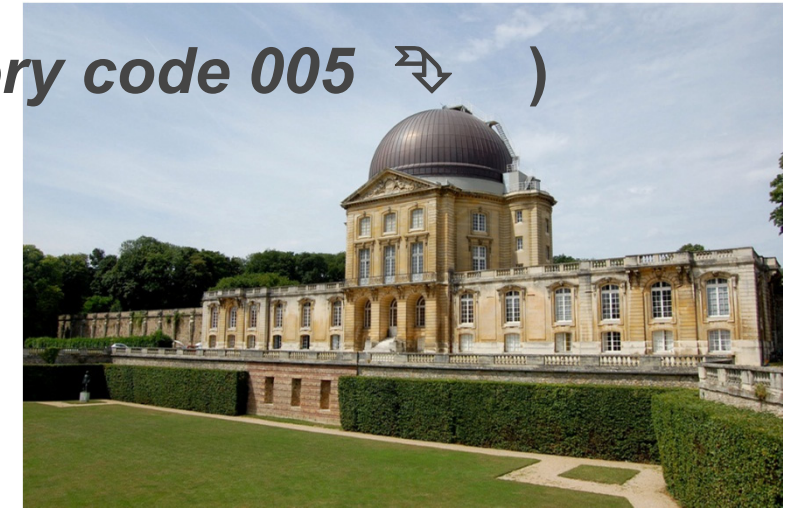
Ground-Based Surveys and the AsteroidFinder Mission

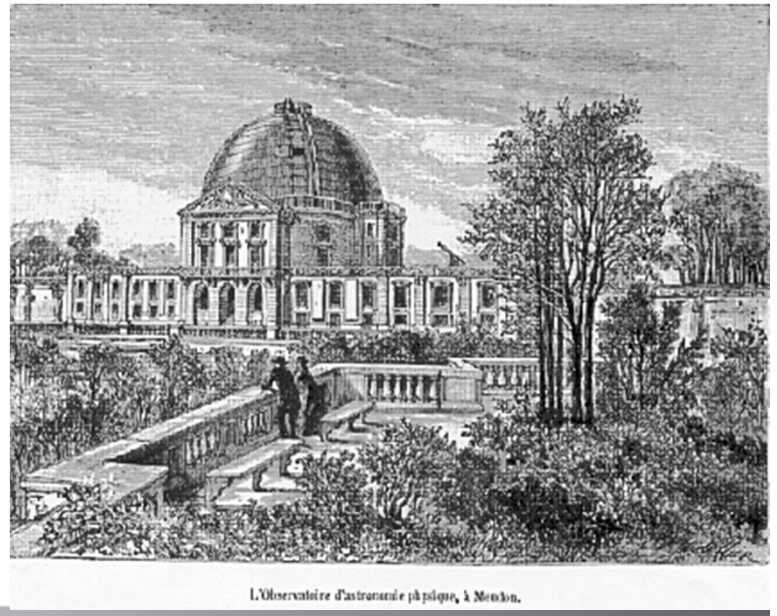
DLR German Aerospace Center

Institute of Space Systems, Bremen

Overview
(as seen from *observatory code 005*)

- a brief history of …
  - visual telescopic searches
  - photographic era surveys
  - CCD era surveys
  - the future
- surface vs space
- AsteroidFinder
- latest news …





L'Observatoire d'astronomie physique, à Meudon.

image: obspm

planetary astronomy:
a history of eyes, minds, and papers

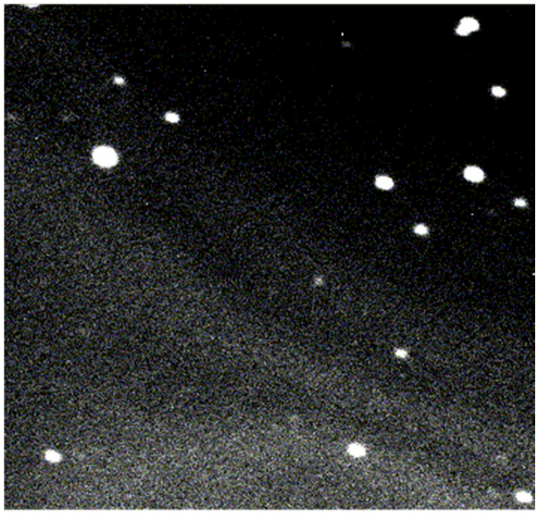
- planets unveil themselves to the patient observer at night
  - πλάνητες ἀστέρες ⇔ planetes asteres ⇔ wandering stars, or
    πλανήτοι ⇔ planētoi ⇔ wanderers
    - 5 to the naked eye, since prehistory *
    - 282287 to the telescope, so far **
- when first discovered, a planetary object
  - is a moving point source among stationary point sources
  - has its location determined to within observational errors in only 3 of 4 dimensions, one of which is time
    - naked eye: ~1' , seconds (Brahe, Kepler, 16th century)
    - nowadays: m" , nanoseconds & radar distance and line-of-sight velocity
- the 4th dimension can only be computed from follow-up observations over time continuously refining an orbit

* Uranus and Vesta can be naked-eye objects – ** (282027) 5069 T-3 highest-numbered object as of 2011 Jun 17, + 8 planets, + 252 numbered comets

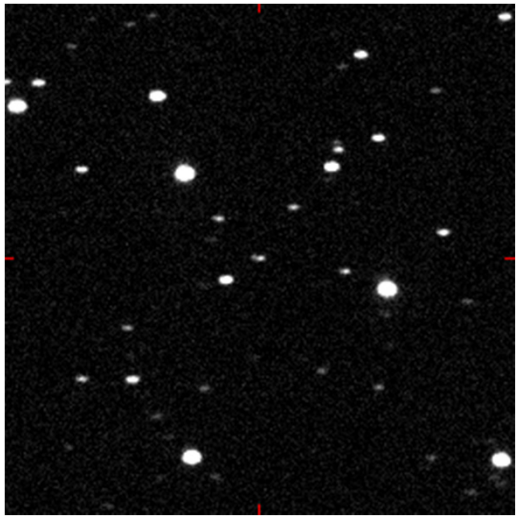
image: Ian Pass via spaceweather.com

motion in the noise floor: planet, star, or cosmics?

search



follow-up



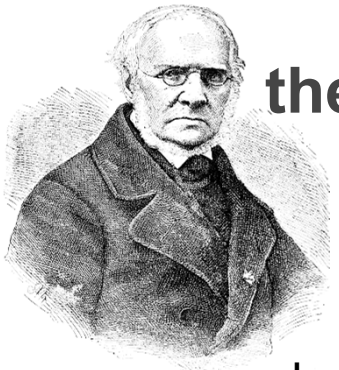
- select a part of the sky expected to yield a high flux of objects
- revisit periodically, ≥3 exposures
- check for changes
- filter for dots moving along a line

- pan with the expected motion of a discovered object
- track as long as possible
- check for deviations
- refine orbit using reference stars

the first survey: „Himmelspolizey“ – international and coordinated from the start

- based on J. de Lalande‘s zoned cooperative survey idea presented at the First European Astronomers Congress (Seeberg Observatory, Gotha, Aug.1798)
- survey collaboration organized by F.X. von Zach & J.H. Schröter,
  - formally established with the founding of the *Astronomische Gesellschaft* at the 2nd European Astronomers Congress (Lilienthal near Bremen, 1800) – the *A.G.* is still active today.
  - based in Weimar (von Zach) and Lilienthal / Bremen (Schröter / H.W.M. Olbers)
- one simple scientific goal: validate Titius-Bode Law by discovery of the „missing planet“ between Mars and Jupiter @ ~2.8 AU
  - ecliptic sky region divided into 24 parts of 15° longitude and ±7 or 8° latitude, assigned to observers
  - extensive ground-breaking work required (star catalogues to be improved, etc)
- 1.1.1801: lucky find of Ceres by Guiseppe Piazzi (who had not been a member) during star chart verification – and right before conjunction with the Sun
- recovery of Ceres by von Zach (7.12.1801) and Olbers enabled by C.F. Gauß in conjuction with other Himmelspolizey observers – would have been lost otherwise
  - first astronomical journals established (*Monatliche Correspondenz*, later *Correspondance Astronomique*) to replace P2P and circulated letters
  - development of new orbit determination methods (e.g. least squares by C.F. Gauß)
- established science against the supremacy of philosophy (e.g. Hegel‘s limit of 7 planets based on Platonic eq.)

images: historic, via de.wikipedia.org



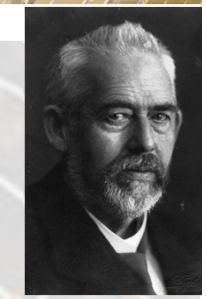
the first amateur: Karl Ludwig Hencke – temperance, Astraea and Hebe

*1793 - †1866, life-time astronomical observer

- became a post official, after being wounded at Großgörschen
- drew star maps in correspondence with Encke during his working life
  - compiled >200 star maps; in parallel to Argelander and others, now in Berlin Academy Library
  - after his retirement in 1837, fully dedicated to astrometric work, although he could not publish maps
- discovered (5) Astrea and (6) Hebe in 1845 and 1847,
  - ***38…40*** years after (4) Vesta
  - professional astronomers had declared the solar system complete
  - jump-started asteroid search ➔ 8 major planets (Humboldt 1851)

- K.L. Hencke was rewarded in 1847 with an annual salary of honour of 1200 Goldmark by the King of Prussia for the discovery of the two asteroids, Astraea and Hebe; today approximately
  - 1200 ℳ ≅ 14500 € by gold value as of mid-2011 (10062 to 18480 € by accepted conversion rules)
  - >180000 € per year by contemporary national-average working hour gross purchase power
    - enjoyed this benefit for more than 19 years until his death in 1866…
- 1848 March Revolution context: Astraea – Goddess of Justice, Hebe – Goddess of Youth

visual and early photographic era surveys



- Himmelspolizey branches into various topics
  - eliminate disturbances: variable stars, novae, astrometry …
  - „Durchmusterung“ (stellar) ➔ “survey“ (now mainly non-stellar)
    - traditional methods and new technologies
- Johann Palisa
  - purely visual, observed 1874-1923, 122 discoveries (#71 of Minor Planet Discoverers according to the MPC list as of 2011 Jun 17)
  - Pula: 15 cm, then Vienna: 68 cm, largest refractor at the time
- Max Wolf
  - photographic, observed 1891-1932, 228 discoveries (#44)
  - 2 * 40 cm Bruce Dual Astrograph at Heidelberg-Königstuhl observatory: donation by Catherine Wolfe Bruce, NYC, USA
- around 1900, Palisa and Wolf tried to re-establish an organized survey akin to the Himmelspolizey of the early 1800‘s – only limited success

photographic era surveys: now and then, here and there, Europe and U.S.

