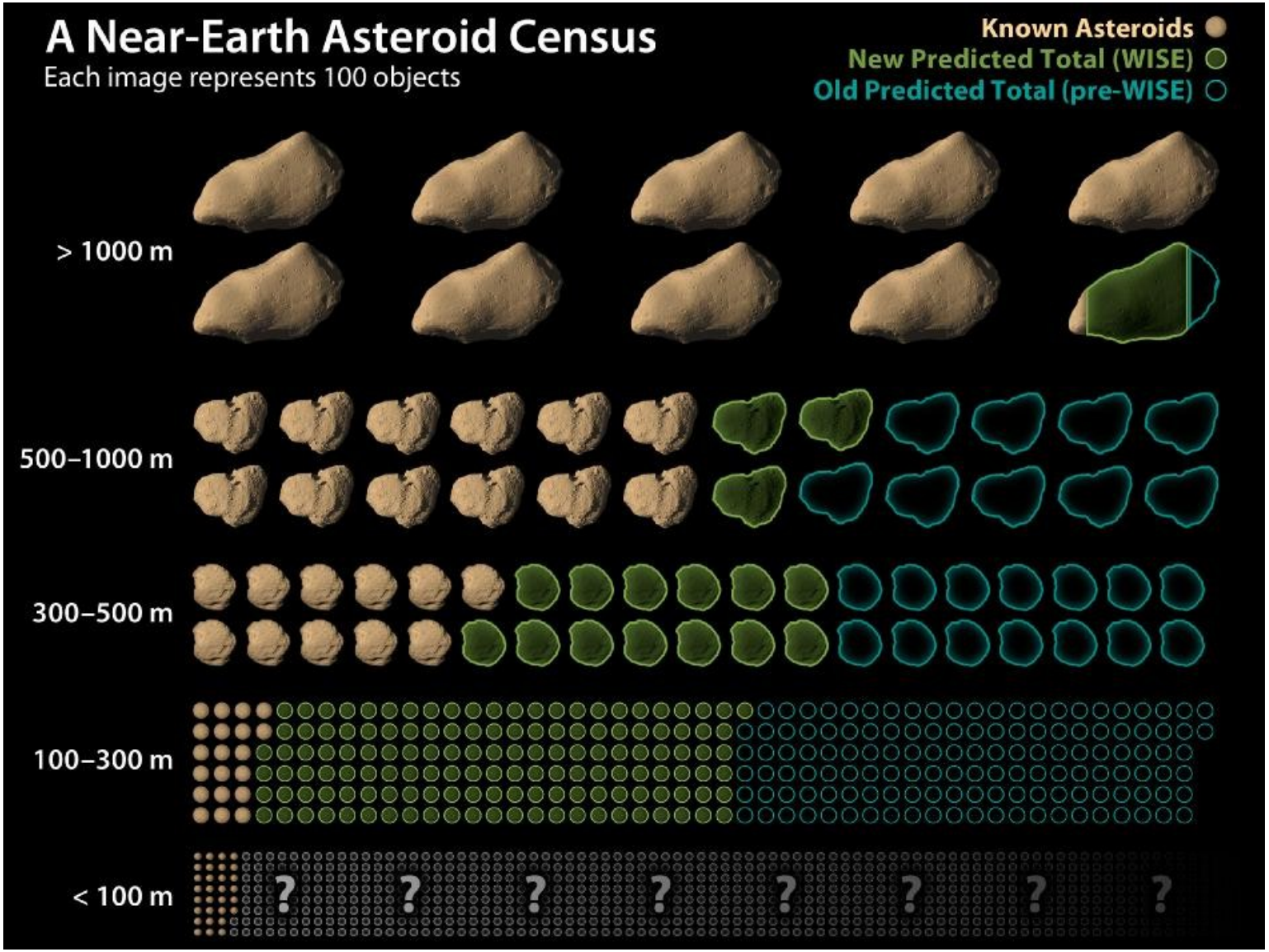
NEAs: Near-Earth Asteroids.

NEAs and the general public

NEAs and the general public

Object	Close-Approach (CA) Date (TDB) YYYY-mmm-DD HH:MM ± D_HH:MM	CA Distance Nominal (LD/AU)
(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



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

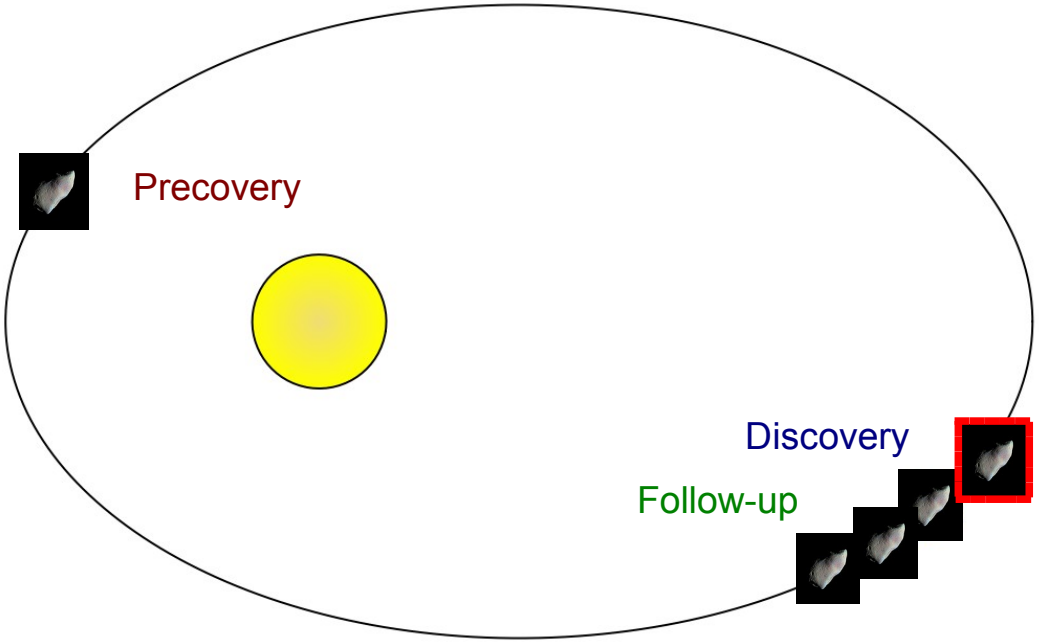
Choose file **No file chosen**

Search radius: 5 arcmin

Search by Date:

Between: 16 March

And: 7 January



Project's components

I. The list of NEAs

MIRROR SITE

HOME ABOUT CONTACT

The International Astronomical Union
Minor Planet Center
The nerve center of asteroid detection in the Solar System

Search MPC

OBSERVERS PUBLIC IAWN

- 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)

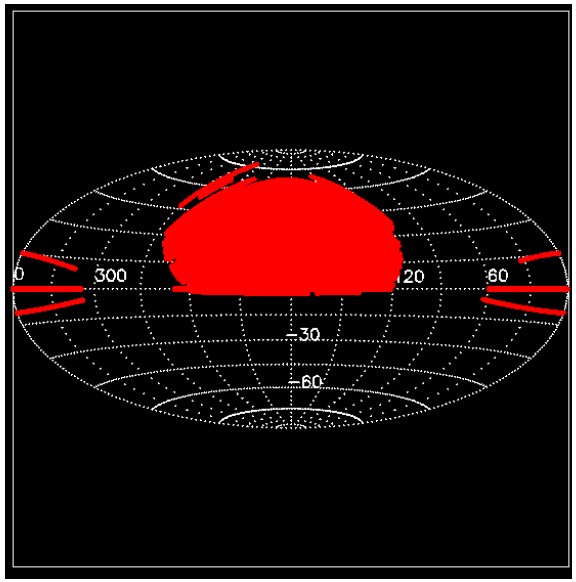
This list is updated daily and is also updated as and when new objects are discovered.

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 Su
	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 FY12	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 FY12	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	0.03364	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 Sur

Project's components

II. The survey (SDSS DR8)

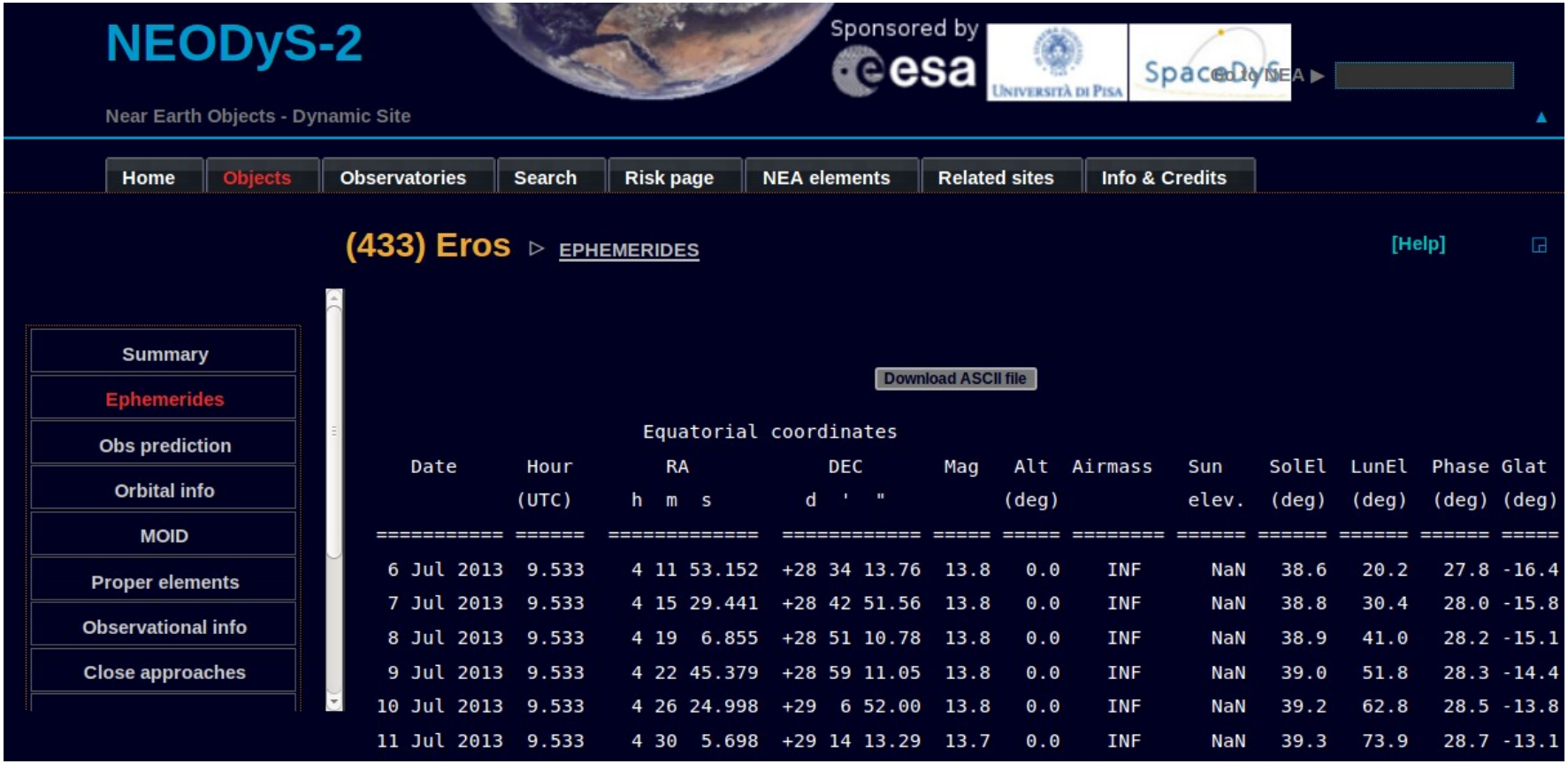


- Almost 10^6 images
- Coverage > 14500 deg²
- Multiwavelength info. (u,g,ri,z)
- Large FoV: 1.5 sq. deg.
- Deep limiting mag.: 22.0, 22.2, 22.2, 21.3 and 20.5.
- Observing sequence: 5.7m (five filters)

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

Project's components

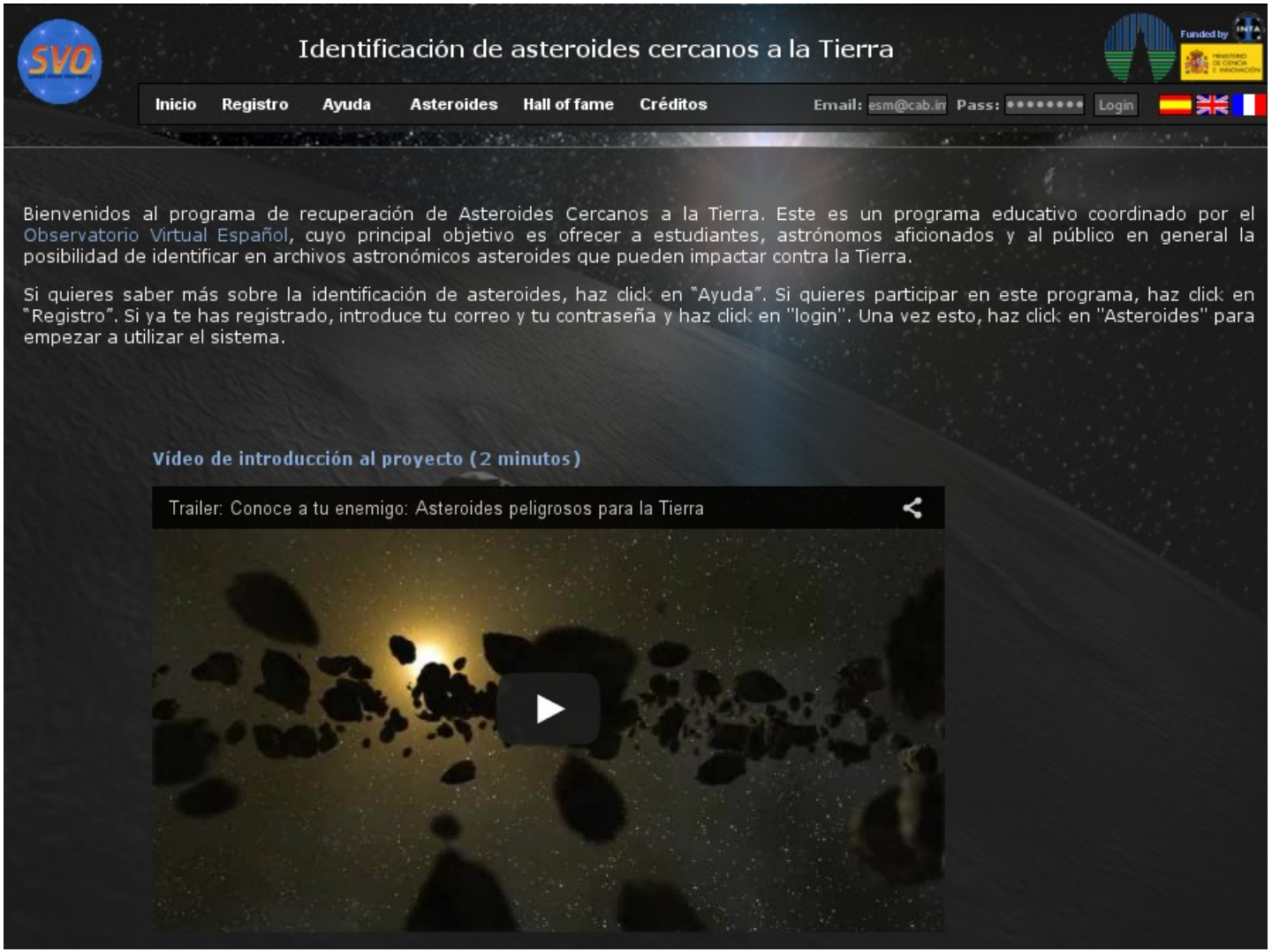
III. The ephemerides



Equatorial coordinates

Date	Hour (UTC)	RA h m s	DEC d ' "	Mag	Alt (deg)	Airmass	Sun elev.	SolEl (deg)	LunEl (deg)	Phase (deg)	Glat (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