- several long-term surveys were carried out
- mostly no or limited coordination, if any parallel work
- often at sites considered too limited for „real“ astronomy
- sometimes amateurs with observatory access

- E. Delporte – 1925-1942, 66 discoveries (#110 shared with A. Kopff)
- Debehogne – 1965-1994, 617 discoveries (#22)

- van Houten et al – 1960-1977, 4466 discoveries, (#7 & #682)
- the Shoemakers et al – 1980-1994, 385 discoveries (#52, #55, #150, #289, #568 (twice) & #844 (thrice))

images: astro.oma.be, usgs.gov

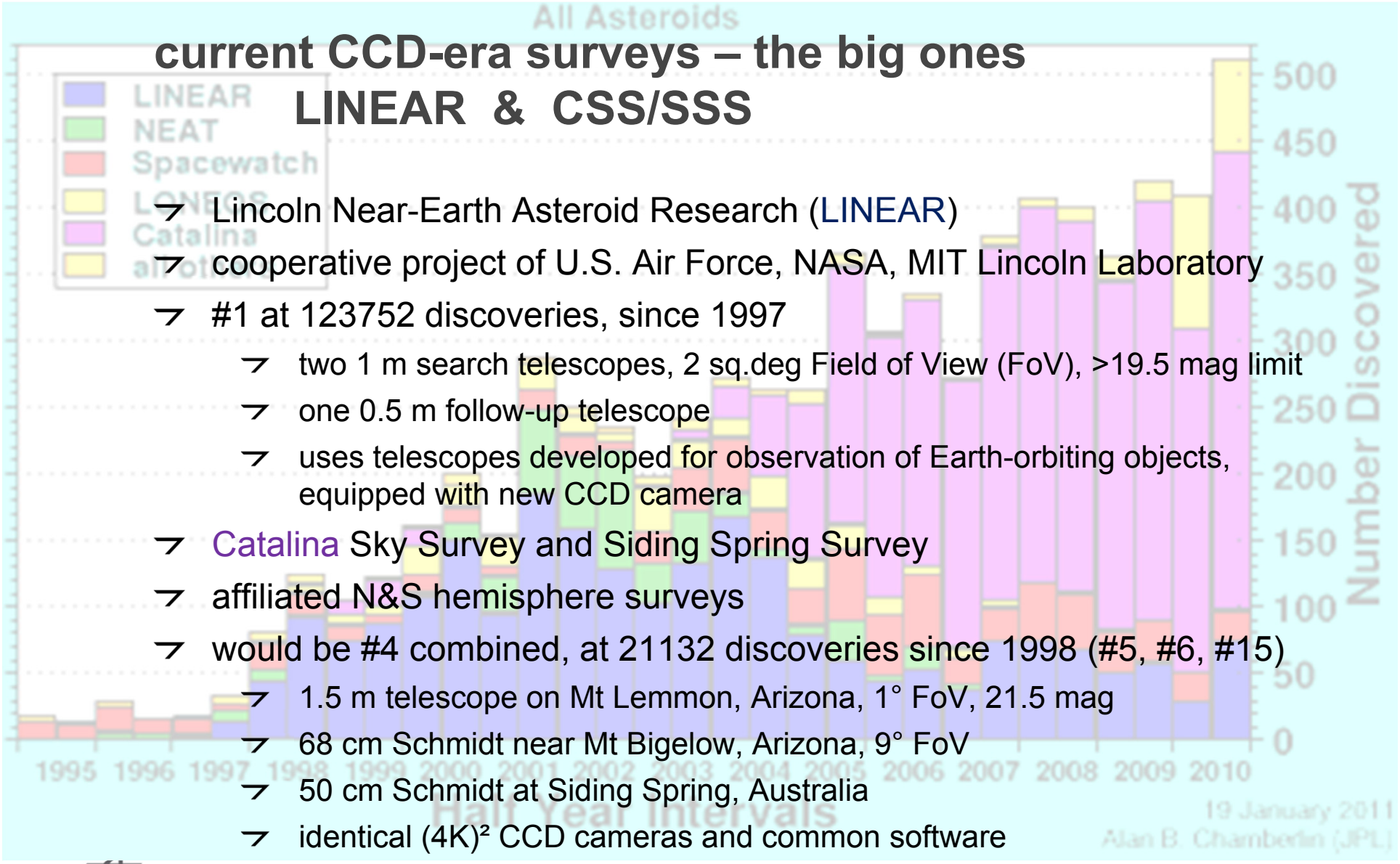
CCD-era surveys: Spacewatch®
the first big CCD survey – active since 1985

- broad small solar system bodies survey
- founded 1980 by T. Gehrels and R.S. McMillan
- 43735 discoveries 1985-2010 (as of 2011 Jun 17, #2)
- CCD-scanning observations 20 nights/lunation
- Steward Observatory 0.9 m Spacewatch Telescope, Kitt Peak
- new Spacewatch 1.8 m Telescope, Kitt Peak (since 2002)

- continuously improved
  - from one 320x512 CCD to mosaic of four 4608x2048 CCDs
  - from 19.6 to 22 mag limiting magnitude
  - from 1.733 to 1 arcsec/pixel

images: 0.9m Robert McMillan, 1.8m Alain Maury (both spacewatch.lpl.arizona.edu)

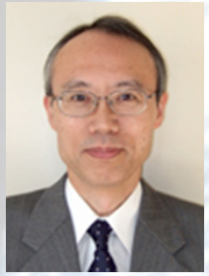
current CCD-era surveys – the big ones
LINEAR & CSS/SSS



- Lincoln Near-Earth Asteroid Research (LINEAR)
- cooperative project of U.S. Air Force, NASA, MIT Lincoln Laboratory
- #1 at 123752 discoveries, since 1997
  - two 1 m search telescopes, 2 sq.deg Field of View (FoV), >19.5 mag limit
  - one 0.5 m follow-up telescope
  - uses telescopes developed for observation of Earth-orbiting objects, equipped with new CCD camera
- Catalina Sky Survey and Siding Spring Survey
- affiliated N&S hemisphere surveys
- would be #4 combined, at 21132 discoveries since 1998 (#5, #6, #15)
  - 1.5 m telescope on Mt Lemmon, Arizona, 1° FoV, 21.5 mag
  - 68 cm Schmidt near Mt Bigelow, Arizona, 9° FoV
  - 50 cm Schmidt at Siding Spring, Australia
  - identical (4K)² CCD cameras and common software

more CCD-era surveys:
retired veterans and „others“ at the top

- NEAT (1995-2007) & LONEOS (1998-2008) still #3 & #4 at 28630 and 16563 discoveries, respectively



Takao Kobayashi, Professor at the Interdisciplinary Graduate School of Science and Engineering at the Tokyo Institute of Technology

- 2469 discoveries in 1991-2002 (#9, #682), at the 25 cm telescope of the Oizumi Observatory, Gunma Prefecture (IAU observatory code 411)

William Kwong Yu ‘Bill‘ Yeung

- 1726 discoveries in 1999-2008 (#10, #682); from Rock Finder Observatory near Calgary (652), and later, Desert Beaver Observatory (919), Desert Eagle Observatory (333) in Arizona, using an 18’’ (45 cm) telescope
- discovered J002E3, the Saturn IVB stage of Apollo 12 in interplanetary orbit

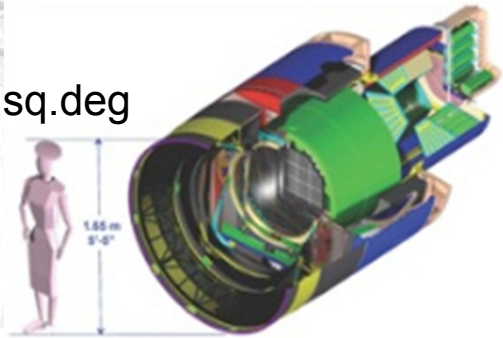
yet more CCD-era surveys: the DLR cooperations ODAS – ADAS – UDAS

- Observatoire de la Côte d'Azur (OCA) – DLR Asteroid Survey
  - Oct.1996-Apr.1999, 15 nights/month, 906 discoveries, still #17 at MPC
  - 2k CCD camera at the 90 cm Schmidt of OCA at Calern (N of Nice)
- Uppsala Astronomical Observatory (UAO) – DLR Asteroid Survey
  - 1999-2005, 208 discoveries, still #48 at MPC
  - $(2K)^2$ CCD camera at the 1 m Schmidt of the UAO at Kvistaberg
- Asiago – DLR Asteroid Survey
  - 2001-2003, 142 discoveries, still #61 at MPC
  - $(2K)^2$ CCD camera at the 67/92 cm Schmidt at Asiago-CimaEkar
- 3 dedicated programmes to search and follow-up asteroids and comets, with special emphasis on NEO's in cooperation and support of global efforts in NEO-research, initiated by the WGNEO of the IAU, and the Spaceguard Foundation

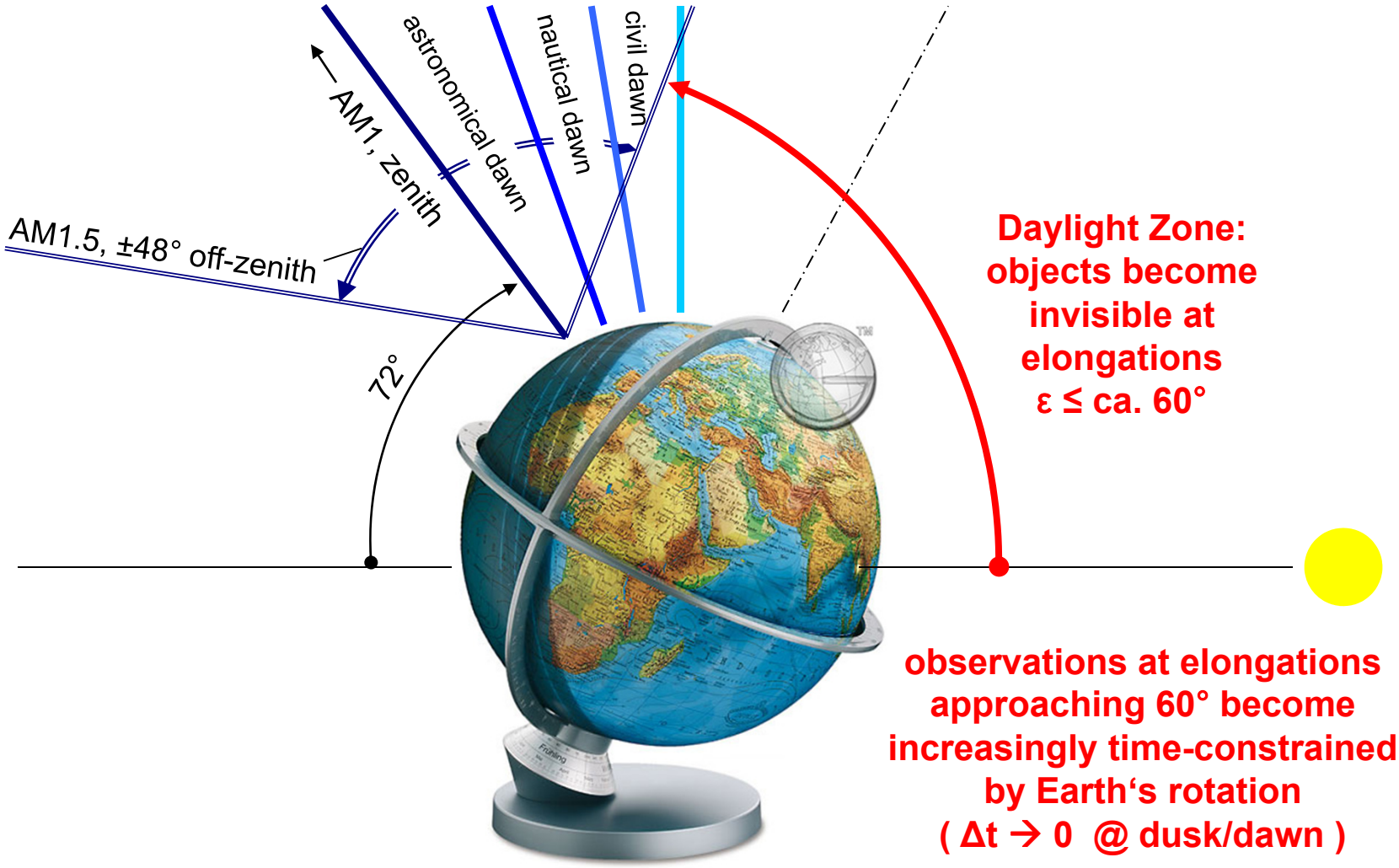
future surveys
North & South, PanSTARRS & LSST

- back to the roots: comprehensive surveys with multiple goals
- other science goals provide enough instrument power for any present NEO-related goal – we‘re no longer a requirem€nt$ driver!
- Panoramic Survey Telescope and Rapid Response System
  - 1.8 m, 3° FoV, 1400 Mpixel, 0“.3 resolution, 6000 sq.deg/night
  - accesible sky imaged 3 times per lunation to 24 mag limit
  - motion compensation without moving parts – OTCCD
  - PS1 in 2010: #682, shared with H.W. Olbers, K.L. Hencke, S. Mottola (twice) & >100 others ;-)
- Large Synoptic Survey Telescope
  - 8.4 m, 3.5° FoV, 3200 Mpixel, 0“.2 resolution, 18000 sq.deg
  - engineering first light expected 2017
  - operational by 2020