The citizen-science project

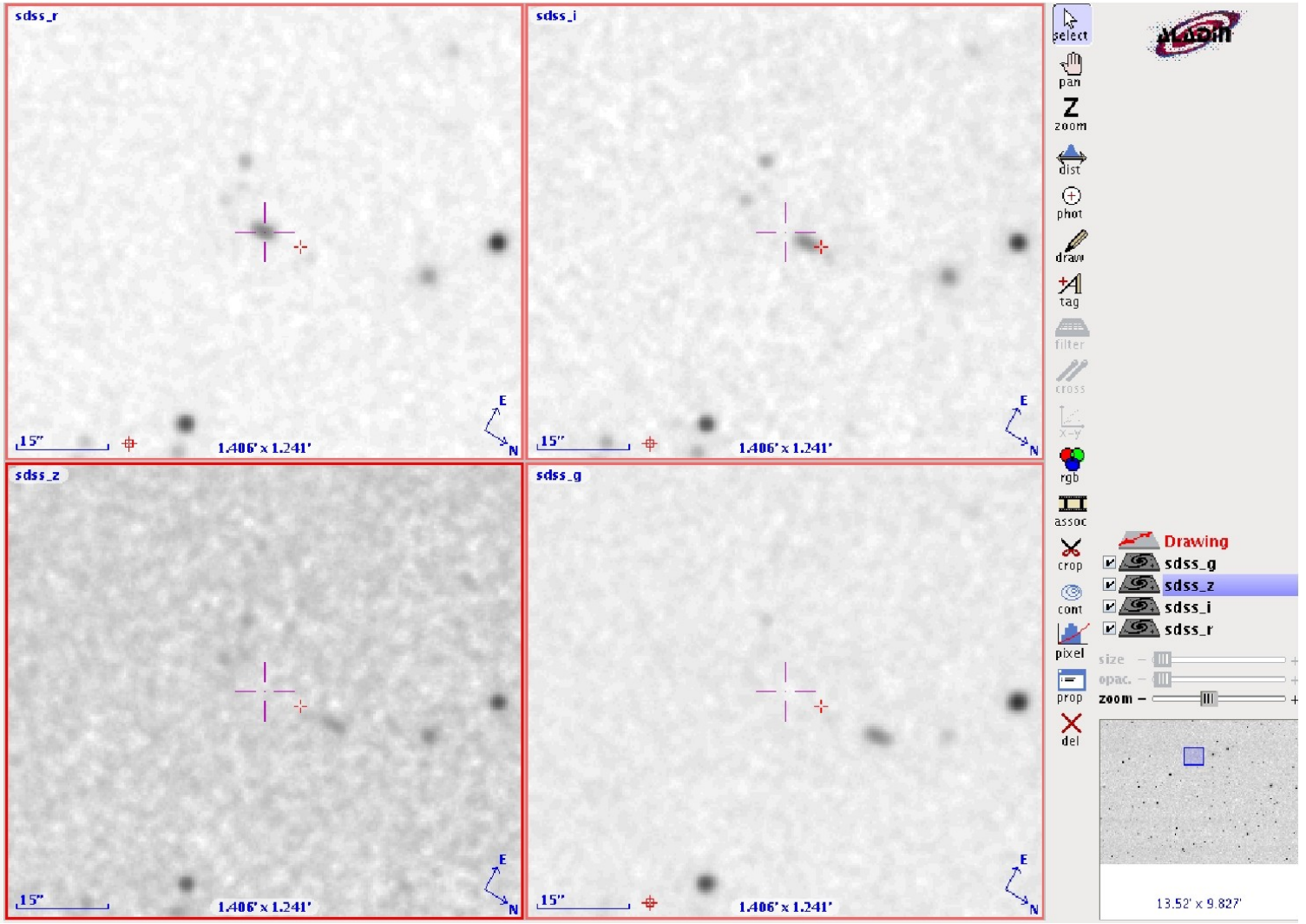


http://www.laeff.cab.inta-csic.es/projects/near

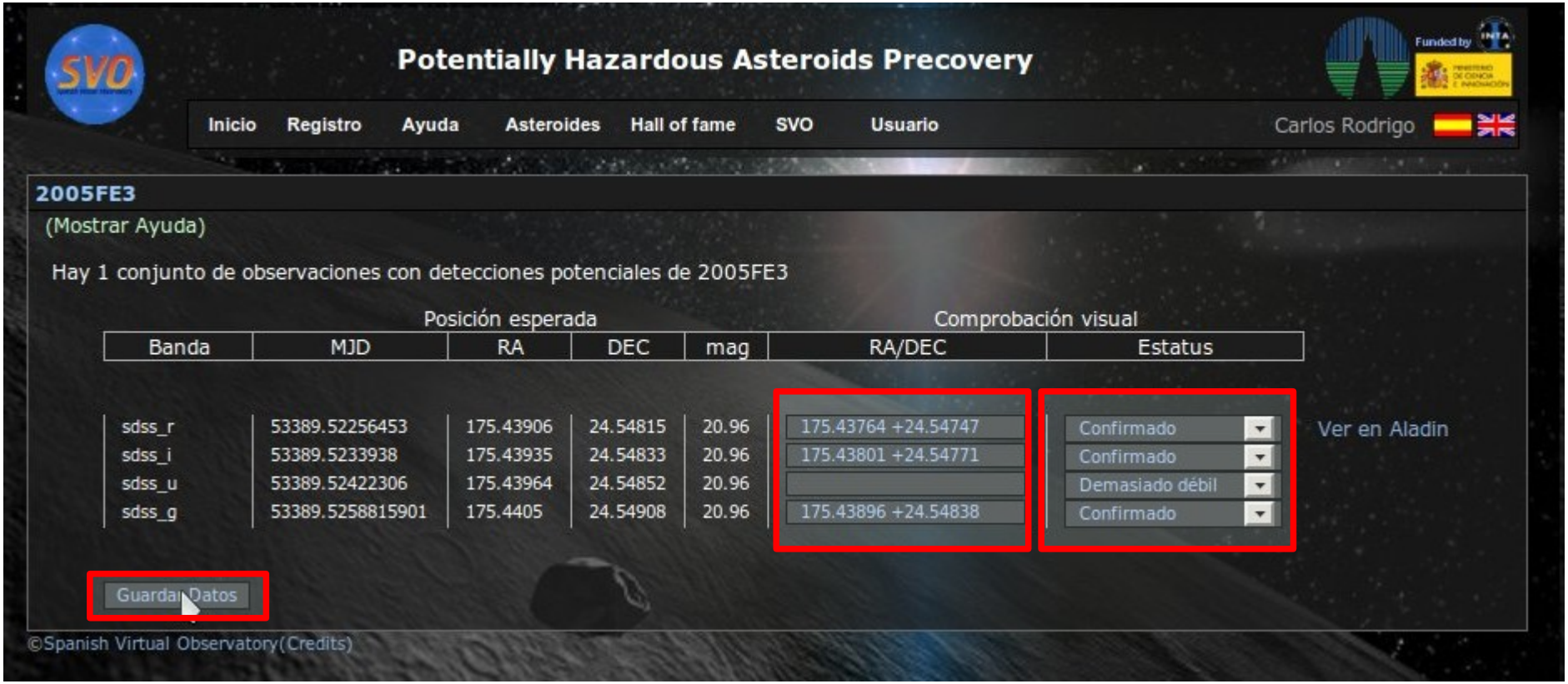
The citizen-science project

The citizen-science project

The citizen-science project



The citizen-science project



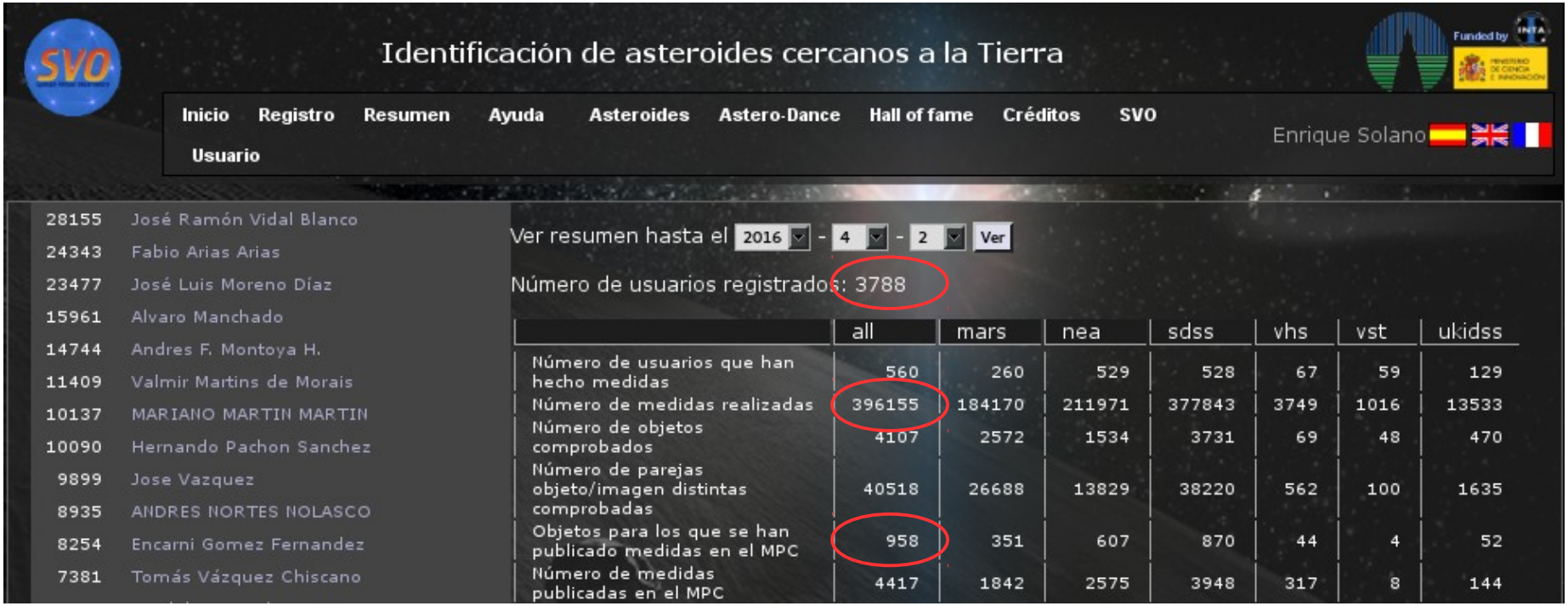
The citizen-science project

SAO/NASA ADS Astronomy Abstract Service

· Find Similar Abstracts (with default settings below)
· Also-Read Articles (Reads History)
·
· Translate This Page

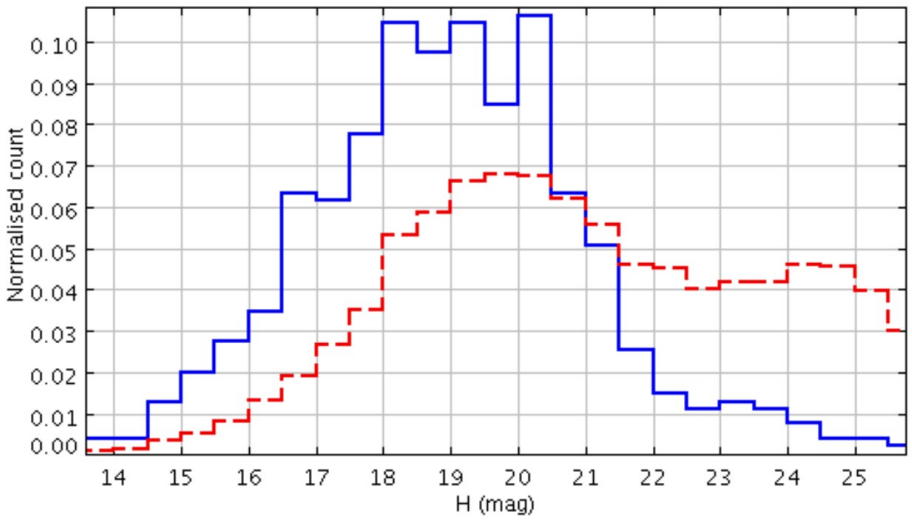
Title:	Minor Planet Observations [645 Apache Point--Sloan Digital Sky Survey]
Authors:	Ivezic, Z.; Survey, S.; Galvez Ranera, E.; de Madrid, P.; Solano, E.; Bustabad Alonso, L.; Car Cuadrado Garcia, J.; de La Osa Lopez, J. M.; Gil Rey, J.; Gutierrez Bulnes, L.; Izarra Cala, J.; Pascual Gutierrez, J. 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