note: this is just the LSST camera, not the LSST telescope! ☺ ➔



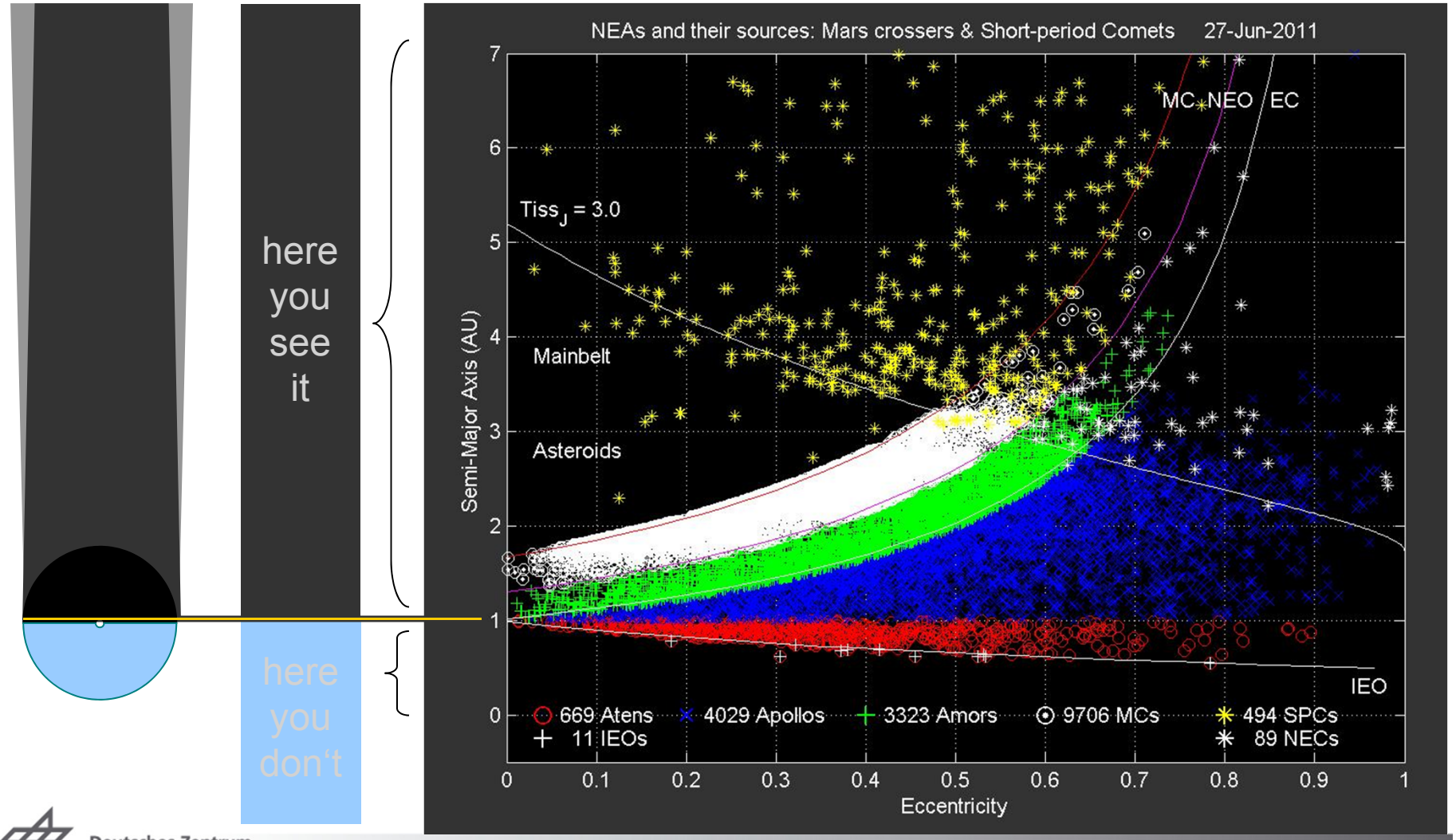
„the sky is the limit“



Daylight Zone: objects become invisible at elongations ε ≤ ca. 60°

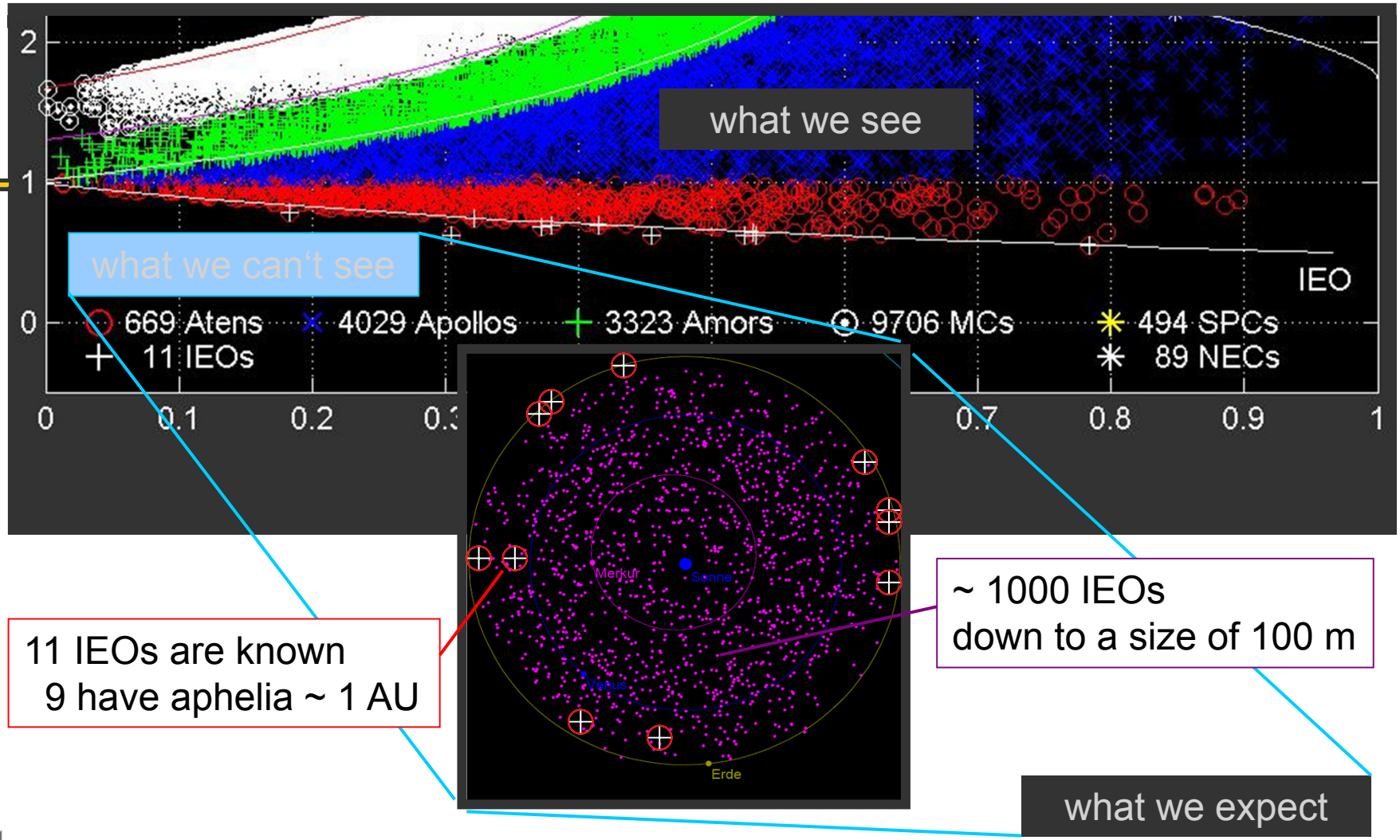
observations at elongations approaching 60° become increasingly time-constrained by Earth‘s rotation (Δt → 0 @ dusk/dawn)

the sky-limited view

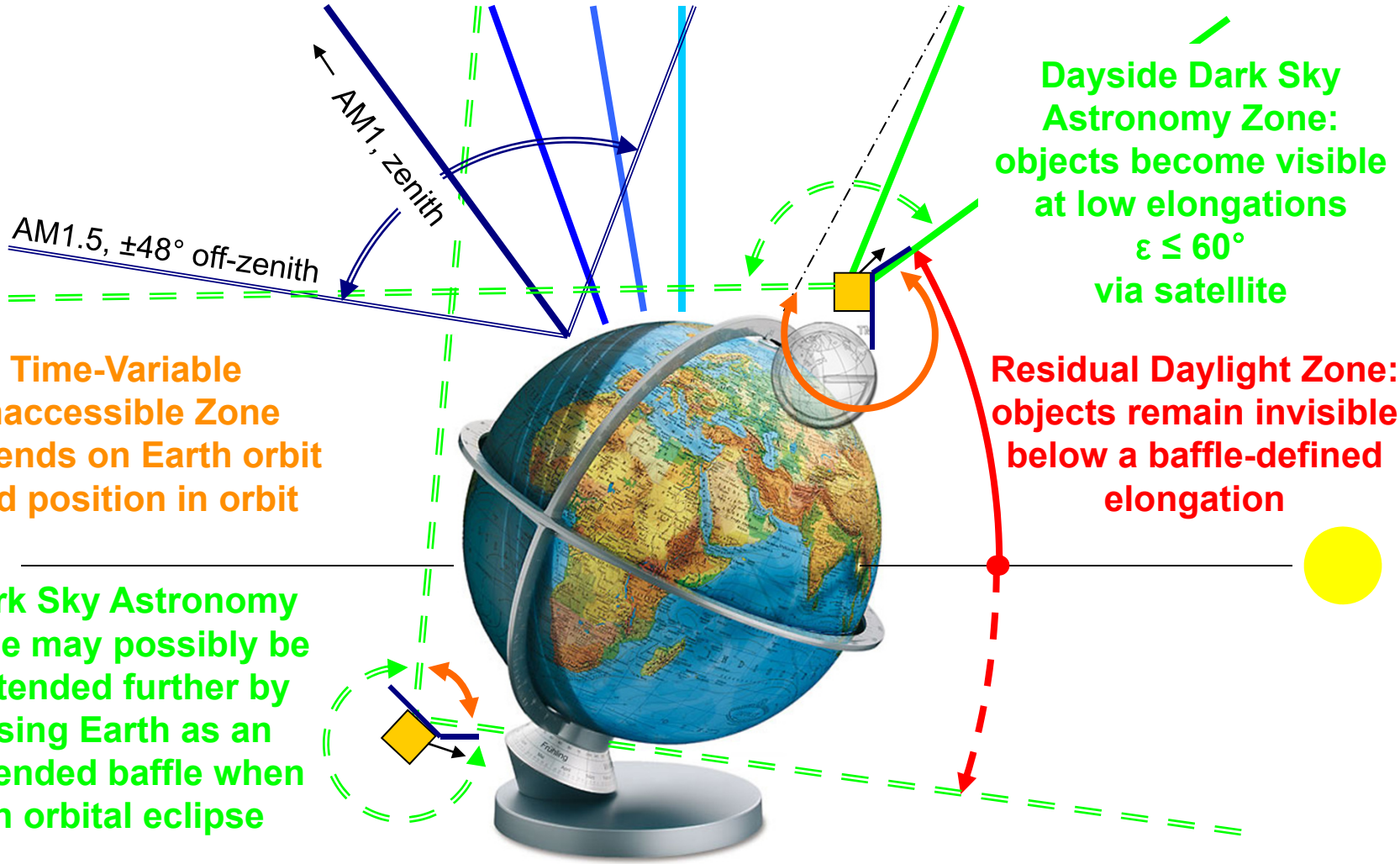


images: EARN / DLR

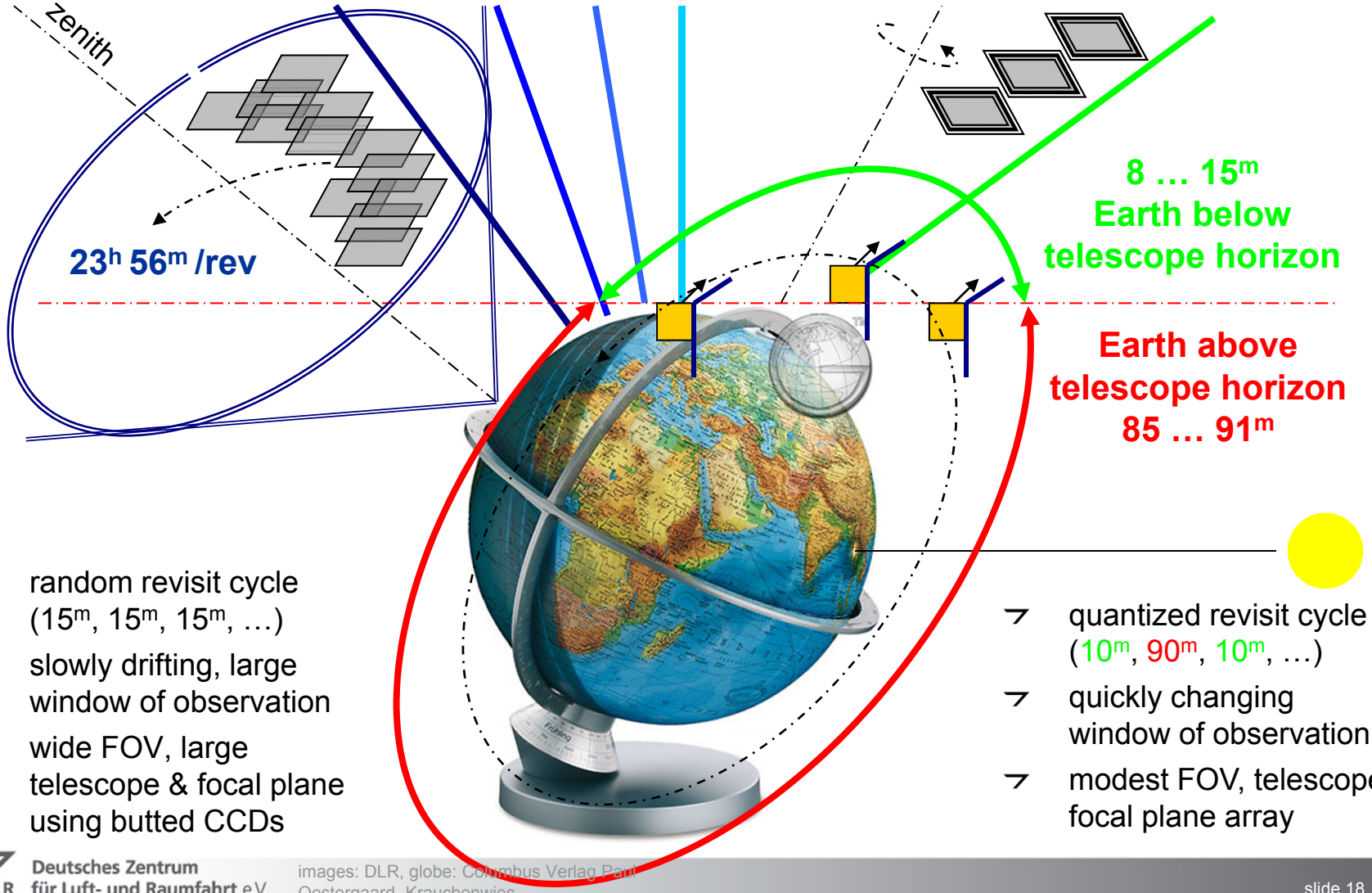
11 IEOs grazing the visibility borderline … of 1000



above the sky: AM0 on a sunny day



from the ground up: motion detection & orbital motion



- random revisit cycle (15m, 15m, 15m, …)
- slowly drifting, large window of observation
- wide FOV, large telescope & focal plane using butted CCDs

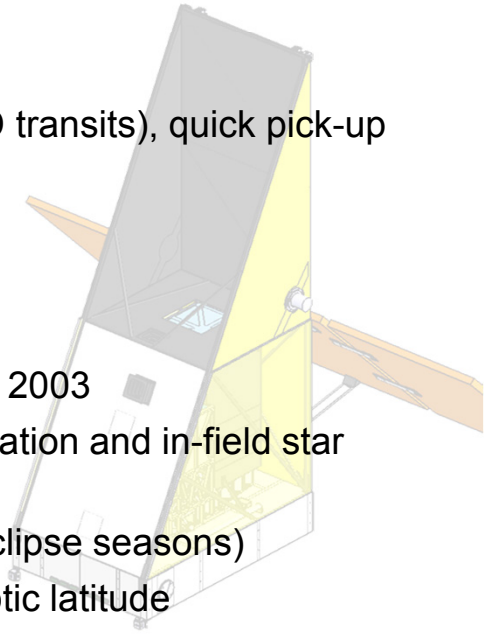
- quantized revisit cycle (10m, 90m, 10m, …)
- quickly changing window of observation
- modest FOV, telescope, focal plane array

images: DLR, globe: Columbus Verlag Paul Oestergaard, Krauchenwies

into the great black yonder: NEOSSat, Gaia & AsteroidFinder

- NEOSSat – launch early 2012
  - 15 cm telescope, like spacecraft based on MOST, polar low Earth orbit
  - 0.86° FoV, $(1K)^2$ CCD camera with on-axis star tracker, 20 mag in 100 s
  - shared with Canadian space debris tracking programme in the first year
  - region of interest 45…55° elongation, ±40° ecliptic latitude

- Gaia – launch 1Q2013
  - stellar astrometry mission at L2
  - SSSB ‚picket fence' characteristics, 2 detections (several CCD transits), quick pick-up by other observer required, or object is lost
  - circular sky scan down to elongations ≥ 45° at one point

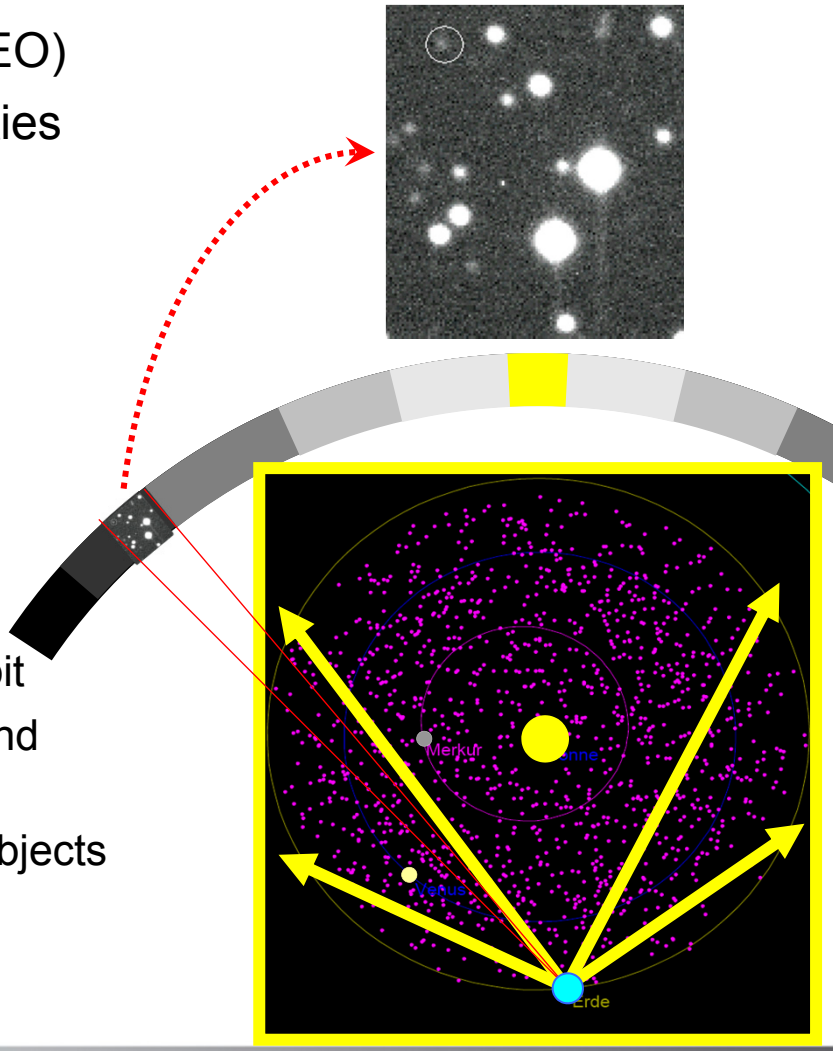


- AsteroidFinder – launch in late 2014
  - 25 cm class telescope, evolved from Earthguard-1 proposal of 2003
  - mosaic of four $(1K)^2$ EMCCDs with electronic motion compensation and in-field star tracker function
  - minimum elongation ≤30° (less may be possible in orbital eclipse seasons)
  - primary region of interest 30…60° ecliptic longitude, ±40° ecliptic latitude

the task: unveil planets to the patient observer at day

- find objects Interior to Earth‘s Orbit (IEO)
- determine and catalogue their properties
  - population
  - orbital properties
  - size-frequency distribution
  - classes, groups, and families

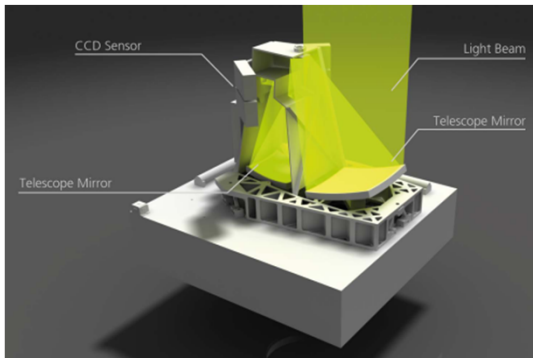
- make use of the non-IEO background for night-like dayside astronomy
  - detect and track objects in Earth orbit
  - detect and track non-IEOs and extend known orbital arcs on the dayside
  - detect and monitor variable stellar objects (stars, supernovae,…)
  - monitor diffuse background

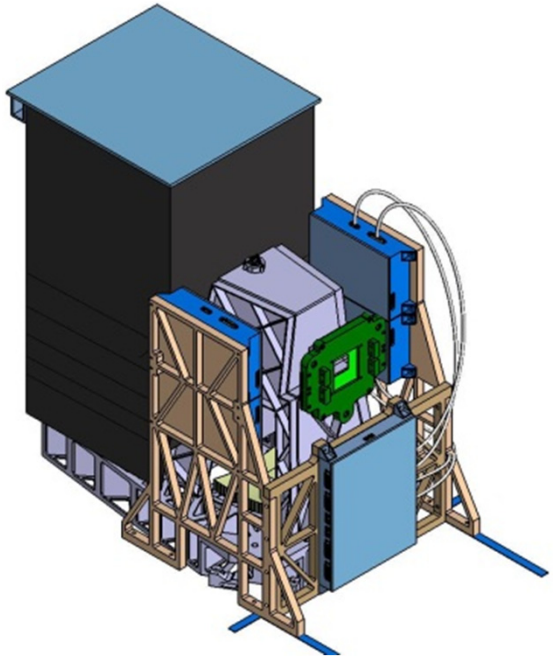


images: EARN / DLR, also via wikipedia

the instrument: advanced optics and electronics

- 3-mirror off-axis telescope design
  - efficient aperture w/o central secondary
  - high straylight suppression
    - Sun : asteroid ~ 10^{18} : 1
    - planet : asteroid ~ 10^{8} : 1
    - asteroid : background ~ 4 : 1
  - high volume utilization
- electron-multiplied CCD sensors
  - fast read-out noise suppression
  - moderate cooling required, T ≤ -80°C
  - registered stacking to remove cosmics and jitter
- 2880 sq.deg/day coverage, net FoV (2°)²
- astrometric accuracy 1“ (1σ)
- 1 year of operations
- limiting magnitude >18.5 mag V in 60s exposure
  - detection SNR > 5