	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



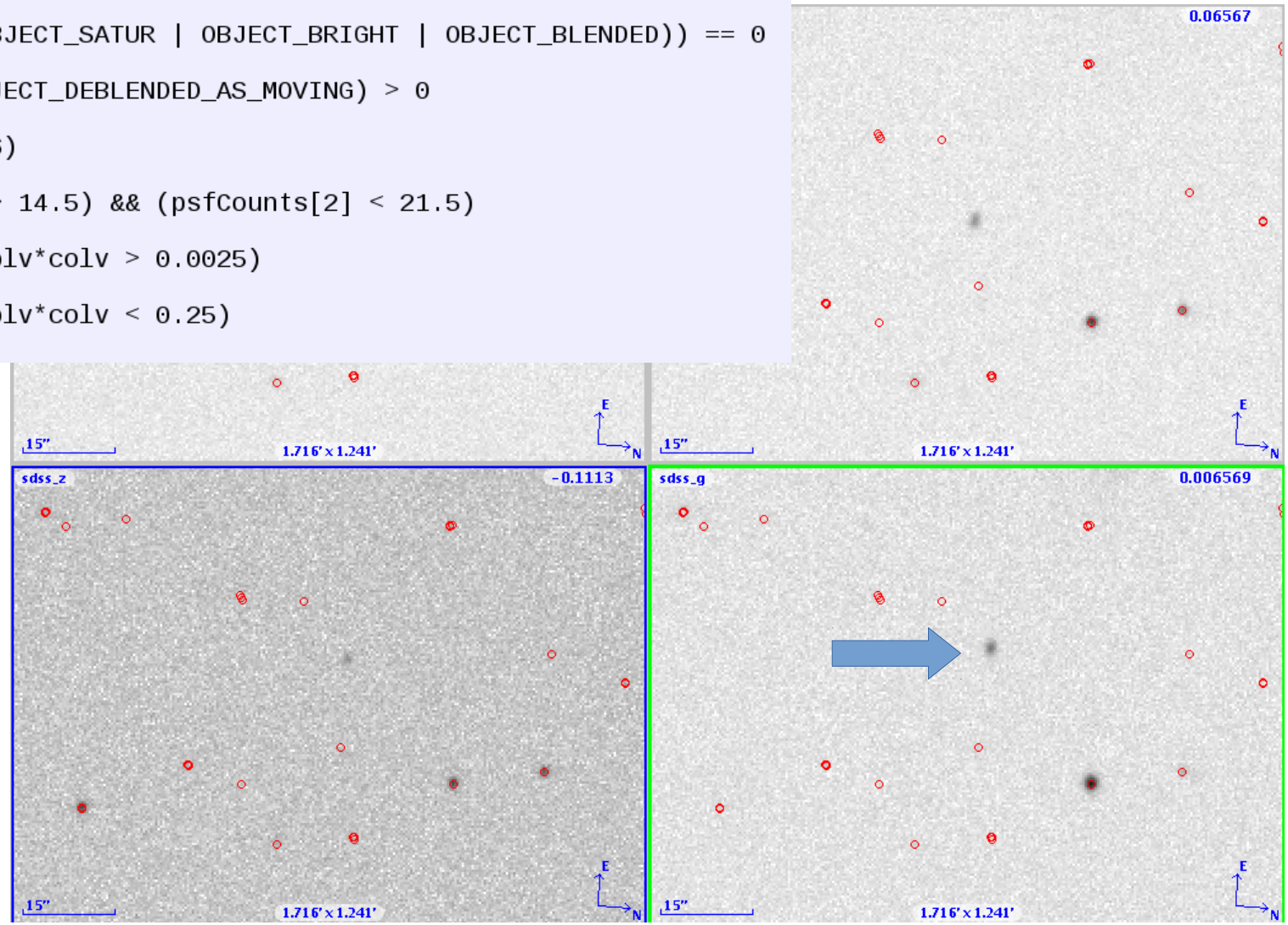
Size: > 300m

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)
)
```



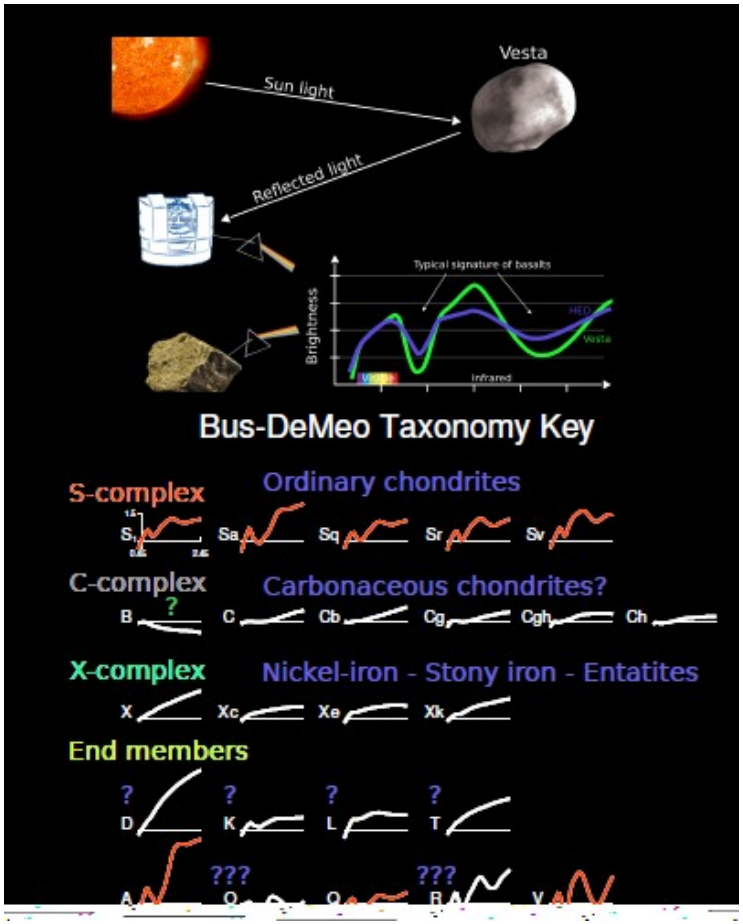
New features

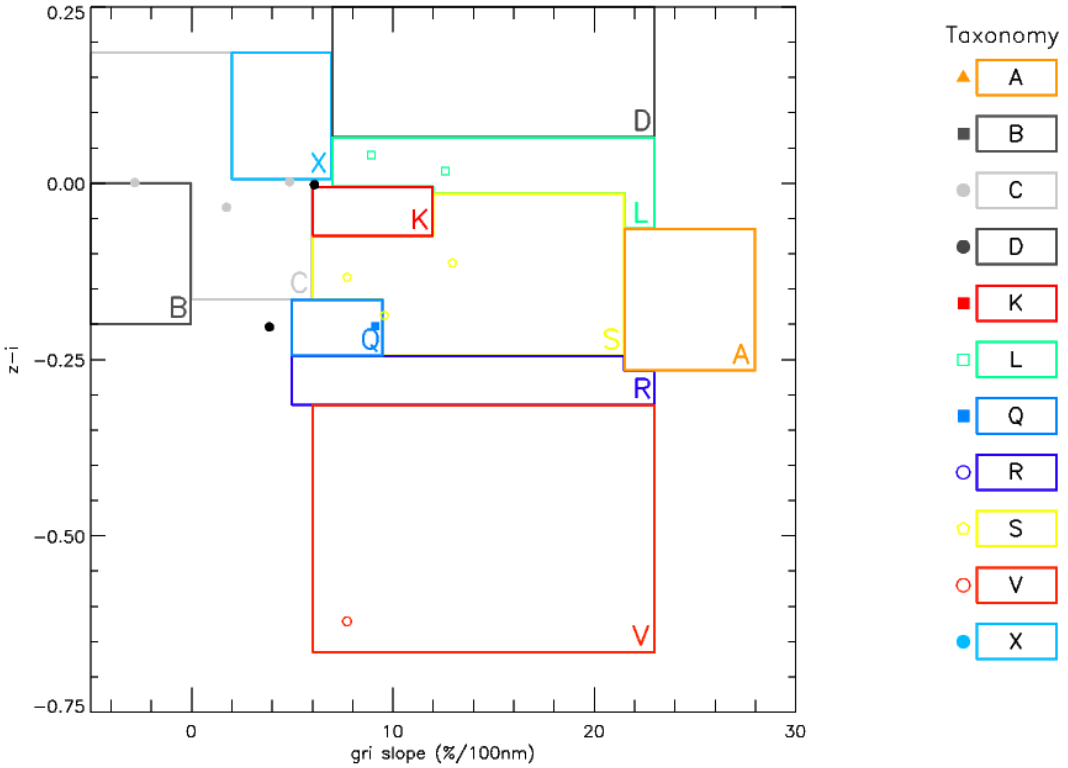
- New surveys: UKIDSS, VISTA /VHS, VST/ATLAS.
- New classes of asteroids: Mars crossers, binary asteroids.
- Rapid response system

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

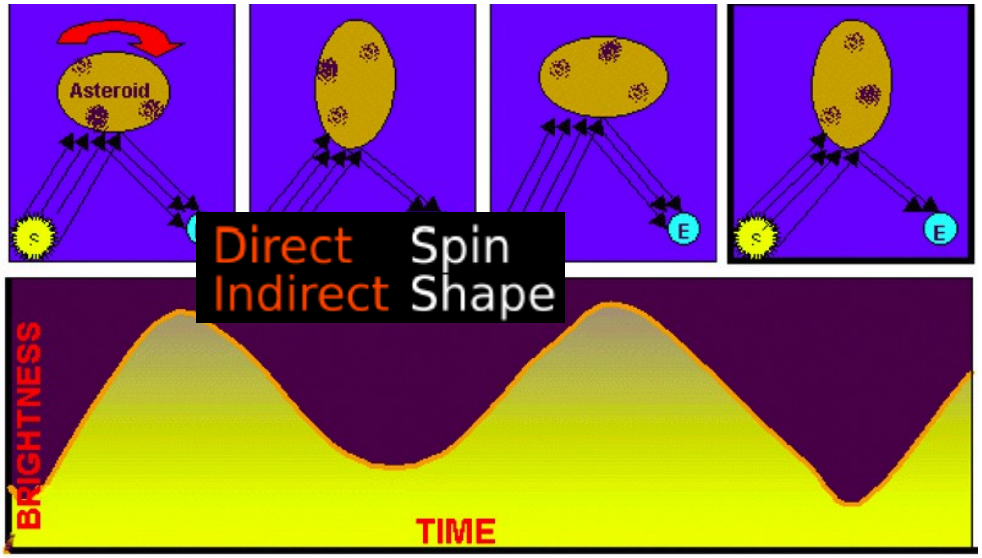




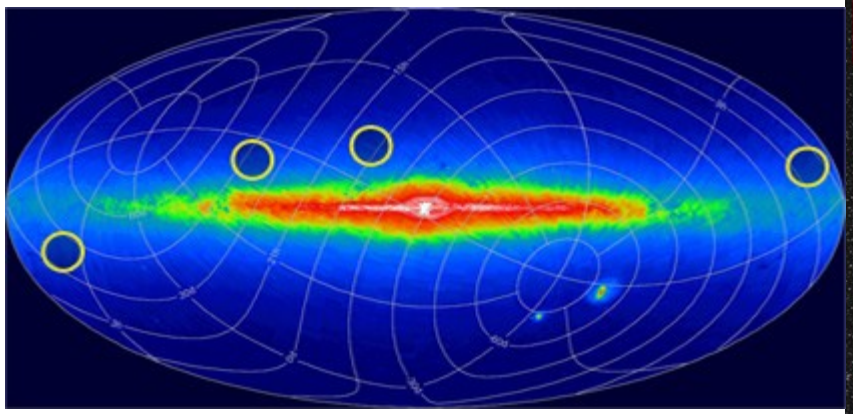
- 206 NEAs and 776 MCs classified.
- Increase of 40% and 663%.

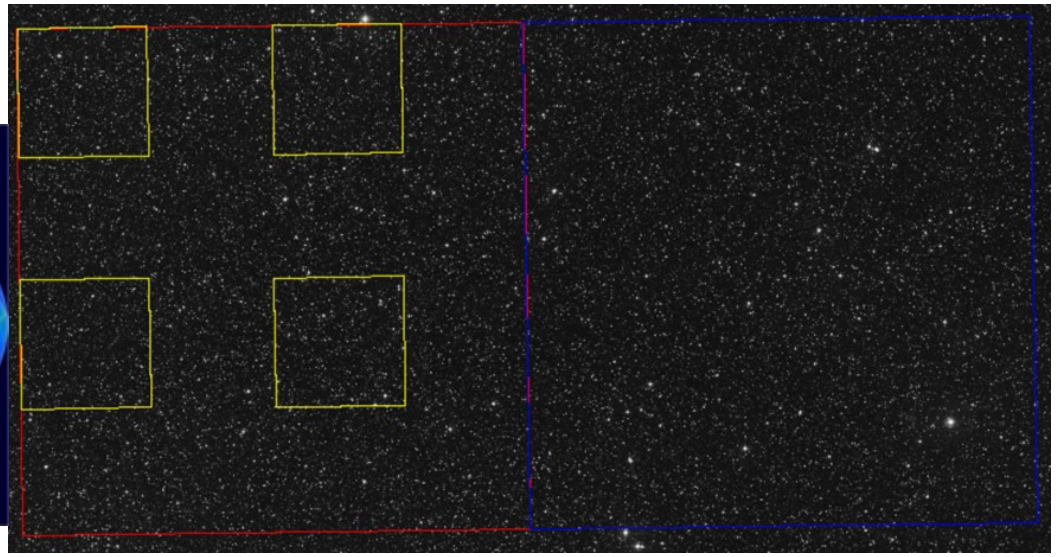
And still more!: Science

- Light curves



The WFCAM Transit Survey



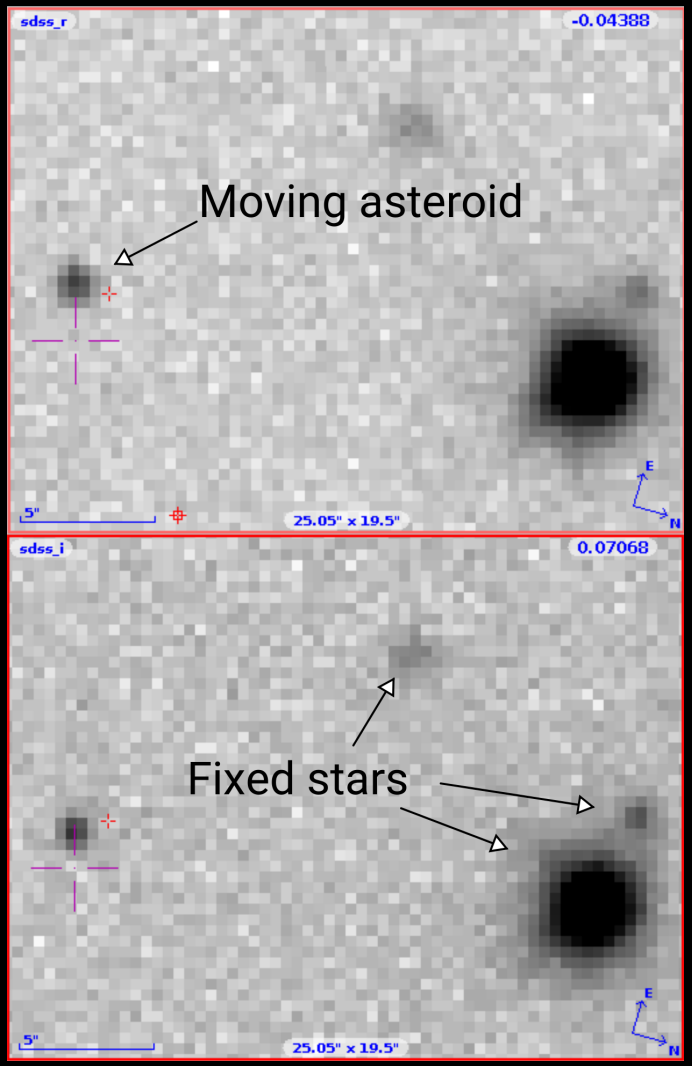


Surface rejuvenation by planetary encounters?

B. Carry[1,2]
E. Solano[3,4]

[1]Lagrange, Observatoire de la Côte d'Azur
[2]IMCCE, Observatoire de Paris
[3]Centro de Astrobiología (INTA-CSIC)
[4]Spanish Virtual Observatory

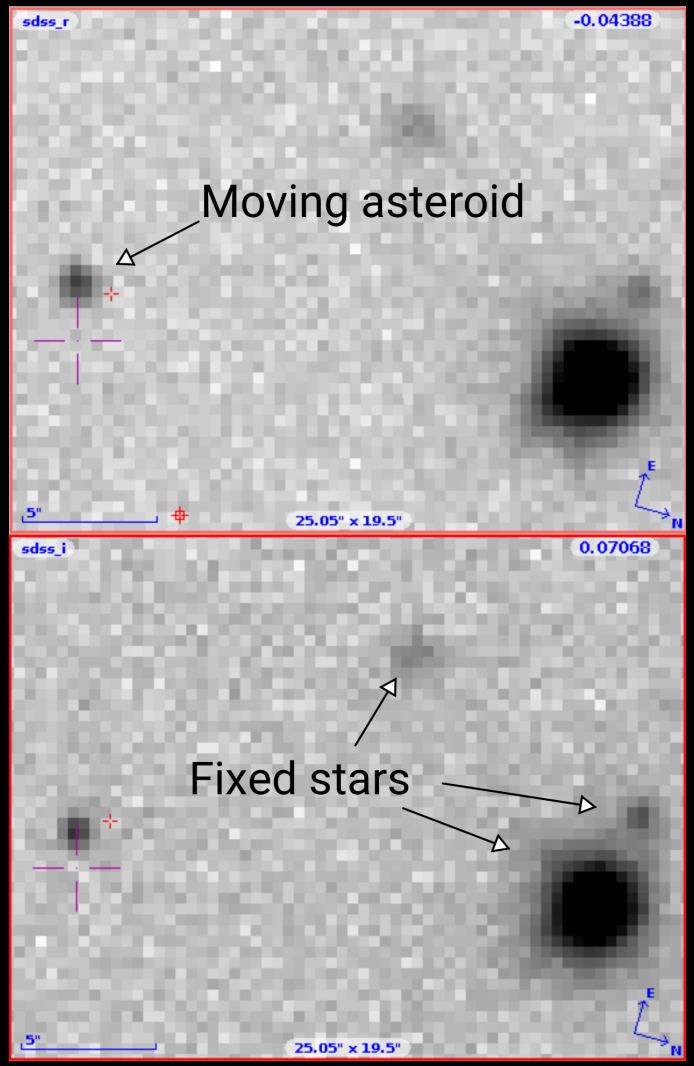
Sloan Digital Sky Survey



Solano et al. 2014

1. SDSS is amazing for asteroids
   - Colors over visible
   - But: miss slow
2. Citizen science program
   - Ephemeris 4 FOV
   - Thousands of clicks
   - Could be avoided!
3. Built large sample
   - NEAs: 35 → 210
   - MCs: 310 → 620
   - 40% and 60% vs. spectra
4. Classify objects

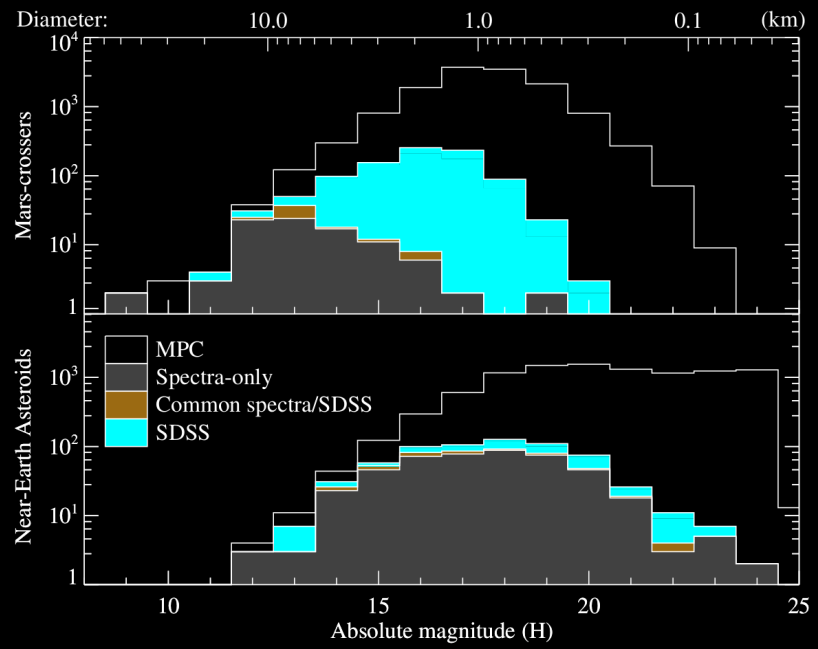
Sloan Digital Sky Survey



Solano et al. 2014

1. SDSS is amazing for asteroids
   - Colors over visible
   - But: miss slow
2. Citizen science program
   - Ephemeris ↔ FOV
   - Thousands of clicks
   - ▸ **Could be avoided!**
3. Built large sample
   - NEAs: 35 → 210
   - MCs: 310 → 620
   - 40% and 60% vs. spectra
4. Classify objects

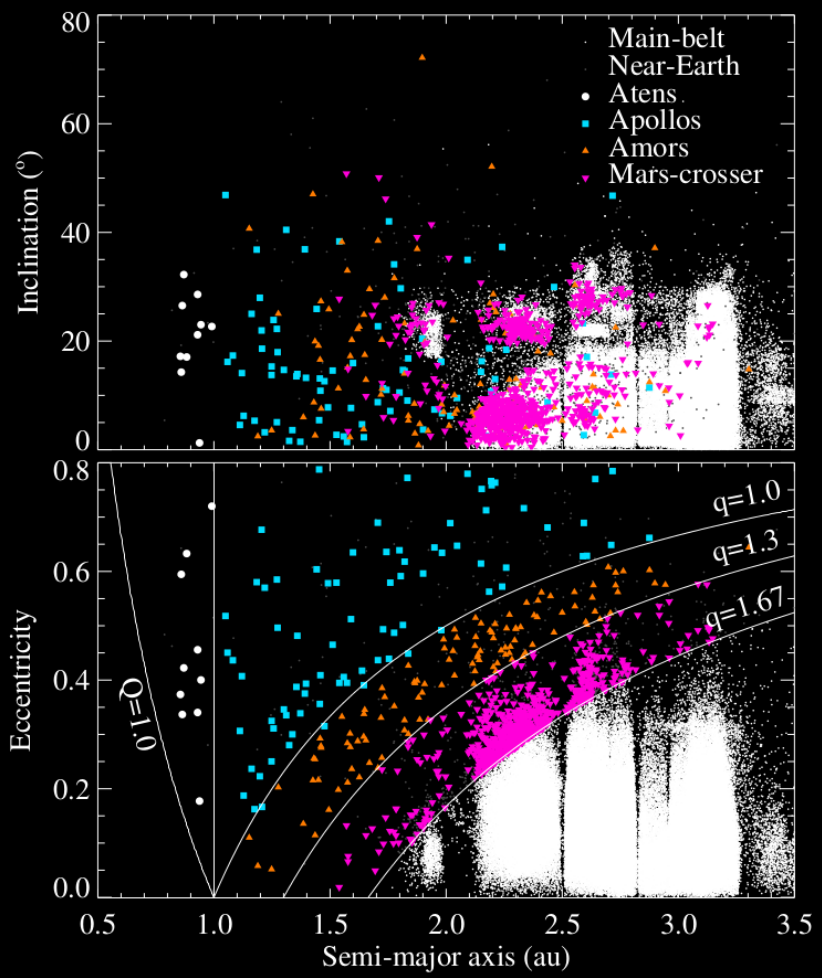
Sloan Digital Sky Survey



Carry et al. 2016

1. SDSS is amazing for asteroids
   - Colors over visible
   - But: miss slow
2. Citizen science program
   - Ephemeris $\leftrightarrow$ FOV
   - Thousands of clicks
   - **Could be avoided!**
3. Built large sample
   - NEAs: 35 $\rightarrow$ 210
   - MCs: 310 $\rightarrow$ 620
   - 40% and 660% *vs* spectra
4. Classify objects
   - Classes in NEAs
   - NEA source regions
   - Surface processes

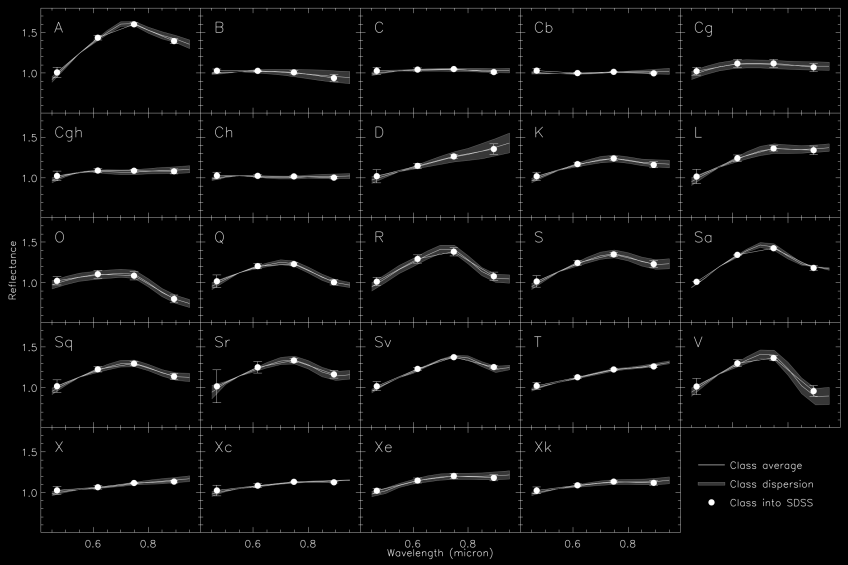
Sloan Digital Sky Survey



Carry et al. 2016

1. SDSS is amazing for asteroids
   - Colors over visible
   - But: miss slow
2. Citizen science program
   - Ephemeris $\leftrightarrow$ FOV
   - Thousands of clicks
   - **Could be avoided!**
3. Built large sample
   - NEAs: 35 $\rightarrow$ 210
   - MCs: 310 $\rightarrow$ 620
   - 40% and 660% *vs* spectra
4. Classify objects
   - Classes in NEAs
   - NEA source regions