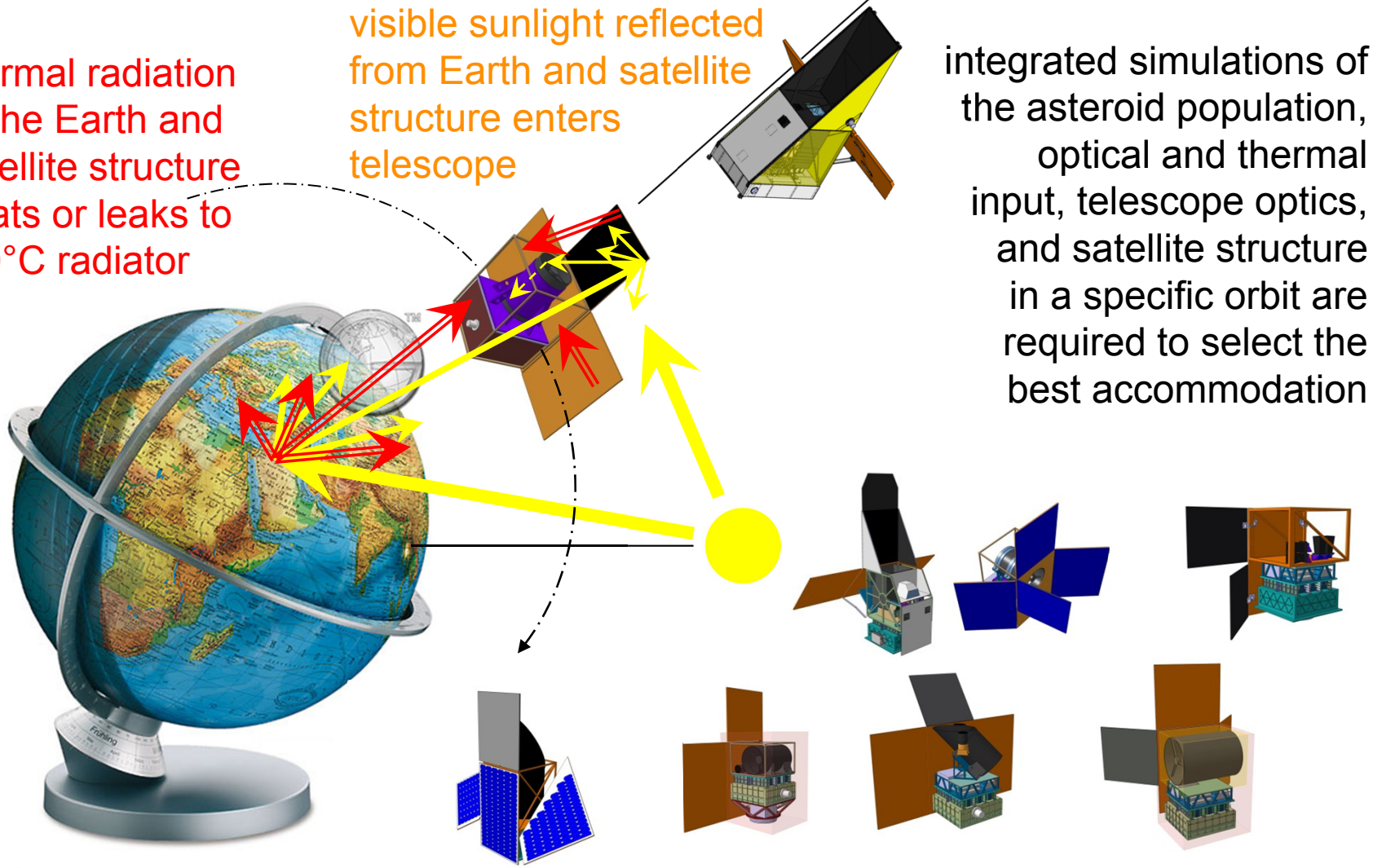
images: DLR

baffling adventures: breaking the sunlight barrier

thermal radiation of the Earth and satellite structure heats or leaks to -80°C radiator

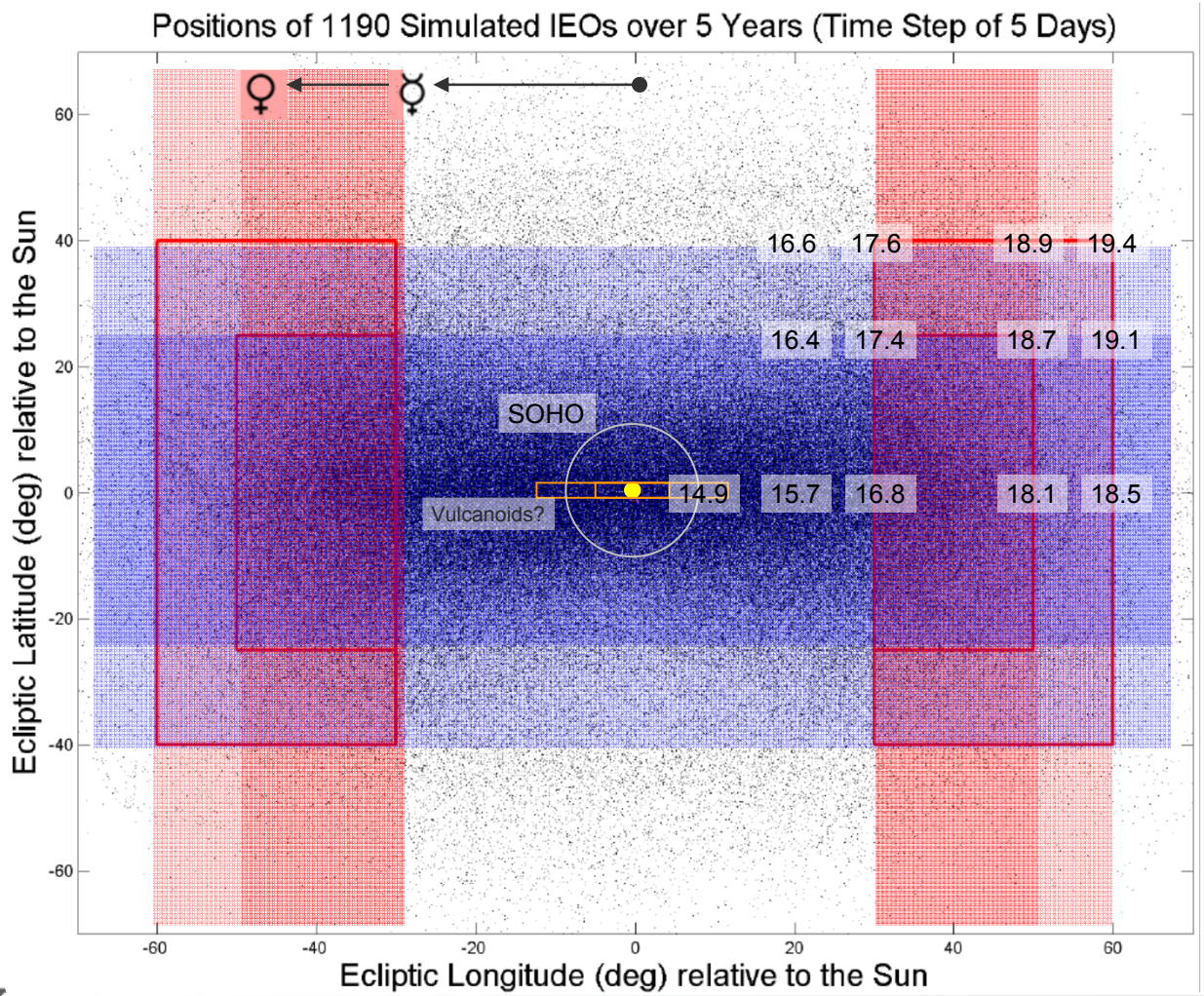
visible sunlight reflected from Earth and satellite structure enters telescope

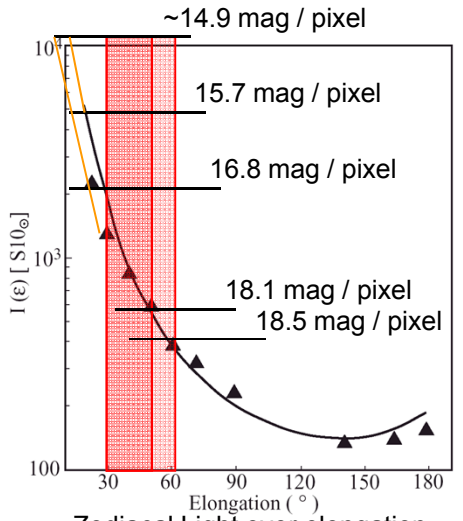
integrated simulations of the asteroid population, optical and thermal input, telescope optics, and satellite structure in a specific orbit are required to select the best accommodation