   - Surface processes

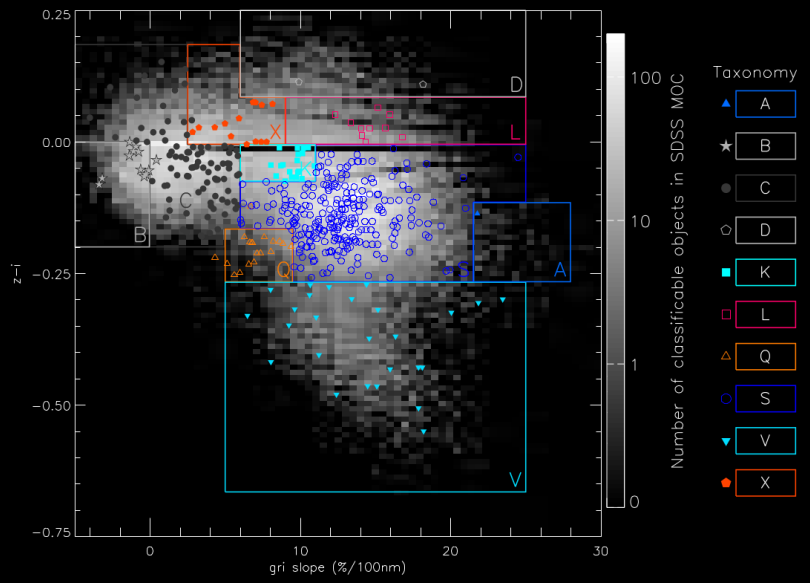
Sloan Digital Sky Survey



DeMeo & Carry, 2013

1. SDSS is amazing for asteroids
   - Colors over visible
   - But: miss slow
2. Citizen science program
   - Ephemeris $\leftrightarrow$ FOV
   - Thousands of clicks
   - **Could be avoided!**
3. Built large sample
   - NEAs: 35 $\rightarrow$ 210
   - MCs: 310 $\rightarrow$ 620
   - 40% and 660% *vs* spectra
4. Classify objects
   - Classes in NEAs
   - NEA source regions
   - Surface processes

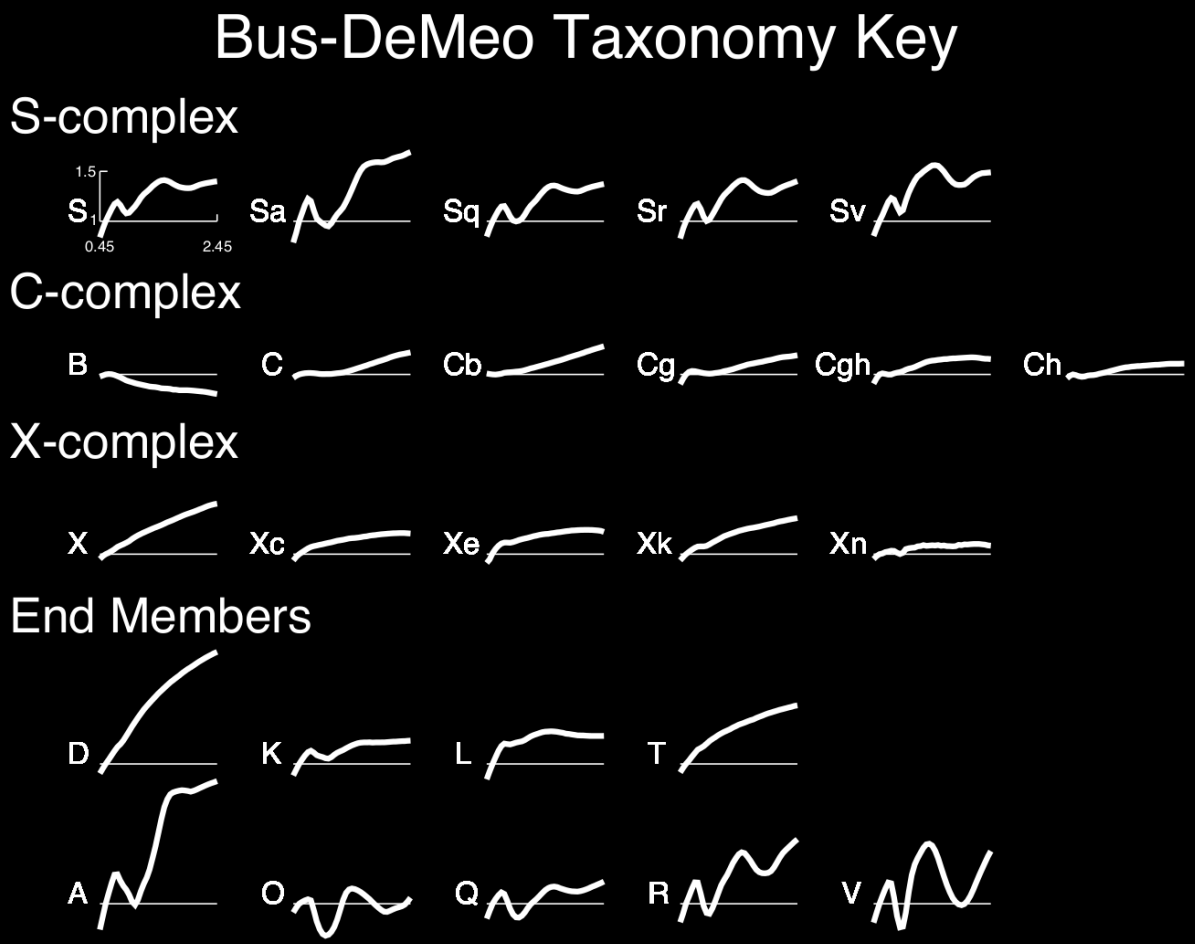
Sloan Digital Sky Survey



Carry et al. 2016

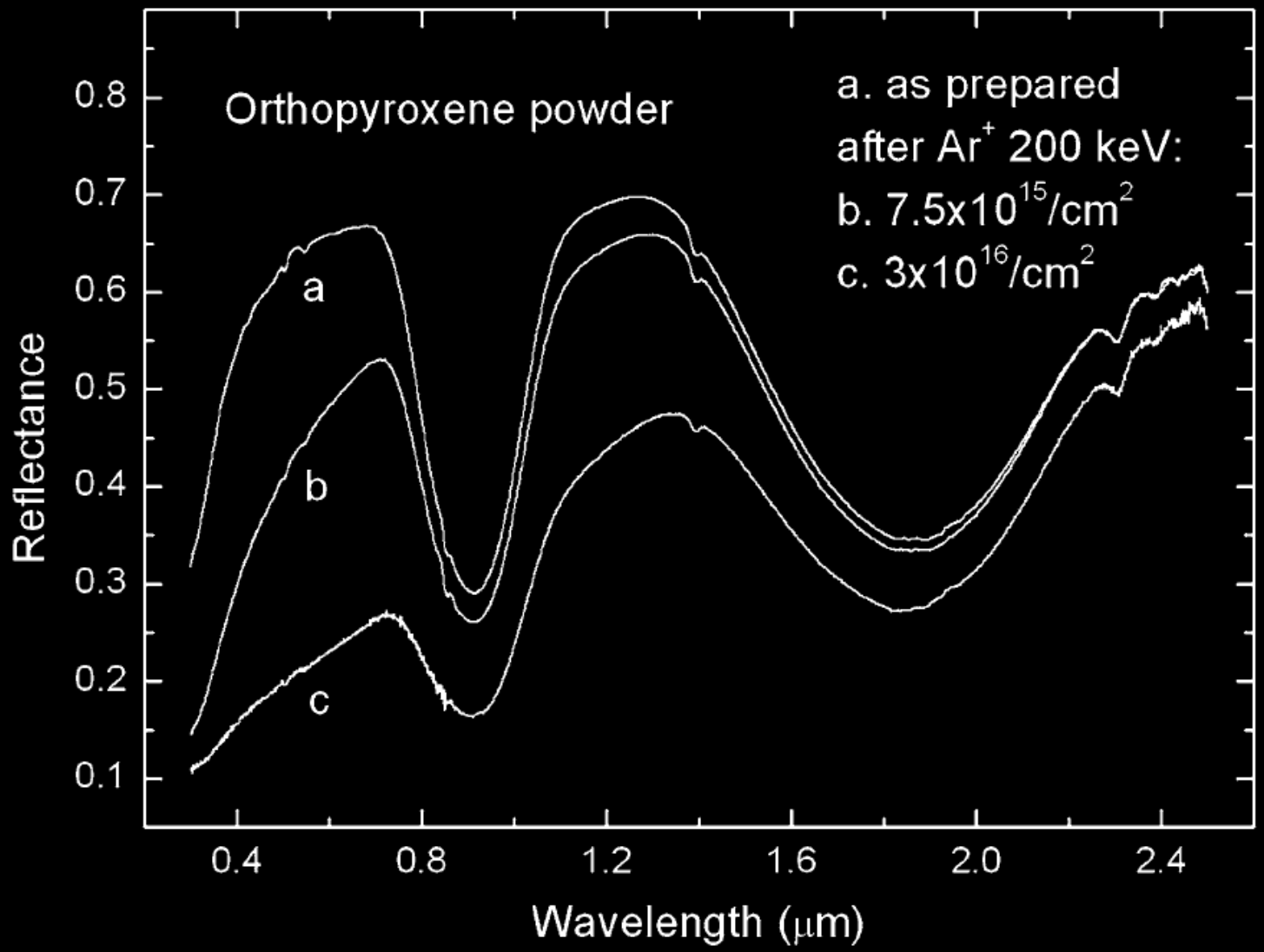
1. SDSS is amazing for asteroids
   - Colors over visible
   - But: miss slow
2. Citizen science program
   - Ephemeris $\leftrightarrow$ FOV
   - Thousands of clicks
   - **Could be avoided!**
3. Built large sample
   - NEAs: 35 $\rightarrow$ 210
   - MCs: 310 $\rightarrow$ 620
   - 40% and 660% *vs* spectra
4. Classify objects
   - Classes in NEAs
   - NEA source regions
   - Surface processes

Asteroid taxonomy



DeMeo et al. 2009

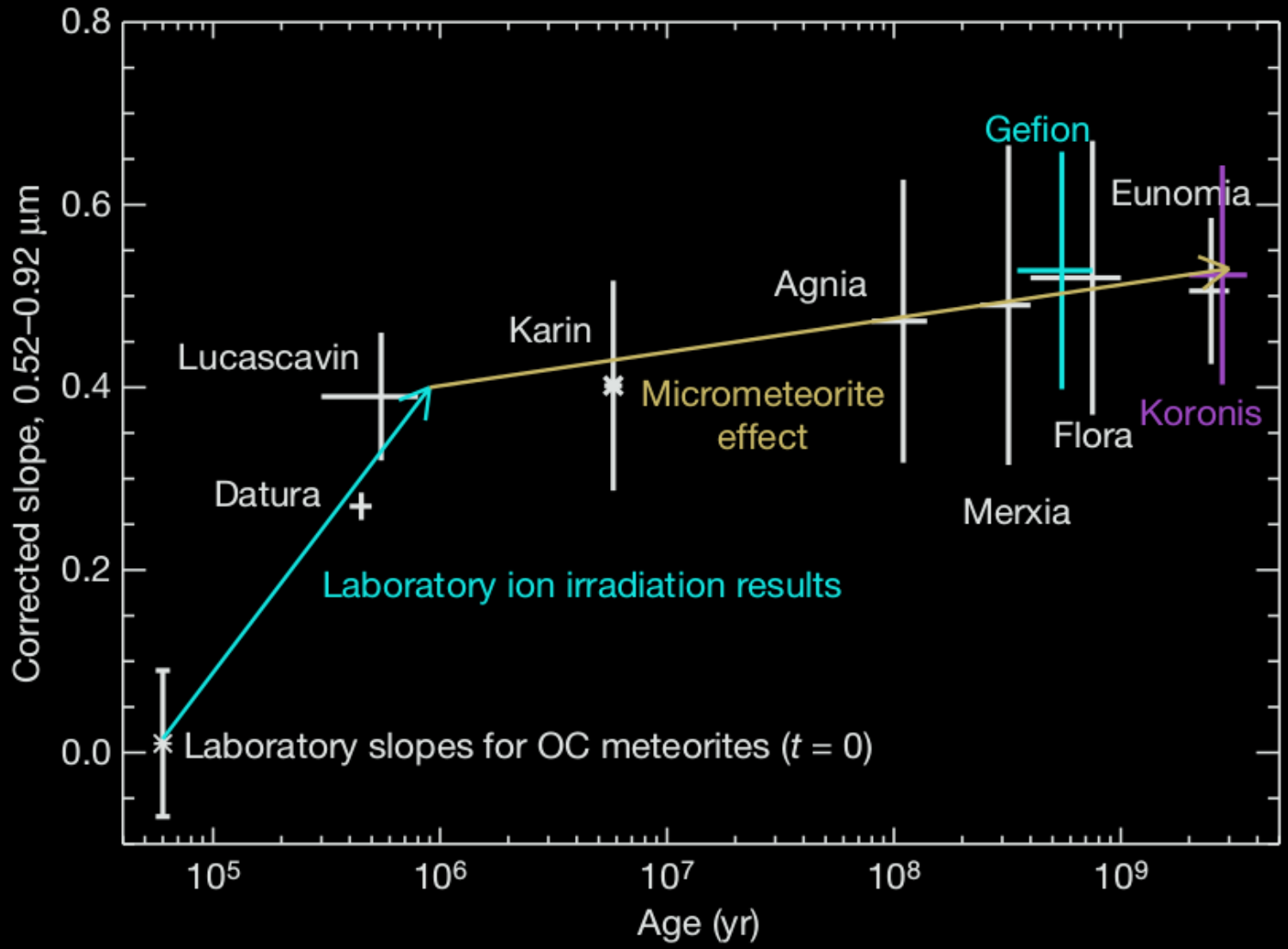
Space weathering effect



Brunetto et al. 2006

→Reddening and darkening

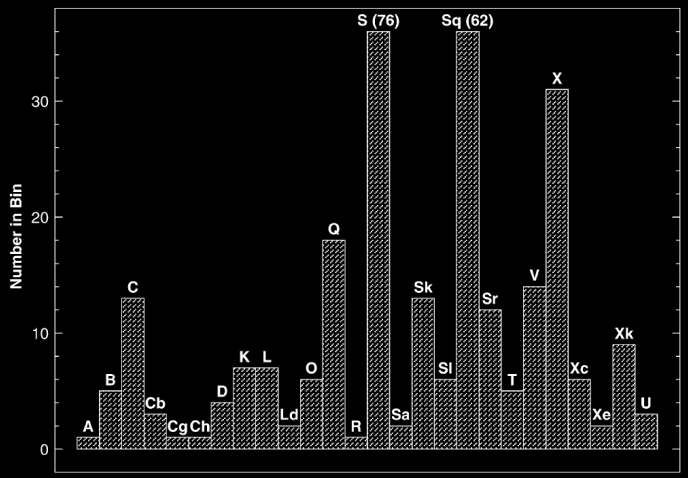
Space weathering timescale



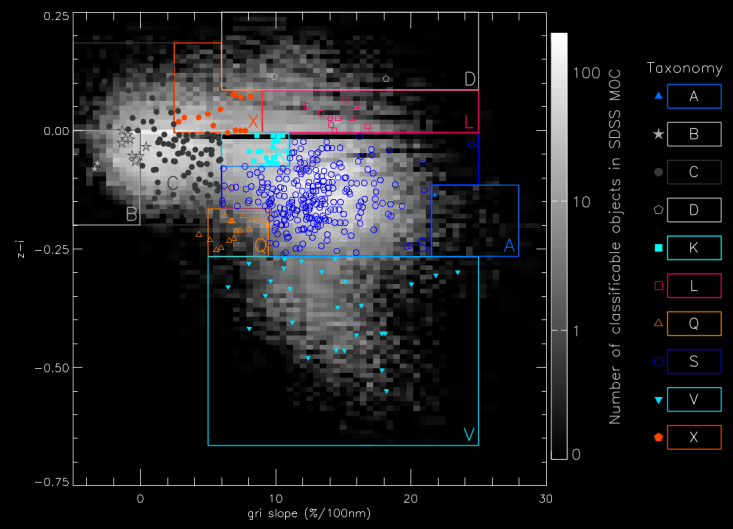
Vernazza et al. 2009