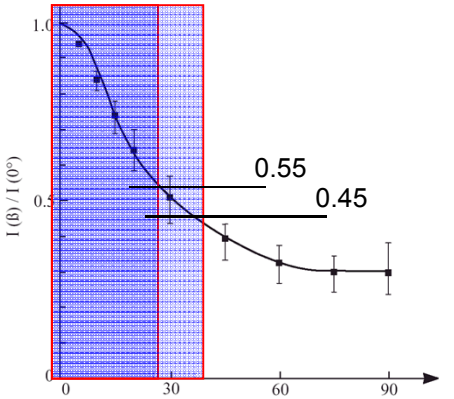
images: DLR, globe: Columbus Verlag Paul Oestergaard, Krauchenwies

found in the glare: pebbles vs dust





Zodiacal Light over elongation



Zodiacal Light rel.to 0° declination

AsteroidFinder spacecraft overview

- project start in 2007
- part of the DLR Research and Development ‚Kompaktsatellit' programmatic line
- extensive use of BIRD and TET heritage
- Sun-synchronous terminator orbit at 600…650 km, LTAN ~06:00
- 180 kg, 1100 · 811 · 2230 mm³ (stowed)
- fixed-deployable solar array, 517 W
- in-house developed C&DH with Middleware architecture and high reliability
- S-band telecommand and housekeeping
- X-band payload data downlink, 28.4 GiB/day
- 3-axis, 3 DoF attitude control, no propulsion
- slew agility 5° in 1 minute
- relative pointing error <0".875 / exposure

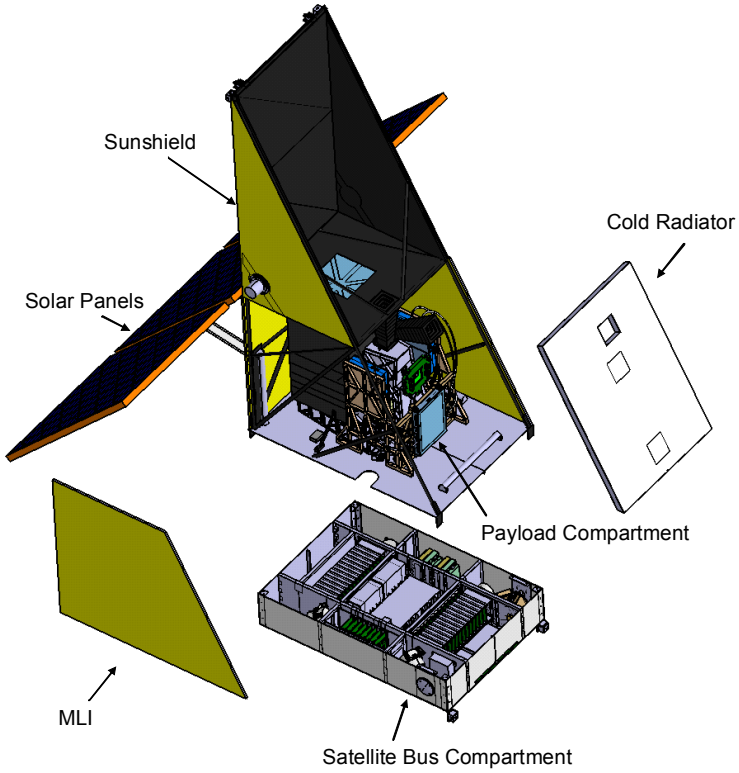
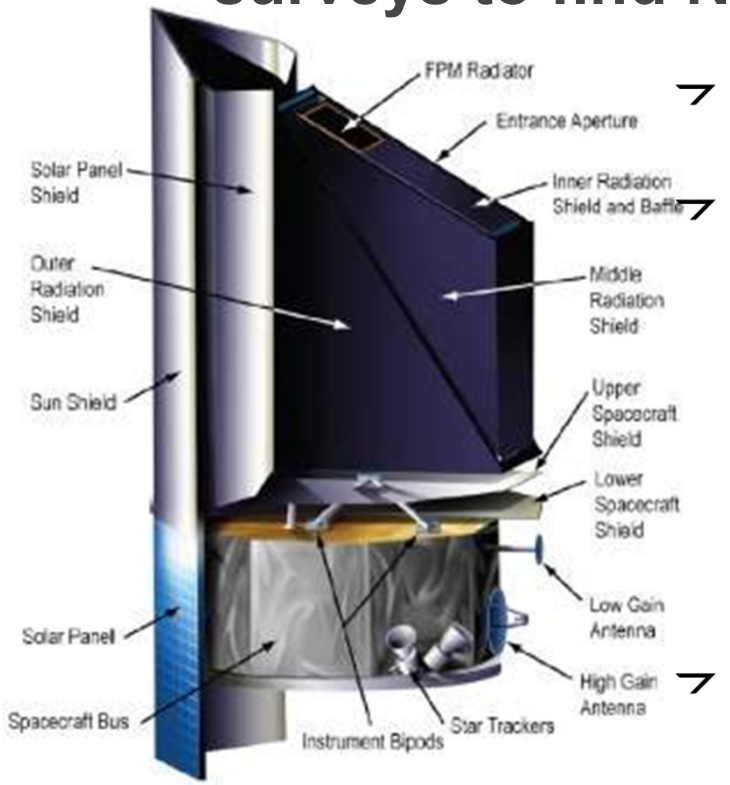


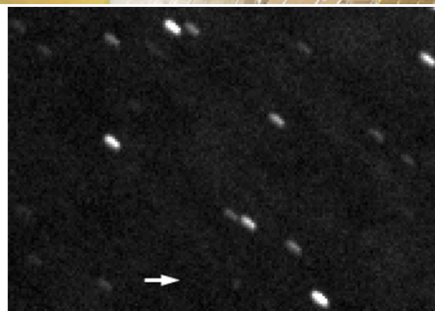
image: DLR

last minute: the U.S. initiative for space-based surveys to find NEOs for manned deep space flight

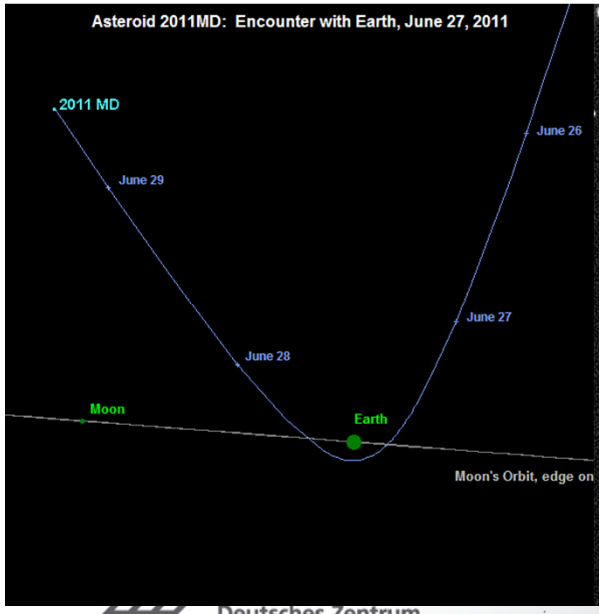


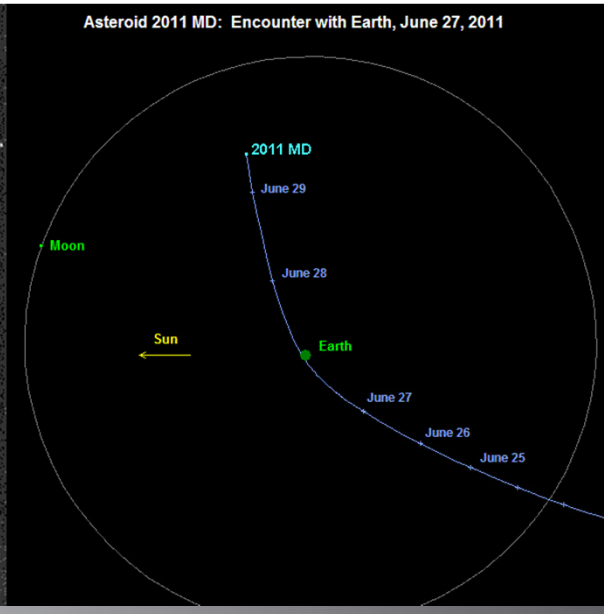
- 4 proposals were briefly presented at the 2nd IAA Planetary Defence Conference in Bucharest (May 2011)
- NEOCam (JPL, A. Mainzer et al) has been selected for technology development (NASA JPL News 05 May 2011)
  - 5 year mission with possible 5 year extension, from 2016, Atlas V launch for Earth-Sun-L1 stationing
  - 50 cm telescope, 11.56 sq.deg FoV, 40°…125° elongation,
  - 3-5 & 6-10 µm HgCdTe, passive cooling to 30 K based on Spitzer technology, 4500 sq.deg/day, 82 Gbits/day
  - slew agility 1.7° in 30 sec incl. settling time
- general shape similarity with AsteroidFinder due to Sun-Earth straylight driven baffle geometry (q.e.d. ☺)
- other proposals:
  - NEOstar to 80° elongation from ~0.7 AU heliocentric orbit
  - NEST in two orbit ioptions, at L2 or Venus-like

just delivered for AsteRisk:
your special asteroid for today: 2011 MD



- discoveries like 2011 MD and 2008 TC_3 are to be expected on an almost daily basis as soon as PanSTARRS and LSST come fully on line
- ~30% of such objects may be discovered in time for NEO science, fireball tourism, meteoritics, or last-minute mitigation measures
  - more about the latter in C. Gritzner's talk later today





Questions?

Who knows whether, when a comet shall approach this globe to destroy it, as it often has been and will be destroyed, men will not tear rocks from their foundations by means of steam, and hurl mountains, as the giants are said to have done, against the flaming mass? - And then we shall have traditions of Titans again, and of wars with Heaven.

Lord Byron, 1822

Asteroid 101: The Sky is the Limit – in detail

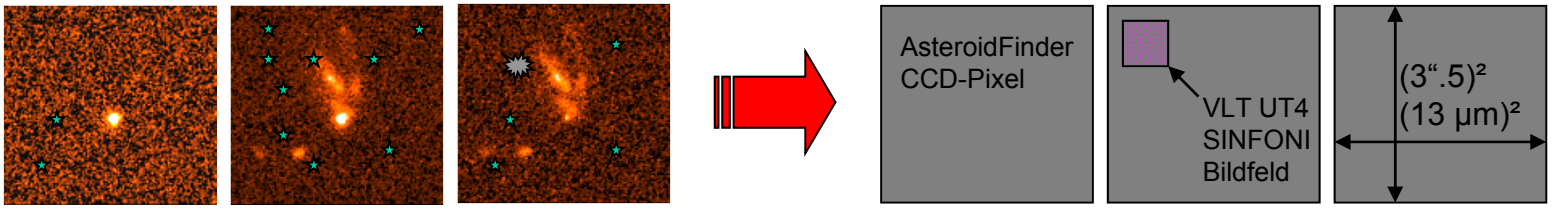
Weather	clouds, haze, water vapour	<	18 km
Blue Sky	scattered sunlight and moonlight	<	80 km
Sky Glow	emission lines of excited molecules	<	250 km *
SatelLight	gas discharge around spacecraft	<	500 km
Air Glow	faint equatorial aurora	<	700 km *
Aurora	bright polar aurora oval	<	1000 km *

***) upper limit dependent on solar activity – *2011/12 is solar maximum*!**

telescope ≠ telescope

- stars and nebulae form a distant diffuse background at any resolution ("Billions and Billions")
- interplanetary dust forms a local background that moves around the Sun (Zodiacal light, Lunar L4/5 dust clouds)
- the corona forms a variable background centered on the Sun, even beyond the area out to 32 solar radii, covered by SOHO LASCO C-3

for every camera and any background,…



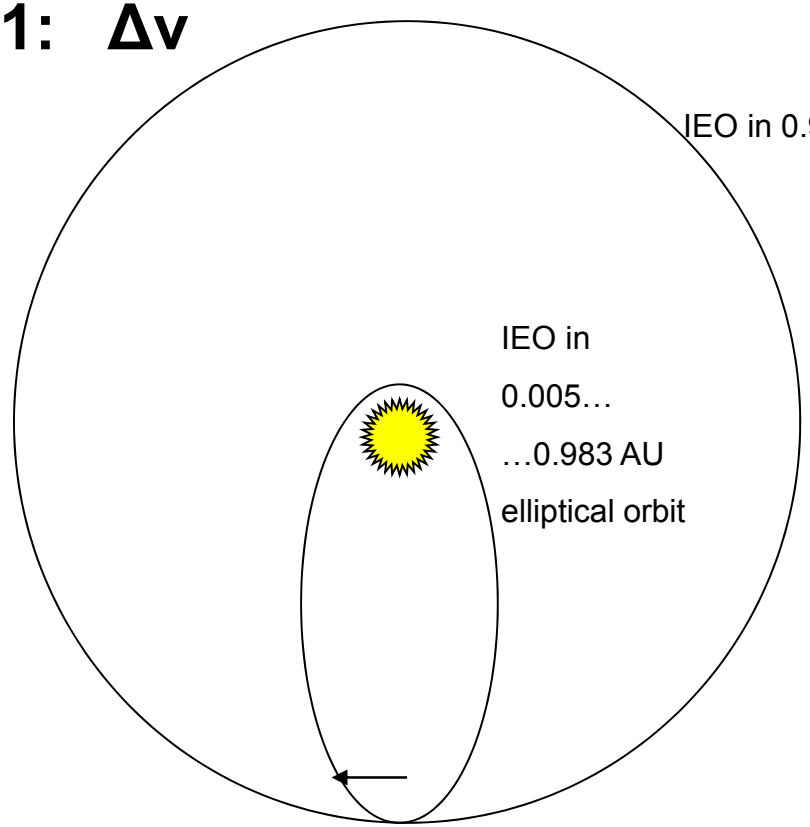
…diffuse background, stellar background, or a passing asteroid can… …*READ EXACTLY THE SAME.*

background image: GRB990123 by HST STIS, cropped to (3".2)² total field, 0".05 detector pixel, 0".025 drizzled —— difference Feb'99-Feb'00 – Feb'99 – Mar'99

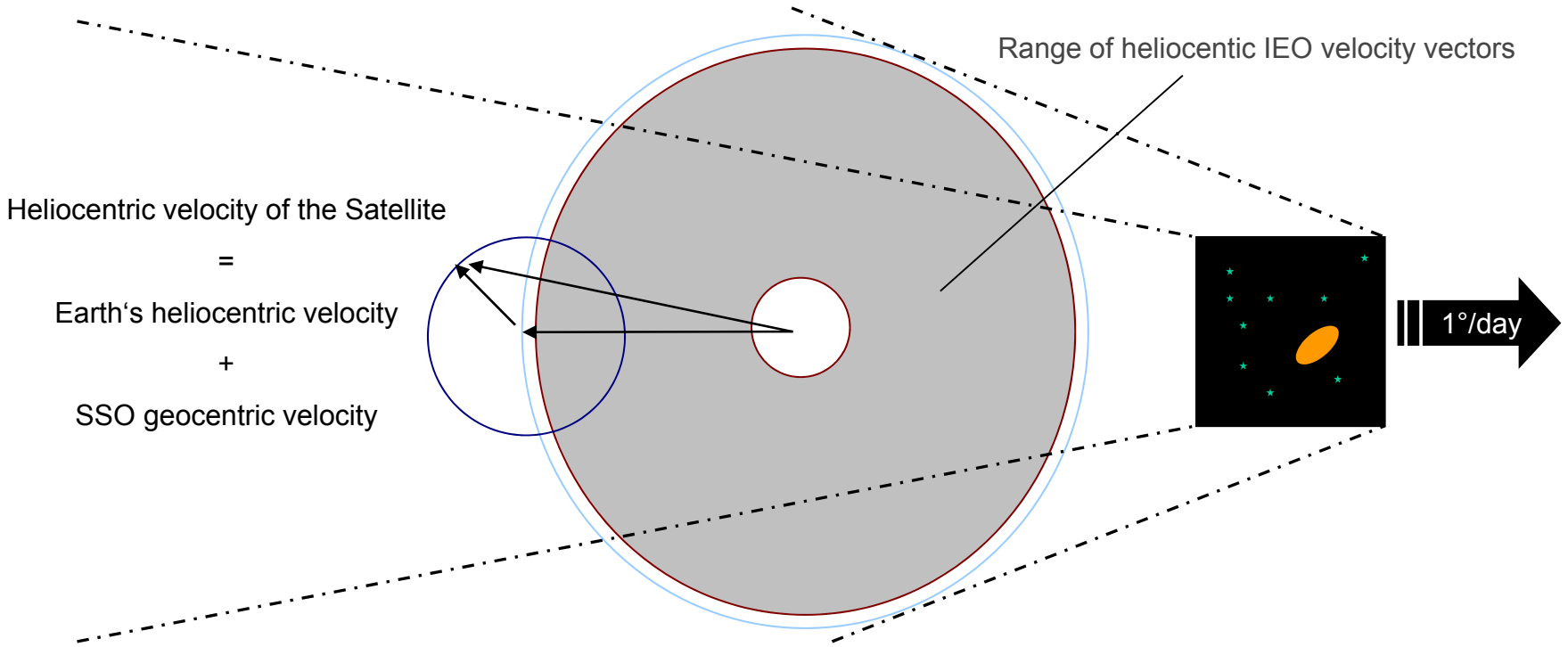
HST FOC in high resolution mode: (3".6)² total FoV – VLT UT4 SINFONI in high resolution mode : (0".8)² total FoV

** *** * * * ** *** * *** ** ** *** * * * ** *** * *** ** ** *** * * * ** *** * *** ** stellar background ~ 1°/day

Asteroid 101: Δv



Asteroid 101: Δv projected

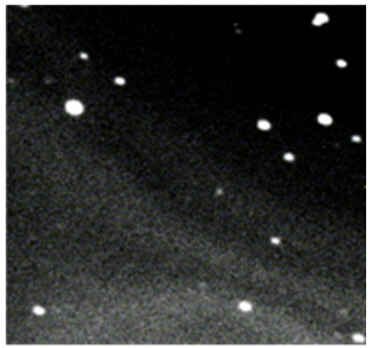


- Zero relative velocities and angular rates are possible, with a few to a few hundred arcseconds/minute being typical
- Impossible to catch all at any time

Asteroid 101: easily over-optimized

- SNR: Keep area covered by pixel tiny
- Yield: Keep area covered by telescope huge
- Catch all sizes: Keep the shutter open for a long time
- Catch all orbits: Watch again and again
  - *Get yourself a huge data volume*

Asteroid 101: The Devil is in the Details



(99942) Apophis

…named after the Ancient Egyptian Uncreator who dwells in the eternal darkness of the underworld. A close Earth flyby on Fri 13 Apr 2029 below geostationary altitude will gravity-assist Apophis for anything between a ~0.1 AU miss and a dead centre Earth impact on 13 Apr 2036, at 2.2E-5 estimated probability.

Hint: (99942) + ✂ + 🔗 → '666' + 42 ;-)