$\rightarrow 10^5$–10^6 years

Existence of fresh NEAs



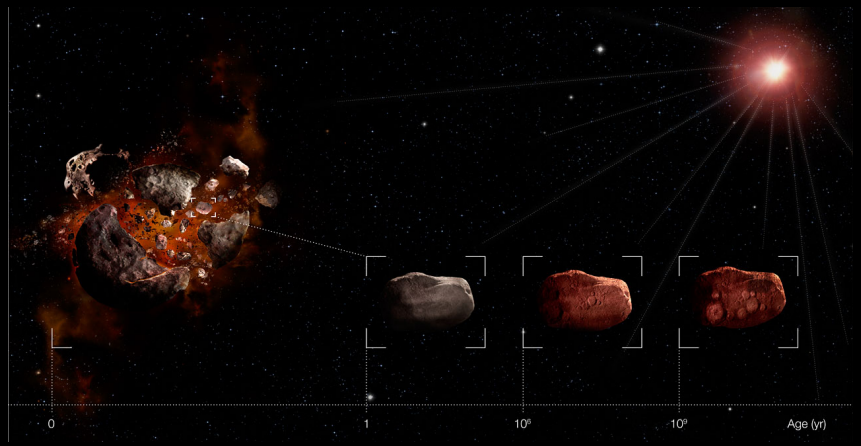
Binzel et al. 2004, 2010



Carry et al. 2016

Rejuvenating processes?

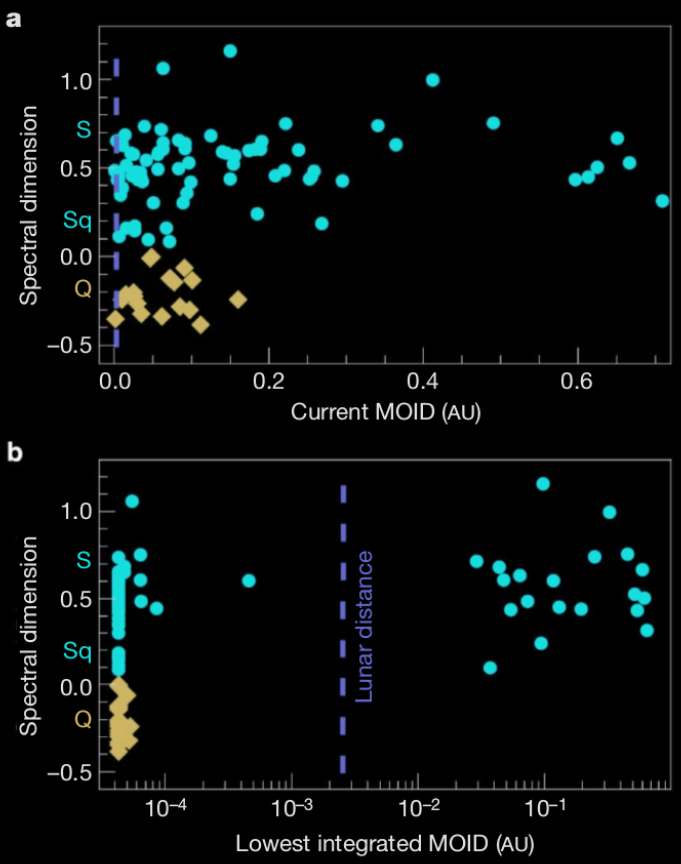
- Collisions
  - Not enough collisions
  - One Q in the MB
- Planetary encounters
  - Qs/types in NEA only
  - Tides during encounter
- YORP spin-up
  - YORP creates binaries
  - Not studied until recently



ESO

Rejuvenating processes?

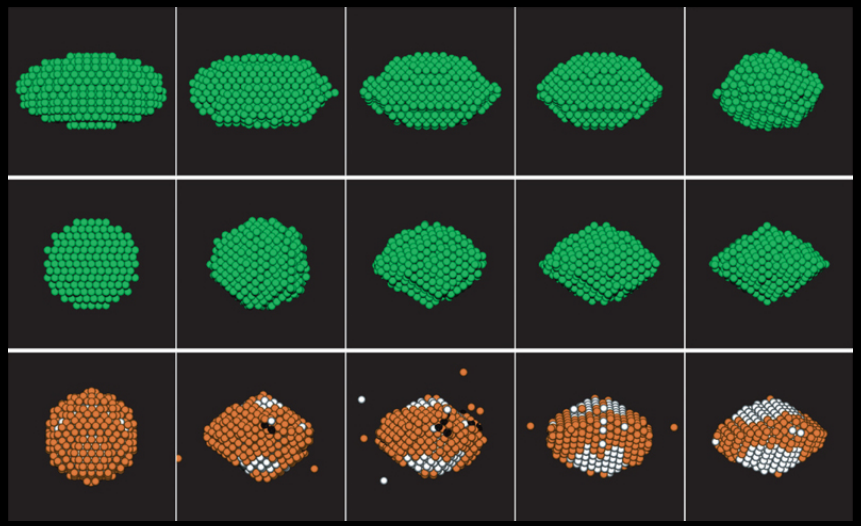
- Collisions
  - Not enough collisions
  - One Q in the MB
- Planetary encounters
  - Q-types in NEA only
  - Tides during encounter
- YORP spin-up
  - YORP creates binaries
  - Not studied until recently



Binzel et al. 2010

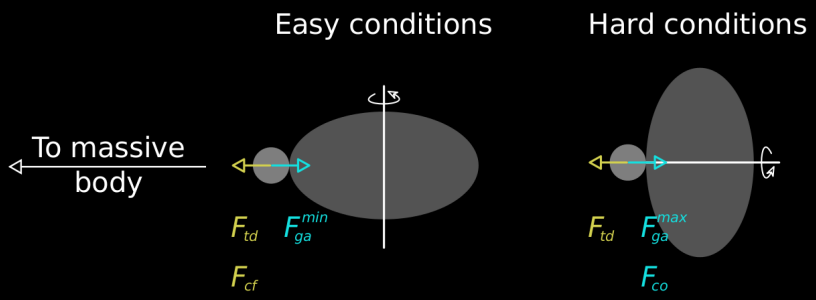
Rejuvenating processes?

- Collisions
  - Not enough collisions
  - One Q in the MB
- Planetary encounters
  - Q-types in NEA only
  - Tides during encounter
- YORP spin-up
  - YORP creates binaries
  - Not studied until recently



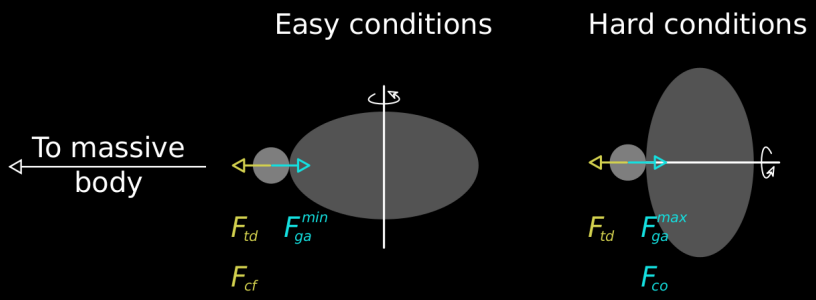
Walsh et al. 2008

Planetary encounters



1. Simple force model on grains
   - Tides, centrifugal forces
   - Gravity, cohesion
2. Set limit cases
   - Fast spinner & obliquity=90
   - Obliquity=0
3. Compare with Q/S history
   - 100 clones per asteroid
   - 1000 ky integration
   - Track errors

Planetary encounters



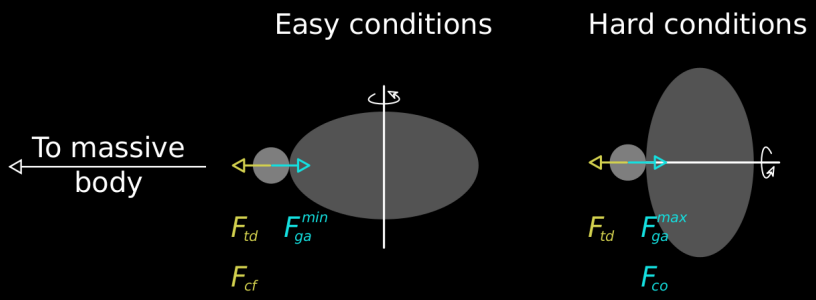
1. Simple force model on grains
   - Tides, centrifugal forces
   - Gravity, cohesion
2. Set limit cases

   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

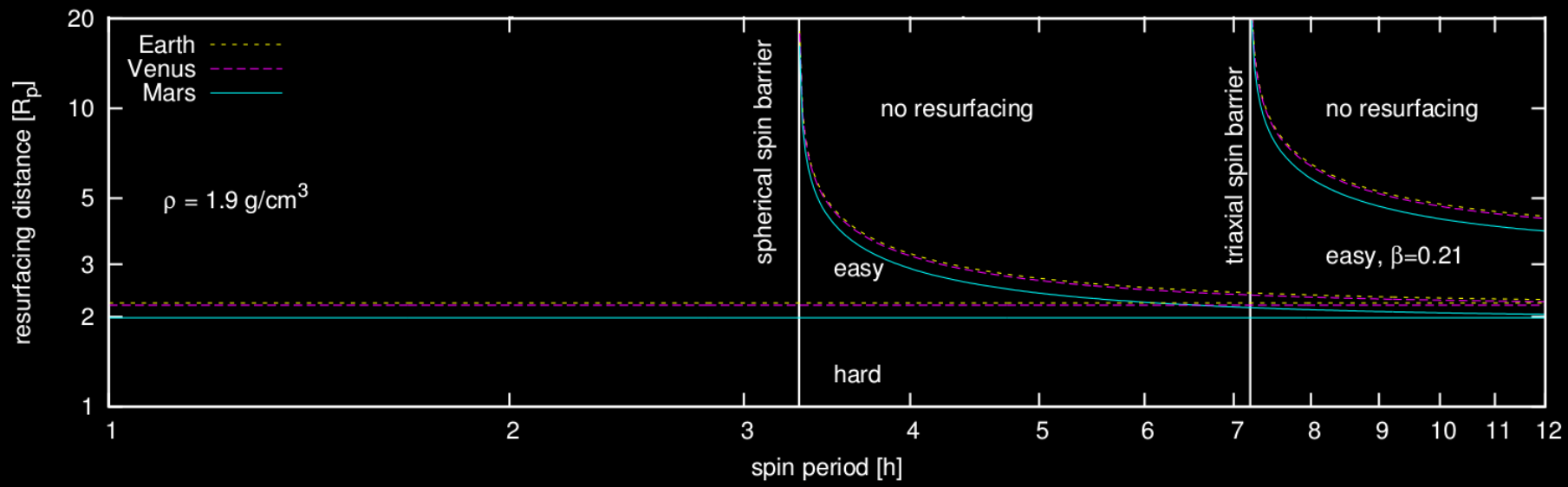


1. Simple force model on grains
   - Tides, centrifugal forces
   - Gravity, cohesion
2. Set limit cases

   easy: Fast spinner & obliquity=90°

   hard: Obliquity=0°
3. Compare with Q/S history
   - 100 clones per asteroid
   - 500 ky integration
   - Track encounters

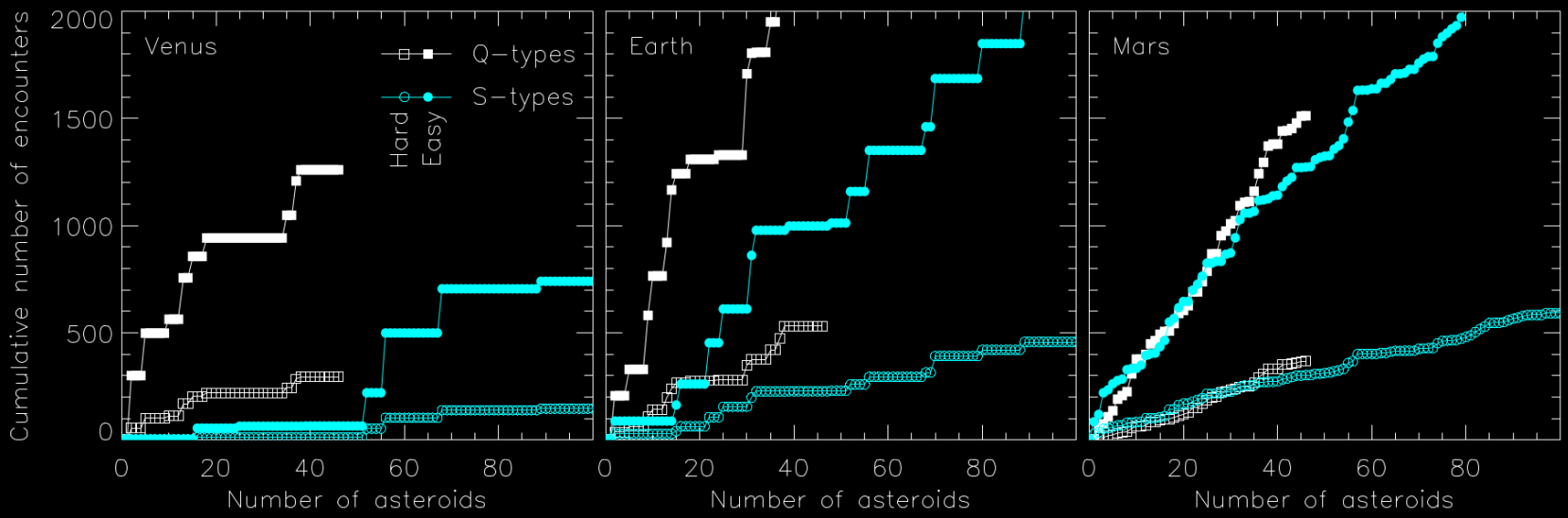
Planetary encounters?



Carry et al. 2016

$\rightarrow 5\ R_p$

Planetary encounters?



Carry et al. 2016

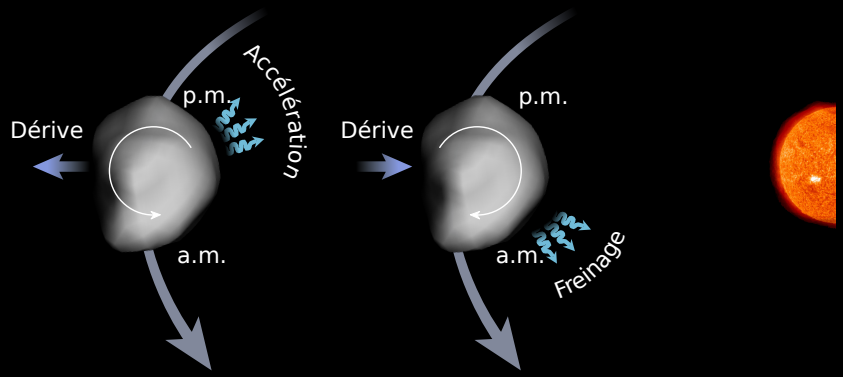
→ Mars?

→ Another process?

YORP fission

1. YORP spins up asteroids

2. Recent YORP study
   - NEAs dyn. integration
   - Simple YORP model
   - Spin threshold



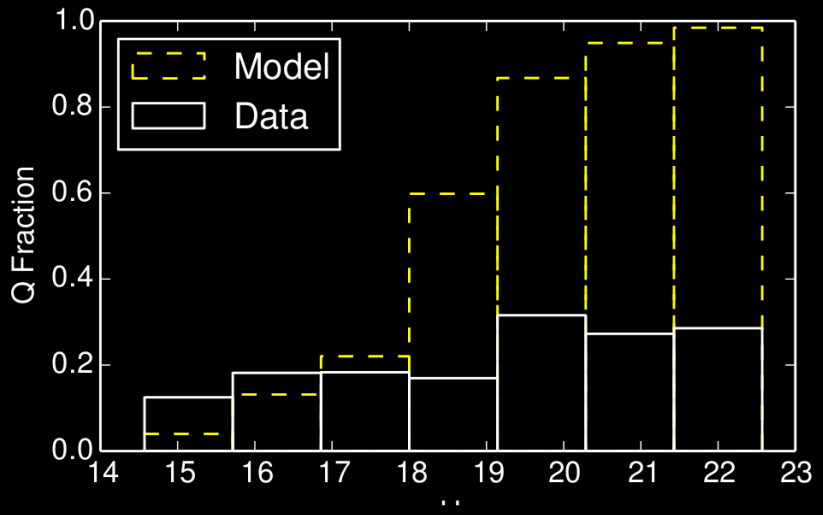
3. Key predictions
   - Q-types in any population
   - Q/S ratio *vs* diameter

YORP fission

1. YORP spins up asteroids

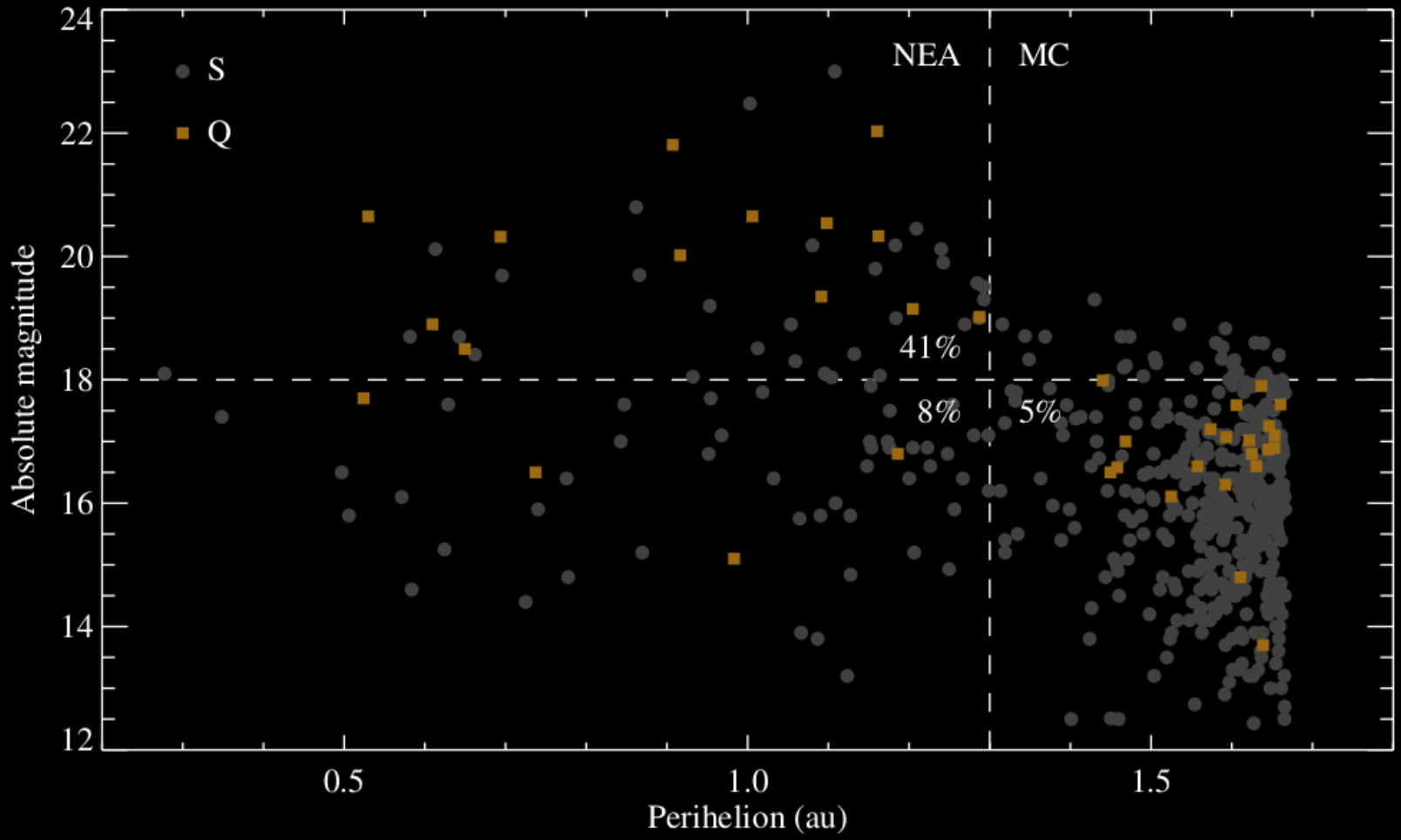
2. Recent YORP study
   - NEAs dyn. integration
   - Simple YORP model
   - Spin threshold

3. Key predictions
   - Q-types in any population
   - Q/S ratio *vs* diameter



Graves et al. 2016

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!